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Systematic Review

Wear of Modern Denture Teeth—A Systematic Review

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Abstract: The purpose of this systematic review was to identify the different methods used to measure artificial teeth wear and to determine which denture teeth (or which combination of tooth types) have better wear resistance. The focused patient, intervention, comparison, and outcome (PICO) question for this review was "which available denture teeth or combination of teeth have higher wear resistance?" The method of testing and measuring the artificial teeth wear was also evaluated as a secondary outcome. We searched OVID Medline, PubMed and SCOPUS using the following terms (MeSH words) with any synonyms and closed terms: "wear", "denture teeth", "denture tooth", or "artificial tooth", "tooth wear", or combination of "denture tooth wear". Database searches were limited to the English language and studies published between years 1997 and 2021. Further hand searches were carried out of studies identified from the bibliographies of relevant articles. The electronic data base search identified 293 articles of which 213 were eliminated after removing duplicates and screening the titles of the articles. A further 31 articles were eliminated upon application of the exclusion criterion and full text reading because they were either not in the English language or were review articles. Only 41 articles met the inclusion criterion; along with addition of one hand search article, a total of 42 articles were included in the review. The studies showed that rate of denture teeth wear is influenced by factors such as the material and composition of the artificial teeth, the denture tooth antagonist, the tooth being replaced, patient's age and sex, the type of removable prosthesis and the amount of the superficial layer removed during occlusal adjustments. The testing parameters were inconsistent across all studies. In conclusion, artificial teeth of same material should be used as antagonists where possible, and the superficial outer layer of the teeth must be preserved as much as possible during occlusal adjustments to enhance wear resistance. Denture teeth should be selected taking into consideration the tooth being replaced, the age and sex of the patient, and the type of prosthesis. Incorporation of nano fillers into acrylic resin teeth does not increase wear resistance; therefore, there is no evidence to favour the use of nano-filled composite teeth over micro-filled or conventional acrylic resin teeth.

Keywords: denture teeth; artificial teeth; wear; wear resistance

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1. Introduction

Wear resistance is an important physical property of artificial teeth used in removable prosthodontics. It is also an important determinant of the longivity of dentures because it determines the ability of the prosthesis to maintain the established occlusal relationship [1]. In addition to aesthetics and speech, patient expectations of their new dentures are also high in respect of masticatory efficiency, which can be compromised if denture teeth wear occurs [2].

Denture teeth wear over time due to forces of mastication during functional and parafunctional movement is inevitable [3,4]. Bruxism and clenching habits have been stated to cause wear of composite restorations through what is known as a two-body tribochemical/biomechanical wear, and this process is referred to clinically as abrasive wear [5,6]. Turssi et al. further say that wear is a function of this tribological system, and the variable movements and loadings that can occur and the aggressive chemical, thermal, and biological components involved make the intraoral tribology of dental composites highly complex [5]. Surface loss is usually observed more on posterior teeth than on the anterior teeth [3]. Teeth wear is of great concern to both patients and clinicians because the altered teeth morphology can result in loss of occlusal vertical dimension, compromised masticatory efficiency, fatigue of the muscles of mastication and patient discomfort, as well as affecting aesthetics [7]. Ultimately dentures are considered inadequate when teeth wear compromises their stability and retention, as it plays a crucial role in occlusal stability on the preservation of crestal ridges. Extensive wear can lead to iatrogenic resorptions and flabby tissues [8]. Excessive wear of denture teeth has also even been reported to affect the quality of life of dentures wearers [3].

Wear resistance is an essential property of denture teeth, since this maintains the patients vertical dimension and masticatory efficiency [9,10]. Porcelain denture teeth were initially used for denture construction until the introduction of acrylic resin teeth in the 1940s, and then composite teeth in the 1980s [11,12]. Acrylic resin teeth are made of polymethyl methacrylate resin (PMMA). To enhance their wear resistance, the double cross-linked (DCL) and interpenetrating network teeth (IPN) are now available with cross linking agents having been added to the chemical structure [13]. Composite layered teeth were initially introduced as micro-filled composites in an effort to improve the wear resistance of artificial teeth; this was later refined by changing the filler particles to nanocomposite in order to improve the materials' polishability [11]. By contrast, the Stober et al., 2010, study reported that acrylic resin teeth (DCL and PMMA) had higher wear resistance than human enamel [14]. It has also been reported that opposing teeth combinations of acrylic to acrylic showed less wear than feldspathic ceramic to ceramic [15]. Recent advances in digital dentistry have also seen introduction of digital dentures, whereby teeth are milled or printed from resin and bonded to the denture base [16]. However, there is a dearth of published data on the wear properties of this modern denture tooth material.

Several in vivo and in vitro studies of wear resistance of acrylic resin, composite and ceramic denture teeth have been conducted using the same teeth or zirconia and human teeth as antagonists [12,13,15]. However, there is no clear guideline in terms of which type of tooth has superior wear resistance properties and which combination of teeth better preserves the teeth morphology over time. Studies have used several methods to measure teeth wear either in vitro, such as the Ivoclar Vivadent method (IVOCLAR) [17], the Zurich method (ZURICH) [18], the Oregon Health Sciences University Oral Wear Simulator (OHSU) [19], the Munich Method (MUNICH) Oslo model [20], and the ACTA method (ACTA) [21], or in vivo, but there is a standard guideline as to which testing equipment or method is better or accurate [22].

Thus, the aims of this study are to: (1) systematically review the different methods used to measure artificial teeth wear and determine which methods are valid; and (2) determine which denture teeth or combination of type of teeth produces better wear resistance outcome.

2. Materials and Methods

2.1. Search Strategy

The focused patient, intervention, comparison, and outcome (PICO) question for this review was "which available denture teeth or combination of teeth have higher wear resistance?" The method of testing and measuring the artificial teeth wear was also evaluated as a secondary outcome. We searched OVID Medline, PubMed and SCOPUS using the following terms (MeSH words) with any synonyms and closed terms: "wear", "denture teeth", "denture tooth", or "artificial tooth", "tooth wear", or combination of "denture tooth wear". Database searches were limited to the English language and studies published between years 1997 and 2021. Further hand searches were carried out of studies identified from the bibliographies of relevant studies. The studies were then included or excluded from the total sample by following the inclusion and exclusion criteria (Table 1).

Table 1. Inclusion and exclusion criteria.

Inclusion Criteria	Exclusion Criteria
Studies published only in English language	Studies in languages other than English
Studies published from year 1997 to year 2021	Studies with animal models
Full-text articles only	Studies irrelevant to the focus question
	Studies with abstracts only
	Review articles
	Case reports

2.2. Selection of Studies

Two independent reviewers (V.M., J.C.) initially reviewed the titles and abstracts of the selected studies. After applying the inclusion and exclusion criteria, full texts were selected for both reading and final selection. All differences in choices between the two authors were analysed by two further reviewers (A.P., M.T.T.), and agreement was established through discussion as per the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.

2.3. Data Extraction and Method of Analysis

The data were independently extracted by the reviewers from all the studies included using data extraction tables. These were double-checked and any questions arising during the screening and the data extraction stage were discussed until agreement was reached by the reviewers. The information extracted from the selected studies for analysis were author(s), years of publication, materials used for the study, testing methods (load applied, sliding distance, number of cycles, and frequency) and testing equipment, evaluation methods, and any further analysis of the worn tooth structure.

2.4. Risk of Bias

The assessment of risk of bias for all included studies used the Consolidated Standards of Reporting Trials (CONSORT) guidelines [23]. The assessment was done at the study level, with each rated as either “unclear”, “low risk” or “high risk”.

3. Results

The electronic data base search identified 293 studies; upon application of the exclusion criterion and full text reading, only 41 studies met the inclusion criterion. Along with the addition of one hand search article [24], a total of 42 studies were included in the review (Figure 1). From the 42 included studies, 11 studies were conducted in vivo [3,24–33], and 31 were in vitro studies [1,7,9–13,16,25,33–54].

The in vitro studies used a range of testing methods to evaluate teeth wear; pin-on-block/disc (n = 4), two-body wear testing machine (n = 5), three-body testing machine (n = 1), masticatory simulator (n = 7), wear testing machine (n = 3), dual-axis chewing simulator (n = 5), fatigue test (n = 1), stainless steel stylus loaded on the specimen (n = 1), and abrasive tester (n = 1) (Table 2). The testing load varied from 2 newtons to 2500 newtons, and the number of cycles ranged from 4.5–120,000 cycles. A total of 23 studies carried out further microscopic analysis of post-wear testing: Scanning Electron Microscopy (SEM) (n = 19), 3D profilometer (n = 3), and stereomicroscope image (n = 1).

Table 2. Testing parameter of in vitro studies (Note: All loads converted to newtons 1 kg = 9.81 N; 1 pound = 4.448 N).

Study	Type of Test	Load Applied	Sliding Distance	Cycle (s)	Frequency	Thermocycling
Abe et al., (2001) [34]	wear-testing machine	9.81 N	4 mm	2×10^5	1 Hz	Not used
Bedini et al., (2012) [35]	fatigue test	34 to 340 N	Not reported	10^6	6 Hz	Not used
Cha et al., (2019) [16]	masticatory simulator	49 N	2–5 mm	3×10^4	Not reported	5 °C and 55 °C
Ghazal and Kern (2009) [36]	masticatory simulator	49 N	Not reported	3×10^5	Not reported	5 °C and 55 °C
Ghazal and Kern (2009) [15]	dual axis chewing simulator	20, 49 and 78 N	0.3 mm	3×10^5	Not reported	5 °C and 55 °C
Ghazal and Kern (2010) [14]	dual axis chewing simulator	49 N	0.3 mm	3×10^5	Not reported	5 °C and 55 °C
Ghazal et al., (2008) [9]	dual-axis-simulator	49 N	0.3 mm	2×10^5	Not reported	21 °C
Ghazal et al., (2008) [13]	dual-axis-simulator	49.04 N	0.3 mm	6×10^5	Not reported	5 °C and 55 °C
Ghazal et al., (2008) [37]	dual-axis-simulator	49.04 N	0.3 mm	6×10^5	Not reported	5 °C and 55 °C
Ghazal et al., (2008) [1]	masticatory simulator	49.04 N	6 mm	1.2×10^6	1.3 Hz	5 °C and 55 °C
Hahnel et al., (2009) [38]	pin-on-block	50 N	1 mm-2 mm	1.2×10^5	1.2 Hz	5 °C and 55 °C
Hao et al., (2014) [39]	abrasive tester	49 N	Not reported	5×10^4	1.2 Hz	Not used
Heintze et al., (2012) [53]	chewing simulator	49.04 N	1 mm	1×10^5	Not reported	5 °C and 55 °C
Hirano et al., (1998) [40]	mechanical wear testing	13.34 N	3 mm	1×10^4	Not reported	Not used
Ilangkumaran et al., (2014) [11]	pin on disc-simulates 2-body wear	2.94 N	Not reported	1×10^3	Not reported	Not used
Kamonwanon et al., (2015) [4]	3-body wear tests	2 N	2 N and 150 rpm	1.8×10^4	Not reported	Not used
Mello et al., (2009) [7]	mechanical abrasion test	5 N	10 mm	4×10^4	4 Hz	Not used
Muhammad et al., (2011) [41]	modified pin-on-block	64 N	sliding distance 180–1080 m	Not reported	Not reported	in artificial saliva at 37 °C
Munshi et al., (2017) [42]	2-body wear machine	49.04 N	Not reported	5×10^4	1 Hz	Not used
Nishino et al., (2001) [43]	two-body impacting-sliding wear test	4.91 N	sliding 3.5 mm	1×10^4	1 Hz	artificial saliva
Ohkubo et al., (2002) [44]	2-body wear testing	49.04 N	Not reported	5×10^4	1 Hz	water spray
Popovic et al., (2017) [45]	chewing simulator	49.04 N	0.2–0.4 mm	1×10^5	Not reported	70 °C
Preis et al., (2018) [46]	pin-on block	50 N	Not reported	1.2×10^5	1.2 Hz	5 °C and 55 °C
Reis et al., (2008) [12]	2-body wear	2.94 N	20 mm	1×10^5	Not reported	37 °C
Sheety and Shenoy (2010) [47]	wear testing procedure	1.96 N	Not reported	1×10^4	Not reported	Not used
Stober et al., (2006) [49]	chewing simulator	40 N	Not reported	1×10^5	8 mm/s, 30 mm/s	continuous rising temperature with water at 25 °C
Stober et al., (2010) [48]	wear simulator	15 N	Not reported	1×10^5	2.2 Hz	Not used
Suwannaroop et al., (2011) [50]	2-body wear tester	15 N	Not reported	1×10^5	16.7 Hz	Not used
Suzuki (2004) [10]	stainless steel stylus was loaded on the specimen	75 N	Not reported	1×10^5	1.2 Hz	Not used
Zeng et al., (2005) [52]	2-body wear testing machine	49 N	grinding distance 2 mm	60 strokes/min	Not reported	37 °C

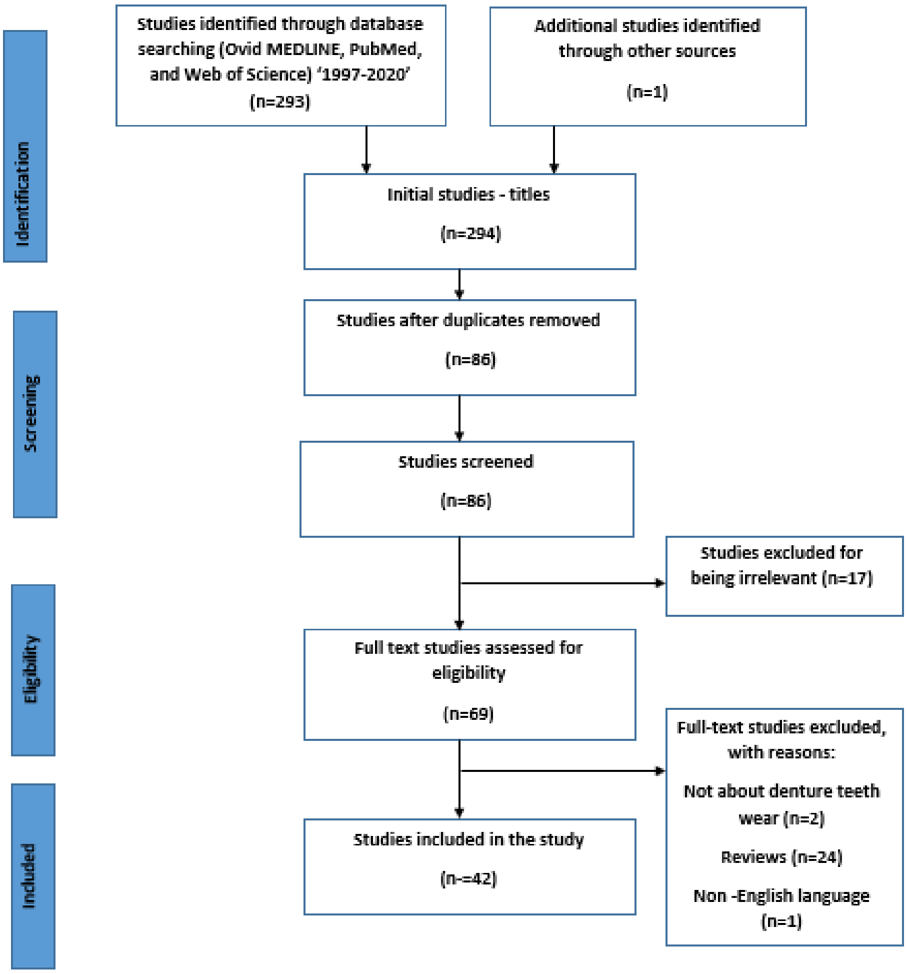

Figure 1. PRISMA flow diagram of literature search and selection process.

3.1. Assessment of Risk of Bias

Most studies showed low risk of bias for outcome and reporting bias; however, it was unclear for allocation concealment and blinding of outcome assessment. Half the studies showed high risk of bias for randomising sequence generation; however, this may be due to the need to select the teeth for dentures in both in vivo and in vitro studies (Figure 2).

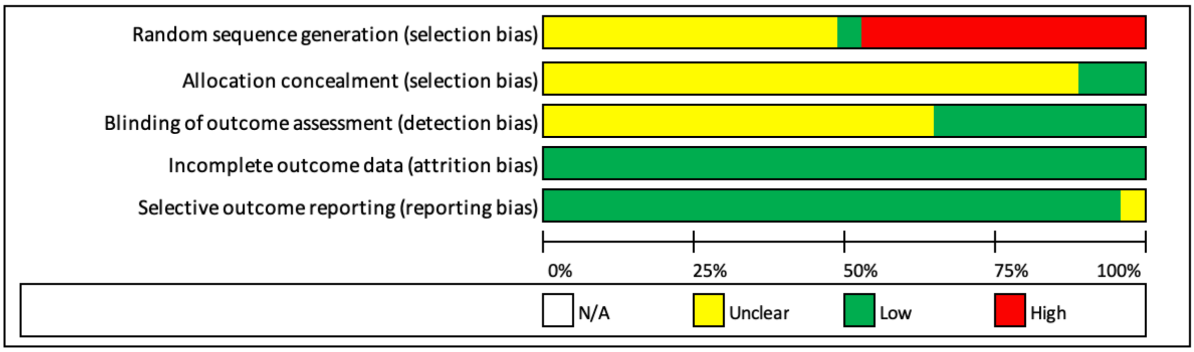

Figure 2. Risk of bias summary of all selected studies.

3.2. PMMA Denture Teeth

A total of 27 studies evaluated the wear of artificial acrylic teeth (PMMA) (Table 3). The wear rate for PMMA denture teeth has been reported to be significantly lower against the same antagonist and human enamel [13,34]. A study also reported that acrylic resin causes minimal damage to opposing human enamel; the study did not record any measurable wear of the enamel [14]. Several studies have indicated that the composition of PMMA influences the wear resistance; the addition of filler particles such as silica and titanium dioxide improve the wear resistance of PMMA [4,9,10,27,40,41,43,47,48,50–53]. By contrast, the findings of Stober et al. (2006) and Ghazal et al. (2008) did not indicate any connection between the wear resistance and the chemical composition of the samples [13,49]. Removal of the superficial layer of certain artificial teeth during occlusal adjustment has also been shown to increase rate of wear [24,50]. Studies have also shown that wear was tooth dependent and the wear rate increased from incisors to molars [28,30]. Gender is another factor influencing the rate of artificial teeth wear with males demonstrating greater wear than females [28,29]. Wear rates of artificial teeth have also been reported to decrease with increasing age of the wearers [30]. A study has also shown that complete denture teeth exhibit lower wear rates than removable partial dentures [29].

Table 3. Main findings of the selected studies on denture teeth wear (PMMA).

Study	Type of Study	Teeth Tested	Antagonist	Outcome
Abe et al., (2001) [34]	in vitro	Semi-crown posteriors and Duracross posteriors (Nissin Dental Products, Kyoto, Japan)	Human enamel	Height loss after 20 × 10^4 sliding times with enamel antagonist for Semi-crown posteriors (acrylic resin) was ~160 µm and for Duracross posteriors (high strength resin) was ~300 µm. High strength resin tends to possess fragile characteristics contrary to its mechanical improvement in comparison with acrylic resin.
Arafa (2016) [3]	in vivo	Heat cure acrylic resin (Meliodent, Bayer dental, Niedernhausen, Germany)	Heat cure acrylic resin	Resin teeth wear increased with time, ranging from 0.076 mm at 6 months to 0.27 mm at 24 months.
Ghazal and Kern (2010) [14]	in vitro	Polystar selection (Merz Dental, Lütjenburg, Germany) and experimental acrylic resin teeth (Ivoclar Vivadent, Schaan, Liechtenstein)	Mandibular human first premolars	Experimental acrylic resin teeth recorded total vertical loss of 140 ± 27µm and Polystar selection recorded total vertical loss of 167 ± 43 µm. Volume loss of experimental resin teeth was 0.069 ± 0.012 mm^3 and for Polystar selection was 0.105 ± 0.024 mm^3
Ghazal et al., (2008) [9]	in vitro	Orthognath (Heraeus-Kulzer, Hanau, Germany), Vitapan Cuspiform (Vita, Germany)	Steatite ceramic ball	The mean vertical loss (µm) and volume loss (mm^3) of Orthognath after 120,000 cycles was 76 ± 11 µm and 0.057 ± 0.014 mm^3, after 240,000 cycles was 96 ± 18 µm and 0.092 ± 0.027 mm^3, after 480,000 cycles 121 ± 18 µm and 0.0138 ± 0.037 mm^3, after 840,000 141 ± 23 µm and 0.191 ± 0.052 mm^3, and after 1,200,000 was 159 ± 23 µm and 0.242 ± 0.061 mm^3. Vitapan Cuspiform after 120,000 cycles was 62 ± 17 µm and 0.036 ± 0.017 mm^3, after 240,000 cycles was 80 ± 23 µm and 0.067 ± 0.032 mm^3, after 480,000 cycles 107 ± 33 µm and 0.121 ± 0.061 mm^3, after 840,000 134 ± 39 µm and 0.197 ± 0.098 mm^3, and after 1,200,000 was 166 ± 47 µm and 0.292 ± 0.136 mm^3.
Ghazal et al., (2008) [13]	in vitro	Experimental resin teeth (Ivoclar Vivadent, Schaan, Liechtenstein)	1st premolar teeth of same tested denture material and caries free human teeth	The experimental teeth recorded total vertical loss of 98 ± 6 µm and total volume loss of 0.035 ± 0.009 mm^3 against the same denture teeth cusps antagonist. Against the human enamel, a total vertical loss of 249 ± 48 µm and total volume loss of 0.093 ± 0.021 mm^3 was recorded.
Ghazal et al., (2008) [37]	in vitro	Experimental resin teeth (Ivoclar Vivadent, Schaan, Liechtenstein), Polystar Selection (Merz Dental, Lütjenburg, Germany)	Buccal cusps of the Mandibular 1st premolar of the same tooth	The experimental resin teeth recorded total vertical loss of 24 ± 3 µm and total volume loss of 0.011 ± 0.001 mm^3. The Polystar selection resin teeth recorded total vertical loss of 34 ± 8 µm and total volume loss of 0.019 ± 0.004 mm^3, which was higher than the experimental resin. The vertical loss of opposing experimental teeth was 36 ± 5 µm, which was less than the opposing Polystar teeth that recorded 38 ± 8 µm of substance loss.
Hahnel et al. (2009) [38]	in vitro	Gnathostar (Ivoclar Vivadent, Schaan, Liechtenstein), SR Orthosit PE (Ivoclar Vivadent, Schaan, Liechtenstein), SR Vivodent PE (Ivoclar Vivadent, Schaan, Liechtenstein), VITA Physiodens (VITA Zahnfabrik, Bad Säckingen, Germany)	Artificial resin teeth, steel, steatite	Vita Physiodens recorded mean vertical loss of 40 µm against antagonist artificial tooth; 171 µm against steel and 302 µm against steatite. SR Vivodent PE recorded mean vertical loss of 95 µm against antagonist artificial tooth; 191 µm against steel and 723 µm against steatite. SR Orthosit PE recorded mean vertical loss of 86 µm against antagonist artificial tooth; 193 µm against steel and 343 µm against steatite. Gnathostar recorded mean vertical loss of 26 µm against antagonist artificial tooth; 183 µm against steel and 347 µm against steatite Gnathostar recorded the least wear values against the three antagonists.

Table 3. *Cont.*

Study	Type of Study	Teeth Tested	Antagonist	Outcome
Hao et al., (2014) [39]	in vitro	Premium 8 (Heraeus Kulzer GmbH, Wasserburg am Bodensee, Germany), Yamachi FX (Yamahachi Dental Mfg Co., Gamagori, Japan), ShengJian/SJ (Dental Material Factory of Shanghai Medical Instrument Co, Shanghai, China)	Silicon nitride ceramic ball	The mean vertical loss for Premium 8 teeth was 1.03 $\pm$ 0.036 µm and mean volume loss was 0.939 $\pm$ 0.055 ($mm^3 \times 10^{-3}$); mean vertical loss for Yamahachi PX teeth were 0.698 $\pm$ 0.032 µm and mean volume loss was 0.650 $\pm$ 0.0062 ($mm^3 \times 10^{-3}$); mean vertical loss for Shenglian/SJ teeth was 12.1 0.0086 µm and mean volume loss was 16.4 0.48 ($mm^3 \times 10^{-3}$).
Heintze et al., (2013) [26]	in vivo	Experimental teeth (Polymethyl methacrylate plus 20% of UDMA/PMMA fillers)	Complete dentures with same denture teeth and also split-mouth and two-arm design	The average Log wear increase was estimated at 0.41 between 6 and 12 months, at 0.28 between 12 and 18 months, and at 0.16, between 18 and 24 months, corresponding to estimated ratios of raw measurements (on the original scale) of the experimental teeth (0.41) = 1.51 between 6 and 12 months, (0.28) = 1.32 between 12 and 18 months, and (0.16) = 1.17 between 18 and 24 months, suggesting a slowing down of the wear increase with time.
Heintze et al., (2012) [53]	in vitro	NFC (Candulor, Opfikon, Switzerland) and EM (Ivoclar Vivadent Schaan, Liechtenstein)	Denture tooth/ceramic antagonist	The mean vertical tooth loss after 12 months of denture wear for NFC denture teeth was lower (140.2 µm) compared to mean vertical loss for EM denture teeth (211.2 µm).
Hirano et al., (1998) [40]	in vitro	Kenson (Myerson, a Division of Austenal Inc., Chicago, IL, USA), Classic (Dentsply Internati, Inc., Saint Louis, Missouri USA)	Enamel abraders	The amount of wear of the Kenson (0.006 $\pm$ 0.002 mm) and the Classic (0.005 $\pm$ 0.003 mm) resin denture teeth was much higher than the composite resin teeth used in the study—DB Plus (0.003 $\pm$ 0.002 mm) and MLI (0.003 $\pm$ 0.002 mm) at 5000 cycles. Similar trends were also found with these two acrylic resin teeth after 10,000 cycles.
Ilangkumaran et al., (2014) [11]	in vitro	Acry Plus (Ruthinium Group, Badia Polesine, Italy)	600 grit sandpaper	The mean wear value of Acry plus teeth was 627.80 µm and was greater compared to nano-composite teeth used in the study.
Jooste et al., (1997) [27]	in vivo	Duravite (Titan Industries, South Africa), Premierdent (Premierdent, South Africa), Vitapan (Vita Zahnfabrik, Bads~ickingen, Germany), Ivoclar Orthosit (Ivoclar AG, Schaan, Liechtenstein), Acrotone (Wright Health Group, Dundee,, Scotland), and Rx1 (Wright Health Group Scotland).	complete dentures	The mean abrasion recorded after three years of denture wear was as follows: Premierdent, 0.528 mm^3; Acrotone, 0.374 mm^3; Vitapan, 0.376 mm^3; Rx1 10.415 mm^3; Duravite, 0.369 mm^3; and Ivoclar Orthosite, 0237 mm^3
Kamonwanon et al., (2015) [4]	in vitro	Major-Dent (Major Prodotti Dentari, Moncalieri, Italy), Major-dent with surface modified with methyltrimethoxysil-ane and SiO_2 nano-particles (Yuda Chemical Industry Co. Ltd. shangyu city, Zhejiang, China), Cosmo HXL (Dentsply Intl, Charlotte, NC 28277,USA), and Gnathostar (Ivoclar Vivadent Schaan, Liechtenstein)	Nylon, end-rounded bristle toothbrush and toothpaste	The mean wear depth of Cosmo HX was 10.5 µm, Major-Dent was 10.8 µm, Gnathostar was 9.3 µm, and Major-Dent with modified surface was 1.1 µm. The modified-surface artificial teeth recorded similar worn surface area values to micro filled composite resin teeth but were significantly different from those of the acrylic resin artificial teeth.
Mello et al., (2009) [7]	in vitro	Biolux Trilux (VIPI Indústria, Comércio, Exportação e Importação de Produtos Odontológicos Ltd.a, Pirassununga, Brazil), Blue Dent (Blue Dent Dental, Brazil), Biocler (DentBras Indústria, Comércio, Importação e Exportação de) Produtos Odontológicos Ltd.a, Pirassununga, Brazil), Orthosit and Gnathostar (Ivoclar Vivadent AG.Schaan, Schaan, Liechtenstein)	Metallic and composite antagonists	The mean wear of teeth against composite antagonists ranged from 2.33 $\pm$ 0.91 µm to 4.50 $\pm$ 0.73 µm; and against metallic antagonists, it ranged from 10.45 $\pm$ 1.42 µm to 1.78$\pm$ 0.42 µm.
Muhammad et al., (2011) [41]	in vitro	Seven artificial teeth samples composed of polymer PMMA (manufacturer not stated)	Moving disc of known material	The wear rate of the artificial teeth in synthetic saliva ranged from 1.2–5.7 (mm^2)/Nn) $\times 10^4$. Silica and titanium dioxide fillers in PMMA polymer significantly improved the wear resistance of PMMA artificial teeth by increasing the reinforcement of the matrix compared to the standard teeth sample.

Table 3. *Cont.*

Study	Type of Study	Teeth Tested	Antagonist	Outcome
Ogle and Dvis (1998) [14]	in vivo	SR-Vivodent Orthotyp-PE (Ivoclar North America, Amherst, NY, USA), Trueblend SLM (Trublend, Dentsply International Inc., York, PA, USA)., Bioform IPN (Dentsply International Inc. Inc., Saint Louis, MO USA).	Complete dentures	Mean wear of teeth recorded after 36 months for males were: SR-Vivodent Orthotyp-PE—272 µm for maxillary dentures and 192 µm for mandibular dentures; Trueblend SLM—266 µm for maxillary dentures and 218 µm for mandibular dentures; Bioform IPN—225 µm for maxillary dentures and 202 µm for mandibular dentures. For Females mean wear recorded were: SR-Vivodent Orthotyp-PE—260 µm for maxillary dentures and 190 µm for mandibular dentures; Trueblend SLM—278 µm for maxillary dentures and 207 µm for mandibular dentures; Bioform IPN—172 µm for maxillary dentures and 114 µm for mandibular dentures. Average teeth wear for maxillary dentures were 243 µm, and for mandibular dentures, it was 181 µm. Greater wear was reported among male denture wearers compare to female denture wearers. Greater wear was also reported for premolars and molars than for canines.
Ohlmann et al., (2007) [28]	in vivo	Vitapan (Vitapan, Vita Zahnfabrik)	No antagonist/natural teeth	Partial denture teeth exhibited a mean total vertical wear of –22.8 µm (±14.9), complete dentures teeth exhibited a mean total vertical wear of –18.9 µm (± 13.2), and overdenture teeth exhibited a mean total vertical wear of –17.4 µm (±16.7). The mean total vertical wear ranged from –5.4 µm (±4.3) for denture teeth with no antagonist to –24.1 µm (±16.7) for denture teeth opposed by a natural tooth. Males demonstrated a significant higher mean total vertical wear (–22.5 µm ± 15.8) than females (–18.7 µm ± 13.1)
Popovic et al., (2017) [45]	in vitro	Pure PMMA (manufacture not stated)	Machine antagonist	Pure PMMA showed maximum tooth loss both after aging (~0.14 mm) and without aging (~0.28 mm) compared to PMMA modified with ZnO NPs; PMMA with 3% by volume of ZnO NPs showed slightly higher wear for both before ageing (0.05 mm) and after ageing (~0.045 mm), compared to the PMMA with 2% by volume of ZnO NPs: without ageing was ~0.04 mm tooth wear, and after ageing was ~0.03 mm tooth wear.
Preis et al., (2018) [46]	in vitro	Trubyte (Dentsply Sirona, Inc., Saint Louis, MO, USA), Kenson (Myerson LCC, Chicago, IL, USA), Vita MFT (Vita Zahnfabrik H. Rauter GmbH & Co. KG, Bad Säckingen, Germany), Bioplus and Genios A (Dentsply Sirona Inc., Saint Louis, MO, USA), Merz Dental Artegral BXL (Merz Dental GmbH, Lütjenburg, Germany)	Spherical steatite	Mean wear of teeth recorded were: Truebyte—753.6 ± 84.4 µm; Kenson—493.8 ± 712 µm; Vita MFT—420.7 ± 84.4 µm; Bioplus—415.8 ± 712 µm; Genios A—387.9 ± 56.6 µm; and for Merz Dental Artegra BXL—358.9 ± 86.0 µm. The composition of the denture teeth determined the rate of wear of teeth. Trubyte had greater wear with PMMA being the major composition compared to the other brands of teeth which had filler materials.
Schmid-Schwap et al., (2009) [30]	in vivo	Experimental acrylic resin (Ivoclar Vivadent AG. Liechtenstein, Schaan, Liechtenstein)	Complete dentures of same teeth	Mean vertical loss recorded after 12 months of denture wear for the experimental resin teeth was 0.060 mm for maxillary dentures and 0.049 mm for mandibular dentures. Wear was tooth dependent (increasing from incisors to molars). These differences diminished once wear rates were adjusted for occlusal area, there was significantly more vertical wear for the posterior teeth than for the anterior teeth in the maxilla.
Sheety and Shenoy (2010) [47]	in vitro	Surana Ultradent (Newstetic, Columbia), Premadent (India), Dentek (S P Dental, Delhi, India)	600 grit silicon carbide paper	Mean weight loss reported after 10,000 cycles were: Surana Ultradent—0.154 gm; Dentrek—0.244 gm; Premadent—0.302 gm. Variation of wear residence could be due to the filler particle. Wear resistance increases with increase in density of the teeth.
Stober et al., (2006) [49]	in vitro	SR-orthotype-PE (Ivoclar-Vivadent, 9494 Schaan, Liechtenstein), Orthognath and Premium 8 (Heraeus Kulzer, Hanau, Germany), Trubyte portrait (Dentsply Int., USA), Artiplus (Dentsply-DeguDent, Hanau, Germany), SR-orthosit-PE (Ivoclar-Vivadent, 9494 Schaan Liechtenstein),	Al_2O_3 balls	Mean volume loss recorded after 100,000 cycles were: SR-Orthotype-PE—114.6 ($mm^3 \times 10^{-3}$); Orthognath—80.1 ($mm^3 \times 10^{-3}$); Premium 8—84.6 ($mm^3 \times 10^{-3}$); Trubyte portrait—123.0 ($mm^3 \times 10^{-3}$); Artiplus—18.7 ($mm^3 \times 10^{-3}$); and SR-Orthosit-PE 61.1 ($mm^3 \times 10^{-3}$). The study reported no connection between the wear resistance and the chemical composition of the samples.
Stober et al., (2010) [48]	in vitro	SR-orthotype-PE (Ivoclar-Vivadent, Liechtenstein), Orthognath and Premium 8 (Heraeus Kulzer, Hanau, Germany), Trubyte portrait (Dentsply Int., York, PA, USA), Artiplus (Dentsply-DeguDent, Hanau, Germany), SR-orthosit-PE (Ivoclar-Vivadent, Liechtenstein)	Fixed partial dentures	The mean vertical loss for six acrylic resin teeth ranged from 123–116 µm. Premium 8 showed the highest vertical loss; while SR-orthoype-PE and Artiplus both showed lowest mean vertical loss. Tooth wear of acrylic resin teeth compared to the reference teeth (ceramic and human) and the composite resin and composite nanofilled is significant. None of the resin materials tested in this study demonstrated the 3-body wear resistance of ceramic teeth or human enamel.

Table 3. *Cont.*

Study	Type of Study	Teeth Tested	Antagonist	Outcome
Suwannaroop et al., (2011) [50]	in vitro	Cosmo HXL (Dentsply International, Inc., Brazil), Major Dent (Major, Prodotti, Dentari, Italy), YamahachiFX and Yamahachi PX (YamahachiDental Mfg.Co., Nishiuracho, Gamagori Japan), Trubyte Bioform IPN (Dentsply International, Inc., York, PA, USA), SR-orthosit-PE (Ivoclar Vivadent, Naturns, Italy)	Ceramic-aluminium oxide (dura white)	Total volume loss recorded were: Cosmo HXL—0.21 (mm^3); Major Dent—0.071 (mm^3); Yamahachi FX—0.054 (mm^3); Trubyte Bioform—0.069 (mm^3); SR-Orthosit-PE—0.040 (mm^3); Yamahachi PX—0.054 (mm^3). There is no correlation between materials properties such as hardness and wear resistance. In selecting artificial denture teeth, not only type, but also composition, and sub-enamel layer properties should be considered as well. Occlusal adjustment prior to, and after, denture delivery will inevitably expose this layer into occlusion with the opposing dentition; natural or artificial.
Suzuki (2004) [10]	in vitro	Biotone (Dentsply, York, PA, USA)	Stainless steel ball	Biotone recorded wear depth of 162.5 µm. The acrylic has a linear polymer chain structure, while all modified resin teeth have a cross-linked structure. An optimal amount of cross-linking improves the mechanical properties of acrylic resin.
Uehara et al., (2019) [24]	in vivo	Artiplus (Dentsply Sirona, York, PA USA), Biotone IPN (Dentsply Sirona, York, PA, USA), Magister (Kulzer GmbH, Hanau, Germany), Premium (Kulzer GmbH), SR Vivodent (Ivoclar Vivadent AG, Schaan, Liechtenstein)	Fixed-ball micro abrasive wear equipment	The mean k coefficient values for the surface layer of the tested teeth reported were: Artiplus—22.6 ± 13.8 k ($\times10^{-4}$); Biotone IPN—36.1 ± 5.9 k ($\times10^{-4}$); Magister—47.8 ± 13.8 k ($\times10^{-4}$); Premium—30.2 ± 6.5 k ($\times10^{-4}$); SR Vivodent—43.1 ± 10.8. The results showed that the wear coefficient values for the superficial layers of Artiplus IPN specimens were significantly lower than those of the SR Vivodent and Magister specimens. This indicates that better wear performance can be expected from Artiplus just before complete wear of the superficial layer. Nevertheless, once the superficial layer is worn away, all the tooth brands studied will likely perform similarly.

3.3. Double Cross-Linked Acrylic (DCL) Denture Teeth

Only four studies evaluated DCL denture teeth (Table 4). The study by Heintze et al., (2012), showed that wear of double cross link acrylic was influenced by the filler particles; DCL with nano-fillers recorded the lowest wear rate against the same denture teeth. However, the study further reported highest wear value for a flat DCL specimen against a conical ceramic antagonist, and interestingly, the lowest wear value for a flat specimen of DCL against a ball-like ceramic antagonist [54]. Wear of DCL denture teeth is also tooth dependent; teeth wear increased from incisors to molars [31,34]. Similar to PMMA, a consistent trend of decreasing wear with increasing age has also been reported for DCL teeth [26,34]. A study showed females denture wearers recorded less wear than men (Heintze et al., 2015). This study further reported a lower rate of wear among patients with good fit dentures and for smokers [26]. The study by Schmid-Schwap et al., (2009), showed greater wear of teeth on the maxillary dentures than mandibular dentures [31].

Table 4. Main findings of the selected studies on denture teeth wear (DCL).

Study	Type of Study	Teeth Tested	Antagonist	Outcome
Heintze et al., (2015) [25]	in vivo	SR Ortholingual and Sr Vivodent (Ivoclar Vivadent, Schaan, Liechtenstein).	Complete dentures with same denture teeth and also split-mouth and two-arm design	Analysis for wear measurements were conducted according to patient- and therapy-related factors. Denture teeth wear was not measured and analysed for individual types of denture teeth. A consistent trend recorded was decreasing wear associated with increasing age. Females recorded less wear than men. Less wear also reported among patients with well fitted dentures and a modest trend towards less wear for smokers.
Heintze et al., (2012) [53]	in vitro	DCL (Ivoclar Vivadent, Schaan, Liechtenstein)	Denture tooth, ceramic	Mean vertical wear of DCL after 12 months of clinical service: DCL molars against DCL premolar antagonist was 107.4 µm, flat specimen against conical ceramic antagonist was 310.7 µm, and flat specimen against ball-like ceramic was 60.0 µm.
Schmid-Schwap et al., (2009) [30]	in vivo	SR Antaris/SR Postaris (Ivoclar Vivadent, Schaan, Liechtenstein)	Complete dentures with same teeth	Median vertical loss and volumetric loss recorded for: maxillary denture teeth: incisors—0.088 mm, canine—0.092 mm, premolars—0.204 mm and molars—0.212 mm. Mandibular denture teeth: incisors—0.055 mm, canine—0.118 mm, premolars—0.121 mm and molars—0.141 mm.
Stober et al., (2014) [33]	in vivo	DCL (Ivoclar Vivadent, Schaan, Liechtenstein).	Complete dentures with same denture teeth and also 5 split- mouth design	Mean occlusal surface wear recorded at: 6 months—56 µm, 12 months—87 µm, 18 months—114 µm, 24 months—131 µm.

3.4. Composite Resin

A total of 12 studies evaluated composite resin denture teeth (Table 5). The vertical loss of composite resin has been reported to be lower than cross-linked and conventional acrylic resin artificial teeth [39,40]. A study by Stober et al., (2010), showed that incorporation of nano-fillers result in more wear compared to composite teeth with traditional micro fillers, while the study by Suzuki et al., (1990), reported that micro-filed composites were harder than other artificial teeth [10,48]. A study by Zeng et al., (2005), showed that the wear resistance was related to the Vickers hardness of the material; teeth wear increased as the hardness reduced [52]. This study further reported that the composites with 68% and 47% organic filler content had higher microhardness and showed better wear resistance than composite with 42% filler content [53]. However, the study by Suwannaroop et al., (2011), did not show any correlation between the material properties and wear resistance, and hence concluded that hardness cannot provide a forecast of teeth material wear resistance [50]. The investigators further stated that when selecting teeth, in-addition to composition, sub-enamel layer properties should also be considered [50].

Table 5. Main findings of the selected studies on denture teeth wear (composite).

Study	Type of Study	Teeth Tested	Antagonist	Outcome
Bedini et al., (2012) [35]	in vitro	Gradia composite (GC America Inc., Alsip, IL, USA), Diamond Crown composite (PEX–Phenolic EpoXine monomer–DL MEDICA s.p.a., Milan, Italy), and Ceramage composite (Shofu Inc., Kyoto, Japan)	Servo-hydraulic 858 MiniBionix testing machine equipped by 5 KN load cell	Mean volume loss for Gradia composite teeth was 2.9 ± 1.9 mm^3, for Diamond composite was 1.8 ± 1.2 mm^3, and for Ceramage composite was 3.0 ± 1.5 mm^3.
Hahnel et al., (2009) [38]	in vitro	Condyloform II NFC (Candulor AG, Opfikon, Switzerland)	Artificial resin teeth, steel, steatite	Antagonist material influence wear of teeth significantly. Condyloform II NFC recorded highest wear against steel (150 µm), followed by steatite antagonist (95 µm), and the lowest wear was recorded against artificial teeth (40 µm).
Hao et al., (2014) [39]	in vitro	Huge Kaijing (Huge Dental Material Inc., Shanghai, China)	Silicon nitride ceramic ball	Huge Kaijing showed the lowest mean vertical loss (0.6360 ± 0.011 µm) and lowest mean volume loss (0.507 ± 0.021 mm^3 $\times 10^{-3}$) when compared to conventional acrylic resin. This value was similar to highly cross-linking polymer teeth used in the study.
Hirano et al., (1998) [40]	in vitro	DB Plus and MLI (Myerson, a Division of Austenal Inc. Chicago, USA)	Enamel abraders	Least wear values were observed with the DB Plus and MLI composite denture teeth, which showed similar wear rates: DB Plus (mean = 0.003, SD = 0.002 mm) and MLI (mean = 0.003, SD = 0.002 mm) composite teeth at 5000 cycles. In addition, similar trends were found with these teeth after 10,000 cycles: DB Plus (mean = 0.004, SD = 0.002 mm) and MLI (mean = 0.004, SD = 0.002 mm) denture teeth.
Kamonwanon et al., (2015) [4]	in vitro	Endura (Shofu Inc., Kyoto, Japan) and SR-Orthosit-PE (Ivoclar Vivadent, Schaan, Liechtenstein)	Nylon end-rounded bristle toothbrushes and toothpaste	Mean wear depth of SR-Orthosite-PE was 1.1 µm and for Endura was 3.8µm. Microfilled and modified composite artificial teeth revealed significantly less wear compared to the acrylic resin artificial teeth.
Nishino et al., (2001) [43]	in vitro	Estenia (Kuraray, Tokyo, Japan)	Hybrid composite resin specimen, porcelain, Au-Ag-PD alloy, Clearfil AP-X, enamel	On the sliding zone, Estenia recorded wear depth value of 2 µm against Estenia teeth antagonist, 18 µm against porcelain antagonist, 8 µm against metal alloy antagonist, 1.8 µm against Clearfil composite antagonist, and 6 µm against enamel antagonist. On the impacting zone, Estenia recorded wear depth value of 1.8 µm against Estenia teeth antagonist, 21 µm against porcelain antagonist, 21 µm against metal alloy antagonist, 2 µm against Clearfil composite antagonist, and 6µm against enamel antagonist.
Stober et al., (2010) [48]	in vitro	SR-Orthosit-PE (Ivoclar Vivadent AG, Schaan, Liechtenstein), Vitapan(VITA Zahnfabrik, Bad Säckingen, Germany)	Stainless steel wheel	Vertical wear after 100,000 cycles in ACTA device for SR-orthosite-PE recorded a mean vertical loss of 84 µm, and Vitapan recorded a vertical loss of 93 µm.
Stober et al., (2012) [32]	In vivo	Vitapan (VITA Zahnfabrik, Bad Säckingen, Germany)	No antagonist, complete denture, partial dentures, natural teeth, crowns, fixed partial denture	Mean vertical loss for entire occlusal surface at 6 months was 8 µm, at 12 months was 18 µm, and at 24 months was 40 µm. The mean vertical loss of denture teeth against no antagonist was 17 µm, against natural teeth was 36 µm, against metal crown was 304 µm, against denture teeth was 39 µm, and against resin veneering material was 15 µm.

Table 5. *Cont.*

Study	Type of Study	Teeth Tested	Antagonist	Outcome
Stober et al., (2020) [31]	in vivo	Vitapan (VITA Zahnfabrik, Bad Säckingen, Germany)	Complete denture, partial dentures, natural teeth, crowns, fixed partial denture	After 24 months, overall wear of the complete occlusal surface of denture teeth was 91 µm, and maximum wear of the occlusal contact areas was 329 µm. Overall wear of the occlusal surface of the denture teeth against no antagonist was 22.7 µm, against complete dentures with same teeth was 58.9 µm, against partial dentures was 67.6 µm, and against natural teeth was 115.8 µm.
Suwannaroop et al., (2011) [50]	in vitro	SR-Orthosit-PE (Ivoclar Vivadent, Italy), Yamahachi PX (Yamahachi Dental Mfg.Co., Gamagori, Aichi, Japan)	Ceramic-aluminium oxide (dura white)	Volume loss of SR-orthosit-PE was 0.040 mm^3 and for Yamahachi PX was 0.056 mm^3. No significant difference in wear resistance was shown between the composite, two of the acrylic resins and porcelain teeth in this study.
Suzuki (2004) [10]	in vitro	SR-Orthosit (Ivoclar/Vivadent, Schaan, Liechtenstein), Endura (Shofu, Kyoto, Japan), Duradent NS Surpass (GC, Tokyo, Japan)	Stainless steel ball	The wear depth recorded for SR orthosit was 93 ± 16.4 µm, for Endura was 71.5 ± 6.8 µm, for Surpass was 69.8 ± 3.3 µm, and for Duradent was 70.0 ± 11.1 µm. The results indicated that all micro-filled composite teeth were significantly harder than other teeth.
Zeng et al., (2005) [52]	in vitro	Endura (Shofu, Kyoto, Japan), Duradent (GC Corp, Tokyo, Japan), Duracross (Nissin, Kyoto, Japan)	Mandibular teeth	The total volume loss recorded for Endura was 0.26 ± 0.07 (mm^3), for Duradent was 0.87 ± 0.03 (mm^3), and for Duracross was 0.22 ± 0.08 (mm^3). The total height loss recorded for Endura was 0.18 ± 0.04 mm, for Duradent was 0.24 ± 0.03mm, and for Duracross was 0.11 ± 0.04 mm. Total volume loss and total height loss are highest in Duradent, followed by Endura, and lowest in Duracross. Greater teeth wear was recorded on the maxillary teeth compared to mandibular teeth.

Type of antagonist material has also been reported to affect the wear resistance of composite teeth; using the same composite antagonist produces better results [36]. Several studies have shown that ceramic and partial denture antagonist result in greater wear of composite teeth [31,32,38,43]. However, a study evaluating wear behaviour of hybrid composite resin artificial teeth found that the hybrid composite against a hybrid composite resin antagonist resulted in lower wear depth, while also wider worn surfaces on the lower specimen than enamel and composite resin antagonist [43]. Irrespective of the type of antagonist, clinically relevant vertical loss of composite denture teeth occurs after 24 months [32].

3.5. Nanocomposite

A total of 12 studies evaluated nanocomposite denture teeth (Table 6). Nano-filled composite teeth has been reported to have greater wear resistance than conventional acrylic resin teeth [9,10,47]. Ghazal and Kern (2010) showed that nano-filled composite causes less wear of the opposing enamel of human teeth than ceramic [14]. Studies have reported that the wear depth of nano-filled composite was not statistically different from those of the micro-filled composite and cross-linked acrylic denture teeth [10,46]. On the contrary to this, the Stober et al., (2010), study showed that incorporation of nanofillers in composite resin teeth resulted in greater wear values compared to traditional microfillers [14]. However, the study by Ghazal et al., (2008), showed no statistical differences in the total vertical substance loss between the combination's nano-filled composite resin against enamel antagonist and feldspathic ceramic against enamel antagonist [9]. The surface roughness of antagonist also influences the wear resistance of nano-filled composite; the wear increases with an increase in surface roughness [36]. Increase in loading force also increases the vertical loss of nano-filled composite teeth [14]. Nano-filled composite shows a high initial wear resistance; however, long-term wear resistance needs improvement to be comparable to natural tooth enamel [9]. The Ghazal et al., (2008), study showed that zirconia and alumina antagonists are better antagonist options against nano-filled composite than felspathic ceramic [9].

Table 6. Main findings of the selected studies on denture teeth wear (nanocomposite).

Study	Type of Study	Teeth Tested	Antagonist	Outcome
Ghazal and Kern (2009) [36]	in vitro	Condyloform II NFC (Candulor AG, Wangen, Switzerland)	Zirconia ceramic balls	Mean wear of condyloform against antagonist surface roughness of 0.24 µm was 33 µm, with a surface roughness of 0.75 µm was 42 µm, and with a surface roughness of 2.75 µm was 65 µm. The wear value of nanofiled composite increased with the increase in antagonist surface roughness.
Ghazal and Kern (2009) [15]	in vitro	Condyloform II NFC (Candulor AG, Wangen, Switzerland)	6 mm zirconia ball	Vertical loss of condyloform teeth under 20 N loading was 29 µm, under 49 N loading was 33 µm, and under 78 N loading was 37 µm. The vertical loss of nano-filled composite increases with loading force. The influence of the loading force on the amount of wear of composite resin was greater than that of human enamel.
Ghazal and Kern (2010) [14]	in vitro	Condylo form NFC II (Candulor AG, Wangen, Switzerland)	Manidbular human first premolars	The vertical loss for Condyloform II was 105 ± 32 µm and volume loss was 0.038 ± 0.0130 µm, which was statistically more wear than ceramic teeth. Compared to ceramic teeth, the vertical loss of opposing human enamel was very low (11 ± 6 µm).
Ghazal et al., (2008) [9]	in vitro	Condyloform II NFC (Candulor AG, Wangen, Switzerland)	Steatite ceramic ball	The mean vertical loss of Condyloform after 120,000 cycles was 50 ± 14 µm, after 240,000 cycles was 65 ± 12 µm, after 480,000 was 84 ± 20 µm, after 840,000 cycles was 102 ± 27 µm, and after 1,200,000 cycles was 117 ± 30 µm. The nano-composite resin teeth of this study showed a high initial wear resistance. However, long-term wear resistance of the composite teeth still needs improvement to be comparable with that of natural tooth enamel.
Ghazal et al., (2008) [13]	in vitro	Condyloform II NFC (Candulor AG, Wangen, Switzerland)	1st premolar teeth of same tested denture material and caries free human teeth	Total vertical loss of condyloform teeth against condylofom antagonist was 35 ± 9 µm and against human enamel was 169 ± 18 µm. The combination of nano-filled composite resin–nano-filled composite resin teeth showed comparable wear values with those of feldspathic ceramic–feldspathic ceramic teeth. The combinations of nano-filled composite resin–enamel and feldspathic ceramic–enamel showed statistically no differences in the total vertical substance loss. However, the wear of the antagonistic human enamel caused by nano-filled composite resin teeth was significantly less than that caused by feldspathic ceramic teeth, but more compared to acrylic resin teeth.
Ghazal et al., (2008) [37]	in vitro	Condyloform II NFC (Candulor AG, Wangen, Switzerland)	Buccal cusps of the mandibular 1st premolar	Total vertical loss of condyloform teeth after 600,000 cycles was 160 ± 14 µm. Condyloform Composite resin teeth demonstrated vertical substance loss values much higher than the acrylic resin and ceramic teeth used in the study.
Ghazal et al., (2008) [1]	in vitro	Condyloform II NFC Candulor AG, Wangen, Switzerland)	Steatite, zirconia, and alumina	The mean vertical loss and volume loss of nanocomposite teeth (Condyloform II NFC) was highest against steatite (157 µm), followed by zirconia (83 µm), and lowest against alumina (71 µm). Zirconia and alumina antagonists cause less wear of nanofilled composite resin than of feldspathic ceramic.
Ilangkumaran et al., (2014) [11]	in vitro	SR Phonares (Ivoclar Vivadent, Amherst, NY, USA)	600 grit sandpaper	Mean value of wear of Phonarres was 507.07 µm. This study confirmed the fact that the nanocomposite teeth had more wear resistance than newly developed acrylic teeth, but the difference was very minimal.
Popovic et al., (2017) [45]	in vitro	synthesized composite PMMA/ZnO NPs (Composite was synthesized by the investigators)	Machine antagonist	PMMA with 3% by volume of ZnO NPs showed slightly higher wear for both before ageing (~7 mm loss of height) and after aging (~6 mm loss of height) compared to the PMMA with 2% by volume of ZnO NPs composite resin, which recorded height loss of ~6 mm before aging and ~5 mm after aging. Denture PMMA teeth reinforced by the ZnO NPs showed better wear resistance by about four times compared to the pure PMMA.
Preis et al., (2018) [46]	in vitro	SR Phonares II (Ivoclar Vivadent inc., Amherst, NY, USA), Physiostar NFC (Candulor AG, Swiss)	Steatite antagonist	Mean wear depth of SR Phonares II was 336.8 ± 53.5 µm and for Physiostar NFC was 324.3 ± 65.1 µm. These wear values were not significantly different from unfilled PMMA with (double) cross-linked or interpenetrating polymer network (IPN) structure, cross-linked PMMA with fillers, and other composite teeth in the study.
Stober et al., (2010) [48]	in vitro	NC Veracia Posterior (Shofu Dental GmbH, Ratingen, Germany), e-Ha, Mondial (Heraeus Kulzer GmbH, Wasserburg am Bodensee, Germany)	Stainless steel wheel	Mean vertical loss in µm after 100,000 cycles in ACTA device for NC Veracia was 116 µm, e-Ha was 88 µm, and for Mondial was 105 µm. For composite resin denture teeth, the incorporation of nanofillers resulted in more wear compared to teeth with traditional micro fillers.
Suzuki (2004) [10]	in vitro	Veracia (Shofu, Kyoto, Japan)	Stainless steel stylus	Veraia recorded wear depth of 90.5 ± 10.2 µm. The nanocomposite denture tooth used in this study possesses superior surface hardness and wear resistance compared to the conventional acrylic denture tooth, and its wear depth was not statistically different from those of the micro-filled composite and cross-linked acrylic denture teeth.

3.6. Porcelain

A total of eight studies evaluated porcelain teeth (Table 7). A study by Abe et al., (2001), showed ceramic and enamel to be the worst antagonist combination for dental restorations; the study reported almost ten times more tooth surface loss of the opposing enamel [34]. Similar findings were also reported by Ghazal and Kern, (2010), which showed more wear of antagonistic enamel than that of feldspathic ceramic teeth [14]. In contrast, the study by Ghazal et al., (2008), showed that ceramic denture teeth demonstrated a two-body wear similar to human enamel [9]. A lower incidence of TMD (temporomandibular disorders) among complete denture wears with porcelain teeth was reported than those with acrylic resin teeth; this is associated to the high wear resistance of porcelain [3]. A study by Wang et al., (2010), which evaluated the effect of pH changes on tooth surface loss of ceramics, found that there was no association with tooth surface loss and pH changes; however, the presence of abrasive particles increased the tooth surface loss [51]. The Ghazal et al., (2008), study showed that zirconia- and alumina-based antagonists are better antagonists against ceramic than steatite due to their better wear resistance against ceramic [1]. A further study showed that although porcelain had the highest hardness value than the other artificial teeth tested, it showed the largest wear value against hybrid composite as the upper opposing specimen [43].

Table 7. Main findings of the selected studies on denture teeth wear (porcelain and 3D-printed).

Study	Type of Study	Teeth Tested	Antagonist	Outcome
		Porcelain		
Abe et al., (2001) [34]	in vitro	Feldspar/silica 100/6 wt.% (Nissin Dental Products, Kyoto, Japan)	Human enamel	The total height loss after 20 × 10^4 sliding times of enamel was ~380 µm and for porcelain was ~40 µm. The surface roughness values after the wear test for porcelain was 3.7 µm and for enamel was 3.6 µm. The greatest height loss among the test pairs was that of the porcelain–enamel pair in the study. The poorest combination is porcelain–enamel.
Arafa, (2016) [3]	in vivo	Porcelain (dent supply, Bensheim, Germany)	Resins and porcelain teeth on dentures	Clinical wear of porcelain denture teeth ranged from 0.022 mm to 0.061 mm across the 6-month to 24-month period. There was a higher incidence of TMD among patients wearing complete dentures with artificial teeth made of acrylic resin in comparison with those wearing complete dentures with teeth made of porcelain.
Ghazal and Kern (2010) [14]	in vitro	Bonartic CT (Candulor, Opfikon, Switzerland)	Mandibular human first premolars	The vertical loss of opposing enamel recorded after 300,000 cycles was 148 ± 16 µm, and for Bonartiic was 21 ± 6 µm. Feldspathic ceramic teeth showed significantly higher wear resistance than composite or acrylic resin teeth.
Ghazal et al., (2008) [9]	in vitro	Bonartic CT (Candulor, Opfikon, Switzerland)	Steatite ceramic ball	After 1,200,000 chewing cycles, the mean vertical substance loss and volume loss for the ceramic teeth was 36 µm and 0.029 mm^3. Ceramic denture teeth demonstrated a two-body wear similar to human enamel.
Ghazal et al., (2008) [13]	in vitro	Bonartic CT (Candulor, Opfikon, Switzerland)	Boanartic CT and human enamel	For the same teeth combination, the vertical loss of antagonist premolar Bonartic teeth recorded was 24 ± 8 µm, and for upper premolar Bonartic teeth it was 43 ± 17 µm. For the Bonartic and human enamel combination, the vertical loss recorded for the antagonist enamel was 143 ± 29 µm, and for the upper Bonartic teeth it was 24 ± 13 µm.
Ghazal et al., (2008) [1]	in vitro	Bonartic CT (Candulor, Opfikon, Switzerland)	Steatite, zirconia, and alumina	The mean vertical loss recorded was as follows: Bonartic against steatite-antagonist: steatite—98 µm and Bonartic—72 µm Bonartic against alumina-antagonist: alumina—9 µm and Bonartic—80 µm Bornartic against zirconia-antagonist: zirconia—7 µm and Bonartic—87 µm
Nishino et al., (2001) [43]	in vitro	Unibond vintage (Shofu, Kyoto, Japan)	Hybrid composite resin specimen	For hybrid composite against porcelain combination, the wear depth of porcelain on the impacting zone against hybrid composite resin was 21 µm and on the sliding zone was 18 µm; while the wear depth of hybrid composite on the impacting zone against hybrid composite resin was 17 µm and on sliding zone was 16.5 µm.
Wang et al., (2010) [52]	in vitro	Y-TZP (Yittria-TetragonalZirconiaPolycrystalline) (manufacturer/supplier not stated)	N/A	The total mass loss of Y-TZP material after 20 hrs of exposure decreased with the increase in pH of the aqueous solution with both presence of erosive particles (pH 2.0–0.587 kg^{-2} to pH of 9.5–0.0347 $kg^{-2)}$. Without the presence of the erosive particles, the total mass loss also reduced slightly (pH 2.0–0.007 kg^{-2} to pH 9.5–0.006 kg^{-2}). The total mass loss remained 0.004 kg^{-2} after exposure to solution with no particles at a pH of 2.0 and at a pH of 9.5.

Table 7. *Cont.*

Study	Type of Study	Teeth Tested	Antagonist	Outcome
		3D-printed		
Cha et al., (2019) [16]	in vitro	DENTCA denture tooth resin (DENTCA, Inc., Torrance, CA, USA)	Chrome cobalt alloy and zirconia	Volume loss of 3D-printed denture teeth DENTCA after 300,000 cycles against zirconia was 0.88 ± 0.15 mm^3 and against metal was ~0.92 ± 0.35 mm^3.

3.7. 3D-Printed Denture Teeth

Only one study was found which evaluated 3D-printed teeth (Table 7). The study reported that three-dimensional printing appeared to be useful for the fabrication of denture teeth with a sufficient level of wear resistance [16]. The results of this study showed that the wear resistance of 3D-printed teeth is comparable to conventional acrylic resin teeth. However, fine cracks were seen on the SEM images against metal antagonist.

4. Discussion

The rate of denture teeth wear is influenced by various factors such as the material and composition of the artificial teeth, the denture tooth antagonist, the tooth being replaced, patient's age and sex, the type of removable prosthesis, and the amount of superficial layer removed during occlusal adjustments. From the eleven in vivo studies, there seems to be a correlation between volumetric loss and surface area of denture teeth. However, findings are inconsistent across all studies due to differing experimental conditions, including type of testing and load applied.

The wear behaviour of the artificial teeth examined differed with regards to their respective compositions. No consistent conclusions have been drawn from studies evaluating the wear resistance of the available denture teeth. In general, higher wear was observed in PMMA teeth without filler particles than PMMA teeth modified with fillers. A study found an association between wear resistance and the Vickers hardness of artificial teeth materials; rate of teeth wear increased as the hardness reduced [10]. In contrast, Suwannaroop et al., (2011), did not find any correlation between the material properties and wear resistance of denture teeth [50]. Composite and nanocomposite teeth have a greater wear resistance compared to PMMA and DCL teeth [39,46]. However, the wear resistance of PMMA teeth can be improved with incorporation of filler particles, such as silica and titanium dioxide [38,41,53]. Similarly, addition of nano-fillers to DCL acrylic resin also improves the wear behaviour of the teeth [53]. The wear property of denture teeth is associated with the micro-structure of the material. PMMA has a linear microstructure, while modified resin teeth with the addition of cross-linking agents have a cross-linked structure. The ideal cross-linking structure of modified resins improves the mechanical properties of denture teeth [10].

Moreover, a better outcome can be achieved in removable prosthodontics by selecting denture teeth according to the type of antagonist. In complete denture fabrication, the same denture teeth should be used for both arches where possible. The study by Heintze et al., (2012), reported the lowest wear rate against the same denture teeth [53]. Similarly, the wear rate of PMMA denture teeth has been reported to be significantly lower against PMMA denture teeth and a human enamel antagonist [12,13]. Ceramic with an enamel antagonist is not a good combination as it results in high rates of wear of the enamel [14,34]. Nano-filled composite as an antagonist against human enamel is a better alternative compared to feldspathic ceramic as it causes less wear of enamel [1]. However, composite teeth with nano-fillers have also been reported to result in more wear compared to teeth with traditional micro-fillers. Significant wear of composite teeth after 24 months has been reported as inevitable, irrespective of the type of antagonist [32].

Wear resistance is gender and tooth dependent, with higher vertical wear demonstrated in male subjects and posterior teeth [28]. Similarly, the study by Stober et al., (2014), also showed maximum vertical loss of the occlusal contact areas of premolars and molars [33]. Age is also an influencing factor for denture teeth wear; wear rates decrease with increasing age of denture wearers [30]. A possible reason for this could be that as individual's age, the type and quantity of their food intake changes along with a decrease in the efficiency of the muscles of mastication.

Material composition of surface layer influences wear resistance. Therefore, the surface layer of artificial teeth should not be polished off or removed during occlusal adjustment to maintain good wear resistance. When compared with complete dentures, teeth on partial dentures exhibit a higher rate of wear [29]. This could be due to the different material of the antagonist, which in most cases are either enamel or ceramic.

The methodology of conducting experiments was inconsistent across all studies and therefore difficult to determine which method is more reliable to measure artificial teeth wear. Various wear testing machines or self-made wear machines, and different testing parameters for wear testing were adopted. This included occlusal wear in vivo, pin-on-block, pin-on-disc, two-body wear testing machine, three-body wear testing machine, and masticatory simulators. Among the methods to measure artificial teeth wear, the masticatory simulator was the most common type of testing, with 49 N load applied for 300,000 cycles. Thermocycling of 5 °C to 55 °C, varying between 30,000 and 60,000 cycles, is often the ageing protocol of choice by researchers.

The limitation of this study was that comparative evaluation of two studies could not be done. From the data search, only one study evaluating 3D-printed teeth was found, and this study's evaluation antagonist was limited to zirconia and metal antagonists with 2-body wear. On the other hand, only one study evaluated the effect of pH changes on tooth surface loss. There are several types of teeth available from the market, and some of them are marketed as products with improved mechanical properties. The results of this systematic review may assist clinicians in selecting denture teeth from the perspective of wear resistance.

5. Conclusions

Based on the findings of this systematic review, the following conclusions were drawn:

1. Artificial teeth should be selectively chosen for dentures taking into consideration the type of antagonist. The same denture teeth should be used as antagonists where possible for the best outcomes.
2. During occlusal adjustment, the superficial layer should be preserved as much as possible to enhance wear resistance.
3. The included studies demonstrated that the incorporation of nano-fillers into acrylic resin teeth does not increase wear resistance. Therefore, there is no evidence to favour the use of nano-filled composite teeth over micro-filled or conventional acrylic resin teeth.
4. The studies reported that wear resistance was related to the tooth, age and sex of patients and the type of prosthesis; therefore, selecting teeth with higher wear resistance for replacement of posterior teeth, partial dentures and for male patients can produce a better outcome.

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References

1. Ghazal, M.; Albashaireh, Z.; Kern, M. Wear resistance of nanofilled composite resin and feldspathic ceramic artificial teeth. *J. Dent.* **2008**, *100*, 441–448. [CrossRef]
2. Smith, P.W.; McCord, J.F. What do patients expect from complete dentures? *J. Dent.* **2004**, *32*, 3–7. [CrossRef]
3. Arafa, K.A. The effects of clinical wear on the incidence of temporomandibular disorders among patients with complete dentures. *J. Taibah Univ. Med. Sci.* **2016**, *11*, 250–254. [CrossRef]
4. Kamonwanon, P.; Yodmongkol, S.; Chantarachindawong, R.; Thaweeboon, S.; Thaweeboon, B.; Srikhirin, T. Wear resistance of a modified polymethyl methacrylate artificial tooth compared to five commercially available artificial tooth materials. *J. Prosthet. Dent.* **2015**, *114*, 286–292. [CrossRef]
5. Turssi, C.P.; Purquerio, B.; Serra, M.S. Wear of Dental Resin Composites: Insights into Underlying Processes and Assessment Methods—A Review. *J. Biomed. Mater. Res.* **2003**, *65B*, 280–285. [CrossRef] [PubMed]
6. Lambrechts, P.; Debels, E.; Van Landuyt, K.; Peumans, M.; Van Meerbeek, B. How to simulate wear? Overview of existing methods. *Dent. Mater.* **2006**, *22*, 693–701. [CrossRef]
7. Mello, P.C.; Coppedê, A.R.; Macedo, A.P.; de Mattos, M.d.G.C.; Rodrigues, R.C.S.; Ribeiro, R.F. Abrasion wear resistance of different artificial teeth opposed to metal and composite antagonists. *J. Appl. Oral Sci.* **2009**, *17*, 451–456. [CrossRef] [PubMed]
8. Dallanora, A.F.; Grasel, C.E.; Heine, C.P.; Demarco, F.F.; Pereira-Cenci, T.; Presta, A.A.; Boscato, N. Prevalence of temporomandibular disorders in a population of complete denture wearers. *Gerodontology* **2012**, *29*, e865–e869. [CrossRef]
9. Ghazal, M.; Yang, B.; Ludwig, K.; Kern, M. Two-body wear of resin and ceramic denture teeth in comparison to human enamel. *Dent. Mater.* **2008**, *24*, 502–507. [CrossRef]
10. Suzuki, S. In vitro wear of Nano-composite denture teeth. *J. Prosthodont.* **2004**, *13*, 238–243. [CrossRef] [PubMed]
11. Ilangkumaran, R.; Srinivasan, J.; Baburajan, K.; Balaji, N. Two Body Wear of Newly Introduced Nanocomposite Teeth and Cross Linked Four Layered Acrylic Teeth: A Comparitive In Vitro Study. *J. Indian Prosthodont. Soc.* **2014**, *14*, 126–131. [CrossRef] [PubMed]
12. Reis, K.R.; Bonfante, G.; Pegoraro, L.F.; Conti, P.C.R.; De Oliveira, P.C.G.; Kaizer, O.B. In vitro wear resistance of three types of polymethyl methacrylate denture teeth. *J. Appl. Oral Sci.* **2008**, *16*, 176–180. [CrossRef]
13. Ghazal, M.; Hedderich, J.; Kern, M. Wear of feldspathic ceramic, nano-filled composite resin and acrylic resin artificial teeth when opposed to different antagonists. *Eur. J. Oral Sci.* **2008**, *116*, 585–592. [CrossRef] [PubMed]
14. Ghazal, M.; Kern, M. Wear of denture teeth and their human enamel antagonists. *Quintessence Int.* **2010**, *41*, 157–163.
15. Ghazal, M.; Kern, M. Wear of human enamel and nano-filled composite resin denture teeth under different loading forces. *J. Oral Rehabil.* **2009**, *36*, 58–64. [CrossRef]
16. Cha, H.S.; Park, J.M.; Kim, T.H.; Lee, J.H. Wear resistance of 3D-printed denture tooth resin opposing zirconia and metal antagonists. *J. Prosthet. Dent.* **2020**, *124*, 387–394. [CrossRef]
17. Scheibenbogen, A.; Manhart, J.; Kunzelmann, K.H.; Hickel, R. One-year clinical evaluation of composite and ceramic inlays in posterior teeth. *J. Prosthet. Dent.* **1998**, *80*, 410–416. [CrossRef]
18. Krejci, I.; Krejci, D.; Lutz, F. P-30.: In vivo study of a posterior composite during 2.5 years. *Dtsch. Zahnarztl. Z.* **1990**, *45*, 773–778.
19. Ferracane, J.L.; Choi, K.K.; Condon, J.R. In vitro wear of packable dental composites. *Compend. Contin. Educ. Dent.* **1999**, *25*, S60–S66.
20. Johnsen, G.F.; Taxt-Lamolle, S.F.; Haugen, H.J. Wear model simulating clinical abrasion on composite filling materials. *Dent. Mater. J.* **2011**, *30*, 739–748. [CrossRef]
21. De Gee, A.J.; Pallav, P. Occlusal wear simulation with the ACTA wear machine. *J. Dent.* **1994**, *22* (Suppl. S1), S21–S27. [CrossRef]
22. Heintze, S.D. How to qualify and validate wear simulation devices and methods. *Dent. Mater.* **2006**, *22*, 712–734. [CrossRef] [PubMed]
23. Faggion, C. Guidelines for Reporting Pre-clinical In Vitro Studies on Dental Materials. *J. Evid. Based Dent. Pract.* **2012**, *12*, 182–189. [CrossRef] [PubMed]
24. Uehara, P.N.; Iegami, C.M.; Tamaki, R.; Ballester, R.Y.; de Souza, R.M.; Laganá, D.C. Analysis of behaviour of the wear coefficient in different layers of acrylic resin teeth. *J. Prosthet. Dent.* **2019**, *121*, 967.e1–967.e6. [CrossRef] [PubMed]
25. Heintze, S.D.; Rousson, V.; Stober, T. Patient- and therapy-related factors on the wear of denture teeth—Results of a clinical trial. *Dent. Mater.* **2015**, *31*, 302–307. [CrossRef]
26. Heintze, S.D.; Zellweger, G.; Sbicego, S.; Rousson, V.; Muñoz-Viveros, C.; Stober, T. Wear of two denture teeth materials in vivo—2-year results. *Dent. Mater.* **2013**, *29*, 191–204. [CrossRef] [PubMed]
27. Jooste, C.; Geerts, G.; Adams, L. Comparison of the clinical abrasion resistance of six commercially available denture teeth. *J. Prosthet. Dent.* **1997**, *77*, 23–27. [CrossRef]
28. Ogle, R.E.; Davis, E.L. Clinical wear study of three commercially available artificial tooth materials: Thirty-six-month results. *J. Prosthet. Dent.* **1998**, *79*, 145–151. [CrossRef]
29. Ohlmann, B.; Rohstock, K.; Kugler, J.; Gilde, H.; Dreyhaupt, J.; Stober, T. Influences on clinical wear of acrylic denture teeth: A pilot study. *Int. J. Prosthodont.* **2007**, *20*, 496–498. [PubMed]

30. Schmid-Schwap, M.; Rousson, V.; Vornwagner, K.; Heintze, S.D. Wear of two artificial tooth materials in vivo: A 12-month pilot study. *J. Prosthet. Dent.* **2009**, *102*, 104–114. [CrossRef]
31. Stober, T.; Bermejo, J.L.; Rues, S.; Rammelsberg, P. Wear of resin denture teeth in partial removable dental prostheses. *J. Prosthodont. Res.* **2020**, *64*, 85–89. [CrossRef] [PubMed]
32. Stober, T.; Geiger, A.; Rues, S.; Dreyhaupt, J.; Rammelsberg, P.; Ohlmann, B. Factors affecting wear of composite resin denture teeth-24-month results from a clinical study. *Clin. Oral Investig.* **2012**, *16*, 413–420. [CrossRef]
33. Stober, T.; Heuschmid, N.; Zellweger, G.; Rousson, V.; Rues, S.; Heintze, S.D. Comparability of clinical wear measurements by optical 3D laser scanning in two different centers. *Dent. Mater.* **2014**, *30*, 499–506. [CrossRef] [PubMed]
34. Abe, Y.; Sato, Y.; Taji, T.; Akagawa, Y.; Lambrechts, P.; Vanherle, G. An in vitro wear study of posterior denture tooth materials on human enamel. *J. Oral Rehabil.* **2001**, *28*, 407–412. [CrossRef] [PubMed]
35. Bedini, R.; Pecci, R.; Notarangelo, G.; Zuppante, F.; Persico, S.; Di Carlo, F. Microtomography evaluation of dental tissue wear surface induced by in vitro simulated chewing cycles on human and composite teeth. *Ann. Ist. Super. Sanita* **2012**, *48*, 65–70. [CrossRef]
36. Ghazal, M.; Kern, M. The influence of antagonistic surface roughness on the wear of human enamel and nanofilled composite resin artificial teeth. *J. Prosthet. Dent.* **2009**, *101*, 342–349. [CrossRef]
37. Ghazal, M.; Steiner, M.; Kern, M. Wear resistance of artificial denture teeth. *Int. J. Prosthodont.* **2008**, *21*, 166–168. [PubMed]
38. Hahnel, S.; Behr, M.; Handel, G.; Rosentritt, M. Two-body wear of artificial acrylic and composite resin teeth in relation to antagonist material. *J. Prosthet. Dent.* **2009**, *101*, 269–278. [CrossRef]
39. Hao, Z.; Yin, H.; Wang, L.; Meng, Y. Wear behavior of seven artificial resin teeth assessed with three-dimensional measurements. *J. Prosthet. Dent.* **2014**, *112*, 1507–1512. [CrossRef]
40. Hirano, S.; May, K.B.; Wagner, W.C.; Hacker, C.H. In vitro wear of resin denture teeth. *J. Prosthet. Dent.* **1998**, *79*, 152–155. [CrossRef]
41. Muhammad, N.; Maitra, S.; Haq, I.U.; Farooq, M. Some studies on the wear resistance of artificial teeth in presence of amorphous SiO_2 and TiO_2 fillers'. *Ceramica* **2011**, *57*, 324–328. [CrossRef]
42. Munshi, N.; Rosenblum, M.; Jiang, S.; Flinton, R. In Vitro Wear Resistance of Nano-Hybrid Composite Denture Teeth. *J. Prosthodont.* **2017**, *26*, 224–229. [CrossRef] [PubMed]
43. Nishino, T.; Asao, T.; Nagamatsu, H.; Kojo, T.; Kakigawa, H.; Kozono, Y.; Uchida, Y. Wearing Behaviors of a Hybrid Composite Resin for Crown and Bridge. *Dent. Mater.* **2001**, *20*, 216–226. [CrossRef]
44. Ohkubo, C.; Shimura, I.; Aoki, T.; Hanatani, S.; Hosoi, T.; Okabe, T. In vitro wear assessment of titanium alloy teeth. *J. Prosthodont.* **2002**, *11*, 263–269. [CrossRef] [PubMed]
45. Popović, D.; Bobovnik, R.; Bolka, S.; Vukadinović, M.; Lazić, V.; Rudolf, R. Synthesis of PMMA/ZnO nanoparticles composite used for resin teeth. *Mater. Technol.* **2017**, *51*, 871–878. [CrossRef]
46. Preis, V.; Hahnel, S.; Behr, M.; Rosentritt, M. Contact wear of artificial denture teeth. *J. Prosthodont. Res.* **2018**, *62*, 252–257. [CrossRef] [PubMed]
47. Shetty, M.S.; Shenoy, K.K. An in vitro analysis of wear resistance of commercially available acrylic denture teeth. *J. Indian Prosthodont. Soc.* **2010**, *10*, 149–153. [CrossRef]
48. Stober, T.; Henninger, M.; Schmitter, M.; Pritsch, M.; Rammelsberg, P. Three-body wear of resin denture teeth with and without nanofillers. *J. Prosthet. Dent.* **2010**, *103*, 108–117. [CrossRef]
49. Stober, T.; Lutz, T.; Gilde, H.; Rammelsberg, P. Wear of resin denture teeth by two-body contact. *Dent. Mater.* **2006**, *22*, 243–249. [CrossRef] [PubMed]
50. Suwannaroop, P.; Chaijareenont, P.; Koottathape, N.; Takahashi, H.; Arksornnukit, M. In vitro wear resistance, hardness and elastic modulus of artificial denture teeth. *Dent. Mater. J.* **2011**, *30*, 461–468. [CrossRef] [PubMed]
51. Wang, H.C.; Stack, M.M.; Li, W.L.; Hong, T.F.; Wang, M.C. On the construction of wear maps for Y-TZP dental ceramics in aqueous environments: PH, exposure time and impact angle effects. *Tribol. Int.* **2010**, *43*, 2258–2267. [CrossRef]
52. Zeng, J.; Sato, Y.; Ohkubo, C.; Hosoi, T. In vitro wear resistance of three types of composite resin denture teeth. *J. Prosthet. Dent.* **2005**, *94*, 453–457. [CrossRef] [PubMed]
53. Heintze, S.D.; Zellweger, G.; Grunert, I.; Muñoz-Viveros, C.A.; Hagenbuch, K. Laboratory methods for evaluating the wear of denture teeth and their correlation with clinical results. *Dent. Mater.* **2012**, *28*, 261–272. [CrossRef] [PubMed]
54. Hernandez, E.P.; Oshida, Y.; Platt, J.A.; Andres, C.J.; Barco, M.T.; Brown, D.T. Mechanical properties of four methylmethacrylate-based resins for provisional fixed restorations. *Biomed. Mater. Eng.* **2004**, *14*, 107–122.