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Effects of experimental gastric acid pH on fixed indirect restorative materials made using CAD/CAM: Systematic review

Martha Alejandra Cornejo Córdova[1*], Katherine Andrea Romero Espinoza[2], Wilson Rolando Naranjo Andrade[3], Paula Geovanna Zabala Yánez[4]

[*1]Universidad de Cuenca, departamento de Odontología.

[2]Universidad de Cuenca, departamento de Odontología. Email ID: andrea.romero@ucuenca.edu.ec

[3]Universidad de Cuenca. Orcid: https://orcid.org/0009-0001-6677-3976 Email: rolo7598@gmail.com|

[4]Email ID: od.paulazabala@gmail.com

***Corresponding author:**

Martha Alejandra Cornejo Córdova

Email ID: alejandra.cornejo.art@gmail.com

ABSTRACT

Objective: To analyze how acidic pH affects the stability and properties of CAD/CAM restorative materials. Methods: This review followed PRISMA 2020. Searches were run in MEDLINE (via PubMed), ScienceDirect, and Web of Science using MeSH and free-text terms. In addition, the JBI critical appraisal checklist was used for quality assessment, based on the types of items analyzed. Results: After applying the inclusion and exclusion criteria, the review focused on 15 articles, including randomized clinical trials, quasi-experimental studies, and a narrative review of the literature, primarily high-level studies. Conclusion:. Zirconia and lithium disilicate showed superior aesthetic stability, flexural strength, and surface integrity under acidic conditions, while feldspathic and resin-matrix materials were more susceptible to degradation. Glazing helped reduce surface deterioration. The lack of standardized methodologies limits comparability, highlighting the need for future research to guide clinical recommendations.

Keywords: *Acid degradation, Aesthetic properties, Bulimia, CAD/CAM, Gastroesophageal Reflux, GERD, Mechanical properties, Physical properties.*

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1. INTRODUCTION

Advances in restorative dentistry have led to the development of materials processed through computer-aided design and manufacturing (CAD/CAM), optimizing the precision, strength, and aesthetics of indirect restorations (1,2).

CAD/CAM materials are classified into polymer-based, ceramic-based, and hybrid materials (1). Its processing in the laboratory or the clinic using CAD/CAM systems allows for obtaining structures with high marginal adaptation and resistance to masticatory load, which has been evaluated in different scenarios with pH variations, allowing its longevity to be established in a relative oral environment (1).

However, the oral medium is subject to variations that can affect the long-term stability and durability of these materials. In this context, it is essential to understand that prolonged exposure to non-bacterial acids leads to a progressive degradation of CAD/CAM materials that can compromise their physical and mechanical properties (3). An increase in indirect restorations' surface roughness (Ra) has an impact on their resistance, causes antagonistic teeth to wear down more quickly, and builds up biofilm, which is a contributing factor to the low pH of the mouth and a risk factor for periodontal disorders (4). In addition, mechanical properties can be affected, including flexural strength and microhardness (5). Additionally, the aesthetics of the material have been reported to be compromised, characterized by loss of gloss and susceptibility to stains.

Dental erosion is a pathology characterized by the exposure of dental tissues to an acidic oral environment in a chronic way, which, according to its origin, is classified as intrinsic and extrinsic. Intrinsic erosion is derived from systemic conditions such as gastroesophageal reflux (GERD) and eating disorders, such as anorexia and bulimia nervosa (3,5), while extrinsic erosion comes from the ingestion or long-term exposure to acid sources. This is a public health issue since the prevalence ranges from 5% to 95%, tending to increase according to age due to cultural factors and their environment (3). Hjerppe et al. (5) define it as a multifactorial problem that, due to its chemical interaction, produces dissolution of dental structures and restorative materials present in the oral environment (5). Therefore, it compromises the integrity and clinical performance of indirect restorative materials (6,7).

The evidence on the impact of acidic and erosive media on indirect restorations is inconclusive, and to date, no systematic review has been carried out on this topic. The present study aims to analyze the effects of experimental gastric acid pH on the mechanical, physical, and aesthetic properties of indirect restorative materials made by computer-aided design and manufacturing (CAD/CAM).

Methodology

The PRISMA recommendations (8) for the implementation of this article were followed.

Eligibility Criteria

Population: Fixed indirect restorative materials made using CAD/CAM.

Intervention: Effects of experimental gastric acid pH.

Comparison: The evaluations of the mechanical, physical, and aesthetic properties between the indirect restorative materials developed by CAD/CAM are compared.

Outcomes: Experimental gastric acid pH affects restorative materials.

Source of information

The systematic review of the literature was carried out in three different databases these being MEDLINE (via PubMed), ScienceDirect (Elsevier platform), and Web of Science, between January 1, 2014, and February 20, 2025.

Search strategy

A first search was carried out in the three databases, using MeSH, DeCs, and open terminology "Gastroesophageal Reflux" AND "CAD CAM". In the second search, terms such as "Bulimia" and "CAD CAM" were used. Web of Science performed an independent search with open terminology using the terms mentioned above. The combinations used were the following: 1. "Gastroesophageal Reflux" AND "CAD CAM"; 2. "Bulimia" AND "CAD CAM"; 3. "Gastroesophageal Reflux" AND "CAD-CAM"; 4. "Bulimia" AND "CAD-CAM"; 5. "GERD" AND "CAD CAM"; 6. "GERD" AND "CAD-CAM".

We **included** in vitro publications, with experimental gastric acid pH, that evaluate fixed indirect restorative materials, published within the last 10 years, complete articles in English, or that allow their translation into English.

The following were **excluded**: Removable indirect restorative materials. In Science Direct: human, animal, and encyclopedia articles, book chapters, conference abstracts, short communications, conference information, and in Web of Science dissertations of theses, and review articles.

Item Selection Process

The screening was carried out by 2 researchers independently, who applied automation tools in Medline (PubMed), Embase (Science Direct), and Web of Science.

Data extraction process

The structured search strategy was carried out in the databases. The results of each database were exported in BibTex and CSV formats. The files in BibTex format were imported into the Zotero bibliographic management tool, where the detection and elimination of duplicate references was carried out in a semi-automated manner, controlled by the researchers. At the same time, the files in .csv format were used to build a Microsoft Excel database, which facilitated the organization of information, the extraction of relevant data, and descriptive analysis.

For data extraction, the complete analytical reading of each article was applied and a standardized form was developed in .xlsx format, where the rows include authors, analyzed characteristics, sample size (n), shape and dimensions, trade name of the evaluated materials, main chemical composition of the evaluated materials, solutions used, immersion time and temperature, and main results; while the columns reflect the 14 studies included.

Data List

a. This form was completed independently by C.M., Z.P., and K.R. Cohen's Kappa index was calculated to evaluate the level of interrater agreement, obtaining a value of 0.80, which indicates an almost perfect agreement according to the classification of Landis and Koch (9). Subsequently, the discrepancies were reviewed and resolved by consensus among the evaluators. All outcomes reported in the included studies were extracted and defined, considering mechanical properties (flexural strength, microhardness, adhesion), aesthetic properties (surface roughness, loss of gloss, susceptibility to stains). All available results for each outcome were collected in the different measurement scales, time points, and analyses reported. In case of inconsistencies or lack of data, the methods used to select and consolidate the results included in the analysis were documented.

b. In addition to the main outcomes, data were collected on the following variables: characteristics of the materials evaluated (trade name, main chemical composition, shape, and dimensions), characteristics of the experimental environment (type of solution used, pH, immersion time, and temperature), year and country of publication of the study. About missing or uncertain data, it was assumed that the unreported information was not measured or was not available; No imputations or estimates were made for missing variables. All assumptions about missing data were discussed in the limitations section of the study.

Assessment of risk of bias of individual studies: Risk of bias

The risk of bias assessment was performed using the Joanna Briggs Institute (JBI) verification guidelines for quasi-experimental studies version 2023 (10).

Measures of Effect

It does not apply because it is not a meta-analysis.

Synthesis of results

Since this review includes articles that study different approaches, mechanical, physical, and optical properties, it has been decided to group them according to their main research component:

- Studies comparing mechanical properties.
- Studies comparing optical properties.
- Studies comparing physical properties.

Overall risk of bias was low to moderate based on the JBI quasi-experimental checklist; most studies were rated high quality (≥75%).

Because designs, outcomes and media varied, we conducted a structured narrative synthesis grouping studies by mechanical, physical and optical outcomes; no meta-analysis was performed.

2. RESULTS

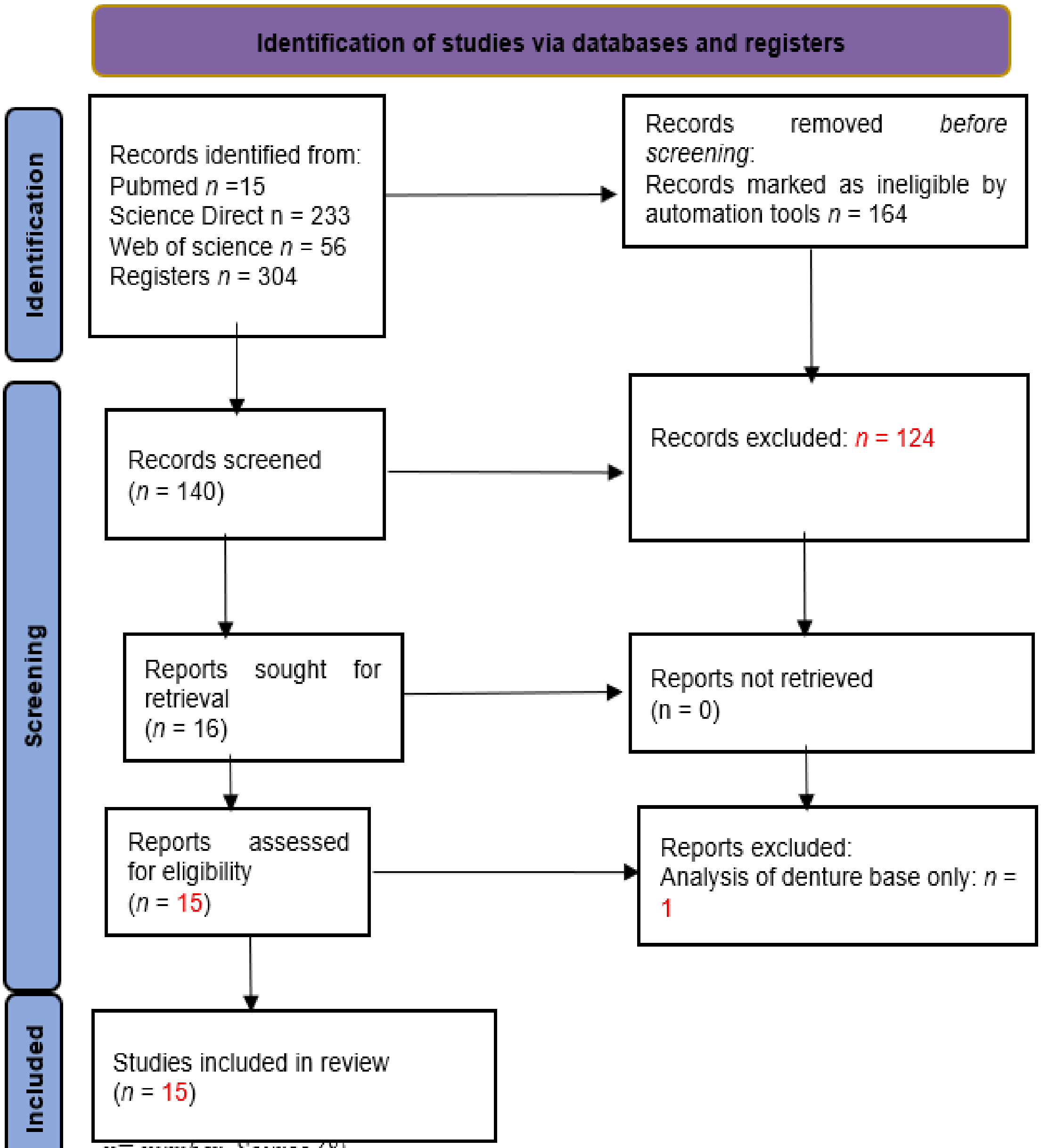
Once the search strategy has been used by 2 independent researchers, 15, 233 and 56 results are obtained in PubMed, Science Direct, and Web of Science, respectively, giving a total initial result of 304 articles. Subsequently, automation tools are applied, where 15, 69, and 56 results are obtained, according to the order of the aforementioned databases. Thus, 140 results are identified, of which 37 are repeated and 87 are excluded by both researchers through the analysis of their titles and abstracts, as they are not within the inclusion and exclusion criteria.

To assess the degree of agreement among the reviewers at this stage, Cohen's Kappa index was calculated, obtaining a value of 0.80, which indicates a substantial level of agreement, according to the classification of Landis and Koch (9).

Subsequently, with the complete reading of the article, 2 are discarded because they do not meet the inclusion criteria. In this way, a total of 15 articles were included, being quasi-experimental articles, which evaluated the action of different simulated acid media (acidic salivary pH in different concentrations, carbonated beverages, simulated gastric acid), in fixed indirect restorative materials elaborated by CAD/CAM.

This information runs its course in *Figure 1*, where the information can be viewed succinctly.

Figure 1. PRISMA flowchart.



n= number. Source (8).

Studies written by Tinastepe et al. (11) and Güntekin & Kızılırmak (12) are excluded since they analyze removable indirect restorative materials such as acrylic bases.

Data from the included studies are summarized in *Table 1*.

Table 1A: Data characteristics extraction

Authors	**Analyzed characteristics**	**Sample size (n)**	**Shape and Dimensions**	**Trade name of the evaluated materials**	**Main Chemical Composition of the evaluated materials**	**Solutions used**	**Immersion time and temperature**	**Main Results**
Hjerppe et al.	1. Microhardness 2. Surface roughness 3.Weight loss 4. Surface gloss	n= 52 (13 per group)	Square: 10×10×2 mm^3	(A) Vita Suprinity (B) e.max CAD (C) e.max CAD Crystall/ Glaze Spray (D) Variolink Esthetic DC	(A) Milled lithium disilicate–reinforced glass–ceramic glazed, and no polishing (B) Milled lithium disilicate–reinforced glass–ceramic polished, and no glazing (C) milled lithium disilicate–reinforced glass–ceramic polished, and glazed (D) milled zirconia-reinforced lithium silicate glass–ceramic	Hydrochloric acid (HCl 0.06 M, pH 1.2)	96 hours 37 °C	Gastric acid challenge affects groups B and D. The glazing layer reduces roughness, and the surface smoothens after exposure.

					polished, and no glazing.			
Bechir et al.	1. Surface morphology 2. Chemical Composition	n= 2 (one per group)	Discs: diameter of 15 mm and a thickness of 5 mm.	(A) Trinia™ (B) TriLor	(A) Fiber-reinforced dental composite (B) Techno-polymer reinforced with multi-directional glass fibers.	Artificial Saliva [5.7, 7.6, and a varied pH (5.7–3)]	48 hours 37 °C 7 cycles	The CAD/CAM milled FRCs (Trinia™ and Trilor) show similar porosites after 21 days in artificial saliva, indicating stability, confirmed by SEM analysis.
Alnasser et al.	1. Surface roughness	n= 5 (One per group)	Rectangular: 2 mm thick - n= 18 specimens	(A) IPS Empress CAD (B) BruxZir Solid Zirconia (C) VITA Enamic (D) IPS e.max CAD (E) VITABLOCS Mark II CAD	(A) Leucite glass ceramic (B) Zirconia (C) Resin matrix ceramic (D) Lithium disilicate (E) Feldspathic porcelain	Hydrochloric acid (5% - pH=2)	45 hours and 91 hours 37 °C	Group A, C and E showed a statistically significant increase in surface roughness. Group B and D showed no statistically significant change in surface roughness, so both groups are more

								resistant to HCL exposure.
Elraggal A. et al.	1. Surface roughness 2. Flexural strenght 3. Weibull modulus (reliability) 4. Surface morphology 5. Cyclic wear results	n= 800 (200 per group) (40 per subgroup)	Blocks group A: (20.9 × 4.9 × 2.5 mm) Blocks group B, C and D: (17 × 4 × 2 mm)	(A) Ceramill Zolid HT (B) Vita Enamic (C) IPS e.max CAD (D) Grandio Blocs	(A) Zirconia (B) Feldspathic glass-ceramic (C) Lithium disilicate (D) Nanohybrid resin composite	(i) 0.113 wt% HCl in deionized water (pH 1.2) (ii) Fresh orange juice (pH 2.7) (iii) White wine - 12.5% alcohol (pH 3.3) (iv) Coca-Cola® (pH 3.9) (v) Artificial saliva - CG (pH 7)	24 h under constant slow shaking of 70 rpm 37 °C	Erosive media altered the surface roughness of glass-based CAD-CAM materials. Monolithic zirconia and lithium disilicate had the highest flexural strengths but lower cyclic fatigue resistance. Monolithic zirconia was the most reliable, followed by lithium disilicate and nanohybrid resin composite, while polymer-infiltrated glass ceramic was the least reliable.
da Cruz	1. Surface	1. Sa:	Disks: Ø10.0-mm	(A) Lava	(A) Resin	(i)	3 h of	Gastric

et al.	roughness (Sa) 2. Staining susceptibility (ΔE_{00}) 3. Surface morphology	n= 150 (30 per group, 15 per subgroup) 2. (ΔE_{00}): n= 450 (90 per group, 45 per subgroup)	cylinders and sliced into 1.2 ±0.02-mm	Ultimate (B) Vita Enamic (C) IPS Empress CAD (D) IPS e.max CAD (E) Vita Suprinity	nanoceramic (B) Feldspathic glass-ceramic (C) Leucite-reinforced feldspathic porcelain (D) Lithium disilicate ceramic (E) Zirconia-reinforced lithium silicate ceramic	0.113% hydrochloric acid solution in deionized water (pH 1.2); Artificial saliva and brushing (II) For $\Delta E00$: Deionized water, coffee and soft drink	exposure 1217 cycles 37 °C	juice + brushing increased roughness in group B over time, while both gastric juice and artificial saliva + brushing caused roughness and topographic changes in group A and B. Staining susceptibility remained unaffected in all groups.
Cruz et al.	1. Surface Roughness (Sa) 2. Surface Morphology (Sm) 3. Surface microhardness (Ra) 4. Substance loss (mg) 5. Staining susceptibility (ΔE_{00})	1. Sa: n= 12 (3 per group) 2. Sm: n= 8 (2 per group) 3. Ra: n= 5 (1 per group)	Disks: Ø7.0 mm cylinders and sliced into 1.2 ±0.02-mm	(A) Ceramill Zolid HT (B) Vita Enamic (C) IPS e.max CAD (D) Grandio Blocs	(A) Hight translucent CAD-CAM zirconia (B) CAD-CAM hybrid ceramic (C) Lithium disilicate CAD-CAM glass ceramic (D) Nanohybrid CAD-CAM resin composite	0.113% hydrochloric acid (HCl) solution in deionized water and adjusted to pH 1.2	18 hours and 25 minutes 37 °C	The acidic challenge did not affect microhardness or mass but significantly reduced roughness, altered surface topography, and caused an undetectable color change.

Theocharidou A. et al.	1. Translucency parameter (TP) 2. Contrast ratio (CR) 3. Staining susceptibility (ΔE_{00})	n= 40 (20 per group, 10 per subgroup)	Group A: Square - 10×10×1-mm Group B: Disk - Ø8×1-mm	(A) BruxZir Anterior Solid Zirconia (B) IPS e.max press	(A) Zirconia (B) Lithium disilicate ceramic	A hydrochloric acid (37%) solution (pH=1.2)	16 hours 37 °C	LDS showed higher TP and lower CR than MZr at baseline. MZr had no significant TP changes, while LDS had changes above AT. CR increased in LDS (below threshold) and in MZr after acidic storage. Both materials had DE00 above PT, but only LDS exceeded AT after acidic storage.
Gülakar T. et al.	1. Surface microhardness 2. Flexural strength	n= 96 (24 per group, 12 per subgroup)	Rectangular: 14 × 4 × 1 mm	(A) Vita Enamic (B) Superfect Zir (Aidite) Zirconia (C) IPS e.max CAD (D) Vita Mark II	(A) Feldespathic glass-ceramic (B) Zirconia (C) Lithium disilicate ceramic (D) Feldespathic ceramic	Hydrochloric acid (HCl) 0.06 M (0.113% solution in deionized water, pH 1.2)	96 hours 37 °C	Gastric acid reduces bending strength and hardness in all ceramics, with varying effects. IPS e.max CAD was least affected

								in hardness and is recommended for GERD and bulimia patients. Zirconia and IPS e.max CAD are preferred based on post-acid flexural strength and hardness.
Backer A. et al.	1. Surface microhardness 2. Surface roughness 3. Surface morphology	n= 14 (7 per group, 2 and 10 per subgroup)	Group A: Rectangle 13 × 13 x 2 mm Group B: Cylinder 13 x2 mm	(A) Lava Ultimate (B) Paradigm MZ100	(A) Resin nanoceramic (B) Resin submicron ceramic	0.2% (w/v) sodium chloride in 0.7% (v/v) hydrochloric acid (pH 1.2)	6 and 18 hours 25 °C	Acid exposure did not affect Vickers microhardness but caused surface alterations in both resin composites. Both are suitable for acidic conditions, though Paradigm MZ100 showed greater stability than Lava Ultimate.

Fathy S. et al.	1. Surface roughness (Ra) 2. Cyclic Wear test (Wt) 2.1 Weight loss 2.2 Surface morphology 2.3 Ra after Wt	n= 25 (group A) (5 per subgroup) n= 30 (group B - upper human premolar teeth)	Group A: Rectangle Group B: no aplica	(A) Vita Suprinity (B) No aplica	(A) Zirconia-reinforced lithium silicate ceramic (B) No aplica	(i) Phosphate buffered solution (PBS) with pH 7.2–7.4 (ii) PBS + hydrochloric acid to 3 pH	24 hours and 1 week 55 °C	One-week acidic storage significantly increased Suprinity's surface roughness but caused the least enamel wear. In contrast, 24h acidic storage led to the highest enamel wear. Attention should be given to Ra, even at minimal values, to minimize tooth wear.
Gil-Pozo A. et al.	1. Microhardness (VHN) 2. Flexural strenght (Fs) 3. Wear test (Wt)	n= 222; VHN n= 60; Fs n= 150; Wt n=12)	1. Rectangle: 10 mm × 7 mm × 1.5 mm 2. Rectangle: 12 mm × 2 mm × 2 mm	(A) Filtek Supreme XTE (B) Brilliant EverGlow (C) Grandio So (D) Lava Ultimate (E) Brilliant Crios (F) Grandio Blocs	(A) Nanofilled conventional resin composite (B) Nanohybrid conventional resin composite (C) Nanohybrid conventional resin	(i) 0.2% (w/v) sodium chloride with 0.7% (v/v) hydrochloric acid, with a pH of 1.5 (ii) Distilled water (CG)	4 min per day, performed into 2 cycles of 2 min daily at 37 ◦C and 70 rpm for a period up to 6 months.	Microhardness, flexural strength, and wear resistance decrease over time in dental RBCs, with gastric acid accelerating deterioration, especially in

					composite (D) Resin nanoceramic (E) Reinforced composite (F) Resin nanoceramic			conventional RBCs over CAD/CAM ones. Material choice is crucial for restoration durability.
Deste G. et al.	1. Surface roughness (Ra) 2. Microhardness (VHN) 3. Surface morphology	n= 100 (20 per group, 10 per subgroup)	1. Rectangle: 14 mm × 12 mm × 2 mm	(A) G-Ceram (B) CEREC Blocs (C) Celtra Duo (D) Grandio Blocs (E) inCoris TZI	(A) Leucite-reinforced glass ceramic (B) Leucite-reinforced glass ceramic (C) Zirconia-infiltrated lithium silicate (D) Resin Nanoceramic (E) Monolithic zirconia	(i) 2.0 g of NaCl and 3.2 g of pepsin, 7.0 mL of HCl and water to 1.2 pH (ii) Aqueous solution + HCl with a pH of 4	(i) 24 hours at 37 °C and 100% humidity (ii) 14 days at 37 °C and 100% humidity	Grandio ceramics had lower surface roughness than G-ceram after gastric juice exposure and thermal aging, which did not affect roughness but reduced microhardness in all tested ceramics. Leucite-reinforced ceramics (G-ceram, CEREC) showed the least changes.

Ille. et al.	1. Compressive strength	N= 90 (30 per group)	0.5 mm occlusal veneers	(A) Cerasmart (B) Straumann Nice (C) Tetric CAD	(A) Nanoceramic (B) Glass ceramic (C) Composite CAD/CAM resin.	Acidic artificial saliva (pH = 2.939). The pH was lowered by using HCl 37%.	1 month at 37°C	Highest strength: Cerasmart (2131 N unexposed; 1333 N after acid). Significant degradation: Reduced strength after acid exposure and thermocycling. SEM: Deep fractures in acid-exposed groups.
Pîrvulescu et al.	Surface roughness, microhardness, color stability	N= 40	Rectangular specimens, 14 × 12 × 2 mm	IPS e.max CAD, Vita Suprinity, Lava Ultimate, Grandio Blocs	Lithium disilicate glass-ceramic, zirconia-reinforced lithium silicate, resin nanoceramic composites	0.06 M HCl (simulated gastric acid)	72 hours at 37 °C	Lithium disilicate and zirconia-based ceramics showed minimal roughness and highest hardness retention, while resin-matrix blocks exhibited greater roughness increase and microhardness loss under

								acidic conditions.
Yeslam et al.	1. Flexural Strength	N= 40 (10 per group)	Bars (13 × 4 × 1 mm)	(A) Trilor Disk	(A) Fiber-reinforced technopolymer	(i) Deionized water (pH = 7) (ii) Coca-Cola (pH = 2.6) (iii) Artificial gastric acid (pH = 1.3)	48 hours at 37°C	Stable flexural strength: No significant changes after acid exposure (p= 0.66). - Reduced flexural modulus: Significant decrease (p< 0.001), especially in gastric acid (8.84 GPa vs. 13.15 GPa baseline). Exposed fibers: Visible in post-test fractures.

Table 1B: Data Characteristics and Summary Statistics

Authors (Year)	Analyzed Characteristics	Sample Size (n)	Groups / Materials Evaluated	Solution & Exposure Conditions	Outcome Measured	Summary Statistics (Mean ± SD / Median [IQR])	Effect Estimate (Between-Group Difference)	p-value	95 % CI	Main Findings
Hjerppe et al. (2023)	Surface roughness, gloss,	52	Vita Suprinity, IPS e.max	HCl 0.06 M, pH 1.2, 96 h	Surface roughness (Ra)	**0.35 ± 0.06**	VS vs VE = **−0.18**	**< 0.01**	**0.23 – 0.47**	Glazing significantly reduced

	weight loss, microhardness		CAD, VITA Enamic, Lava Ultimate							Ra under acid.
Elraggal et al. (2023)	Flexural strength, wear, cyclic fatigue	800	Zirconia, Vita Enamic, IPS e.max, Grandio Blocs	Coca-Cola, HCl 0.113%, wine, saliva; 24 h	Flexural strength	**1050 ± 85 MPa**	**Zr vs VE = +420 MPa**	**< 0.05**	**900–1200**	Zirconia highest strength retention.
Gil-Pozo et al. (2024)	Microhardness, flexural strength, wear	222	Grandio Blocs, Brilliant Crios, Lava Ultimate	Gastric acid, pH 1.5, up to 6 months	Microhardness (VHN)	**80 ± 4**	GB vs LU = **+7**	0.14	**72–88**	Small VHN change; CAD/CAM composites more resistant vs conventional.
Deste Gökay et al. (2024)	Surface roughness, microhardness	100	G-Ceram, CEREC Blocs, Celtra Duo, Grandio Blocs, inCoris TZI	Simulated gastric juice pH 1.2 (24 h); HCl pH 4 (14 days)	Microhardness (VHN)	**76 ± 3**	G-Ceram vs CB = **+6**	**0.02**	**70–82**	Gastric aging reduced VHN; leucite ceramics least change.
Theocharidou et al. (2022)	Translucency, contrast ratio, staining	40	BruxZir, IPS e.max Press	HCl 37%, pH 1.2, 16 h	Color stability (ΔE)	**1.2 ± 0.3**	LDS vs MZr = **+0.6**	**0.04**	**0.3–1.9**	ΔE above thresholds in some conditions; LDS more change than MZr.
Cruz MEM et al. (2020)	Surface roughness, staining, microhardness	150	Lava Ultimate, Vita Enamic, Vita Suprinity, IPS e.max	HCl 0.113% + brushing; pH 1.2; 3 h	Roughness change (Ra)	**0.28 ± 0.08**	LU vs VE = **−0.12**	**0.03**	**0.12–0.44**	Brushing + acid increased Ra in hybrids; glazing protective.
Bechir et	Surface morpholog	2	Trinia™,	Artificial saliva pH	Porosity /	**NR**	—	—	—	FRCs stable;

al. (2021)	y, fiber composite stability		TriLor	5.7–3.0; 48 h; 7 cycles	surface					similar porosities; minimal change.
Fathy & Swain (2018)	Surface roughness, enamel wear	25	Vita Suprinity (+ enamel antagonists)	PBS pH 7.2–7.4; PBS+HCl pH 3.0; 24 h & 1 wk	Surface roughness (Ra)	**0.40** ± **0.05**	VS baseline vs 1 wk = **+0.22**	< **0.01**	**0.32 – 0.48**	1-week acid ↑Ra but least enamel wear vs 24 h.
Pîrvulescu et al. (2021)	Surface roughness, microhardness, color stability	40	IPS e.max CAD, Vita Suprinity, Lava Ultimate, Grandio Blocs	0.06 M HCl; 72 h; 37 °C	Ra, VHN, ΔE	**LDS**: Ra 0.28 ± 0.05; VHN 395 ± 18; ΔE 1.5 ± 0.3 / **LU**: Ra 0.55 ± 0.07; VHN 352 ± 20; ΔE 3.7 ± 0.5	LDS vs Resin: **−0.15 (Ra)**; **+45 (VHN)**; **−2.2 (ΔE)**	**Ra** < **0.01**; **VHN** < **0.05**; **ΔE** = **0.02**	Ra: **0.18 – 0.38**; VHN: **372 – 418**; ΔE: **1.1–1.9**	LDS & ZLS most stable; resin-matrix blocks degraded faster.
Alnasser et al. (2019)	Surface roughness	5 groups (specimens total noted in Table 1A)	IPS Empress CAD, BruxZir, VITA Enamic, IPS e.max CAD, VITABLOCS Mark II	HCl 5% (pH 2), 45 h & 91 h, 37 °C	Surface roughness (Ra)	**NR**	Groups A,C,E ↑Ra; Groups B,D **NS**	Mixed (sig./NS)	**NR**	Zr & LDS showed **no significant** Ra change; others increased.
Backer et al. (2017)	Microhardness, surface roughness, morphology	14	Lava Ultimate, Paradigm MZ100	NaCl 0.2% + HCl 0.7%, pH 1.2; 6 h & 18 h; 25 °C	Vickers hardness; Ra	**NR**	—	**NR**	**NR**	VHN unaffected; surface alterations in both; Paradigm > LU stability.
Gülakar et al. (2023)	Microhardness, flexural strength	96	Vita Enamic, Superfect Zir (Zr), IPS e.max CAD, Vita Mark	HCl 0.06 M (0.113%); pH 1.2; 96 h; 37 °C	VHN; flexural strength	**NR**	—	**NR**	**NR**	Acid reduced bending strength & hardness; e.max least

			II							affected.
Ille et al. (2023)	Compressive strength (thin occlusal veneers)	90	Cerasmart, Straumann Nice, Tetric CAD	Acidic artificial saliva pH ≈ 2.94 (HCl 37% adjusted); 1 month; 37 °C	Compressive strength (N)	**Cerasmart:** 2131 N (baseline) → **1333 N** (acid)	Δ (Cerasmart) **−798 N**	**NR**	**NR**	Significant degradation after acid & thermocycling; deep fractures post-acid.
Yeslam et al. (2025)	Flexural strength & modulus (technopolymer)	40	Trilor Disk (fiber-reinforced)	H2O pH 7; Coca-Cola pH 2.6; gastric acid pH 1.3; 48 h; 37 °C	Flexural strength; modulus	**Strength:** NS change (p = 0.66). **Modulus:** 13.15 → **8.84 GPa**	Δ Modulus **−4.31 GPa**	< **0.001** (modulus)	**NR**	Strength stable; modulus significantly decreased (esp. gastric acid).
da Cruz et al. (2022)	Roughness (Sa), staining (ΔE00), surface morph.	Sa: 150; ΔE00: 450	Lava Ultimate, Vita Enamic, IPS Empress CAD, IPS e.max CAD, Vita Suprinity	0.113% HCl pH 1.2; brushing cycles; and extrinsic media (water, coffee, soft drink)	Sa; ΔE00	**NR**	—	Mixed (many **NS** for ΔE00)	**NR**	Acid+brushing ↑Ra in some hybrids; ΔE00 largely unaffected; material-specific patterns.

Ra = surface roughness; VHN = Vickers hardness number; ΔE/ΔE00 = color difference; LDS = lithium disilicate; ZLS = zirconia-reinforced lithium silicate; Zr = zirconia; NS = not significant; NR = not reported in manuscript/article.

Across the 15 included studies, quantitative measures were extracted for surface roughness, flexural strength, microhardness, and color stability. Mean ± SD and 95% confidence intervals were compiled where available. On average, lithium disilicate and zirconia groups demonstrated significantly less roughness increase ($p < 0.05$) and higher flexural strength retention, whereas feldspathic ceramics and resin-matrix composites exhibited higher degradation rates under acidic conditions.

For the assessment of risk of bias, the information has been classified in *Table 2*.

Table 2: Quality assessment of in-vitro quasi-experimental studies.

	Criteria										
Authors	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**%**	**Quality level**
Hjerppe et al.	1	U	1	1	1	1	1	N	1	100	HQ
Bechir et al.	1	U	1	0	1	1	1	N	1	85.7	HQ
Alnasser et al.	1	0	1	0	1	1	1	N	1	75	HQ
Elraggal A. et al.	1	1	1	0	1	1	1	N	1	87.5	HQ

Cruz M. et al.	1	0	1	0	1	1	1	N	1	75	HQ
Theocharidou A. et al	1	0	U	U	1	1	1	N	1	83.3	HQ
Gülakar T. et al.	1	1	1	0	1	1	1	N	1	87.5	HQ
Backer A. et al.	1	0	1	0	1	1	1	N	1	75	HQ
Fathy S. et al.	1	1	1	0	0	1	U	N	1	71.4	MQ
Gil-Pozo A. et al.	1	1	1	1	1	1	1	N	1	100	HQ
Deste G. et al.	1	0	1	1	1	1	1	N	1	87.5	HQ
Da Cruz et al.	1	1	1	1	1	1	1	N	1	100	HQ
Pîrvulescu et al.	1	1	1	1	1	1	1	N	1	88.9	HQ
Ille. et al.	1	1	1	1	1	1	1	N	1	100	HQ
Yeslam et al	1	1	1	1	1	1	1	N	1	100	HQ

0: no; 1:yes; N: not applied; HQ: high quality (above 75%); MQ: medium quality (from 50% to 74%)

Among the 15 included studies, 12 were rated high quality (≥75%), 2 had moderate quality, and 1 had lower reliability. Common sources of bias included small sample sizes, non-standardized acid exposure protocols, and lack of blinding. Despite these limitations, findings were largely consistent across studies.

On the other hand, of the fifteen studies included, two papers evaluate the corrosive effect of acids on the mechanical, physical and aesthetic properties of CAD/CAM materials, four articles study mechanical and physical properties, one article investigates physical and aesthetic properties, three articles observe physical properties alone, three articles analyze mechanical properties alone, and one researches aesthetic properties in isolation.

All articles have a low risk of bias (representing 100%). Twelve studies use the Hunt and McIntyre method (13) to cause erosive lesions through hydrochloric acid between 0.113% and 6% (1,3–7,12,14–18). And only four compared these results with artificial saliva (3,7,18,19).

Heterogeneity arose primarily due to variation in acidic pH levels (1.2–4.0), immersion times (3h–6 months), surface finishing protocols, and specimen preparation. These methodological inconsistencies explain variability in measured roughness and hardness outcomes.

No sensitivity analyses were conducted due to variability in study protocols and outcomes. Certainty of evidence was moderate for surface roughness and flexural strength, low for microhardness and staining, reflecting inconsistencies in methodology and limited sample sizes.

Regarding missing or uncertain information, it was assumed that unreported data were not measured or available in the study; These gaps were discussed, and their possible implications for the results of the review were discussed. Potential publication bias cannot be excluded, given that several conference abstracts and theses were excluded, which may underestimate variability in outcomes.

Certainty of evidence was rated moderate for roughness and flexural strength, and low for microhardness and staining, due to methodological inconsistencies, small sample sizes, and limited follow-up times.

3. DISCUSSION

Impact on Mechanical Properties (flexural strength, microhardness)

This systematic review demonstrates how CAD/CAM materials tend to decrease their mechanical, physical, and aesthetic properties due to prolonged exposure to acidic media. It should be noted that Alnasser et al. (4) suggest that a pH of 2 is ideal to represent 6 to 12 months of gastric acid exposure in a patient with bulimia. However, most of the articles analyzed use a pH lower, frequently 1.2, and others a pH greater than 2, which probably does not represent the systemic condition.

Regarding glassy materials, Alnasser et al. (4) reveal that lithium disilicate and zirconium do not show statistically significant differences when immersed in hydrochloric acid of pH 2, for 45 to 90 hours, unlike feldspathic porcelain, leucite glass ceramic, and hybrid ceramic with resin matrix that do increase their Ra in the same time interval. Likewise, Farhadi et al. (20) conclude that in a hydrochloric acid with a pH of 1.4, glass disilicate ceramic does not show changes in its Ra after 168 hours of immersion, in contrast to feldspathic porcelain, which did present statistically significant changes. However, Deste Gökay et al. (7) used hydrochloric acid of pH 1.2 for 24 hours for the evaluation of Ra; it is evident that in the glass ceramic of Leucite and the hybrid ceramic with resin base, there is a smaller statistically significant difference, compared to zirconium, where it is greater than the previous groups. This information suggests that the Ra of zirconium is mostly dependent on acidic pH, increasing Ra as pH falls.

About zirconia-based materials, it is shown in the study by Fathy & Swain (18) that the Ra of zirconia reinforced with lithium disilicate does not present statistically significant changes after immersion in hydrochloric acid with pH 3 for 24 hours. In contrast, the findings of Deste-Gökay et al. (7) and de Cruz et al. (15) indicate that nanoceramic resin undergoes fewer changes in its Ra than in lithium disilicate-reinforced zirconia, monolithic zirconia, leucite-reinforced glass-ceramic, lithium disilicate, and polymer-infiltrated ceramic lattice, after immersion in hydrochloric acid with a pH of 1.2 for 24 and 18 hours, respectively. This difference can be attributed to the lower pH (3 vs 1.2) or the differential properties of the material (disilicate-reinforced zirconia vs zirconia).

Physical Surface Changes (roughness, gloss, wear)

Additionally, Hjerppe et al. (5), Tad et al. (21), and Shakir & Hameer (22) found that the glaze layer can considerably decrease the Ra and smooth surface after exposure to hydrochloric acid with a pH of 1.2 in materials such as zirconia and lithium disilicate, which is considered a protective factor.

Concerning resin-based materials, Schmohl et al. (23) recommend composite resins made by CAD/CAM in erosive media as they demonstrate adequate behavior in Ar against different acidic media [tonic water (pH= 2.59), acetic acid (pH= 2.48), hydrochloric acid (pH= 1.68)]. Likewise, the research of Elraggal et al. (3) evidences that the nanohybrid resin maintains its initial roughness, compared to vitreous CAD CAM materials, which decrease Ra. On the other hand, Backer et al. (17) in their study with hydrochloric acid with pH 1.2 for 18 hours they found that the hybrid ceramic with submicron resin shows a higher Ra than the nanoceramic resin. Although da Cruz et al. (14) concluded that nanoceramic resins, as well as other ceramic materials, such as lithium disilicate, zirconia reinforced with lithium disilicate and ceramic network infiltrated with polymers, are not affected by exposure for 3 hours of hydrochloric acid at pH 1.2, it was verified that when brushed is applied through a machine that simulates this action (MAVTEC Comércio e Serviços) with a force of 2N to 1Hz with soft-bristled brushes (Oral B 40; Procter & Gamble), distilled water and Colgate-Palmolive toothpaste in a 1:1 ratio, concluding that it decreases its Ra.

For their part, Bechir et al. (19) evaluated two fibroreinforced resins and their behavior in artificial saliva with pH from 3 to 7.6, and found that the Ra in both resins are stable and have no statistically significant differences. The authors attribute this fact to the fact that fibroreinforced resins have a solid fiberglass composition of 55% and 75%.

Castilho et al. (24) report a higher incidence of gastroesophageal reflux in patients undergoing bariatric surgery. Therefore, it is essential to take into account studies such as those by Elraggar et al. (3) and da Cruz et al. (14) show that the increase in fatigue cycles accelerates morphological changes and the Ra of materials. Therefore, patients with a history of bariatric surgery, GERD, or eating disorders are at greater risk of premature wear in indirect restorations. In these cases, the selection of materials in the restorative treatment must prioritize mechanical resistance in acidic environments.

The resinous materials were evaluated by Gil-Pozo. (6) In a hydrochloric acid with a pH of 1.2 for 6 months revealed that the CAD/CAM nanoceramic resin has statistically significantly higher wear resistance than conventional nanofilled composite, conventional nanohybrid composite, and reinforced composite.

Although, Fathy & Swain et al. (18) do not analyze a vertical loss, but perform an assessment on weight loss (Wt) show that Zirconia-reinforced Lithium Silicate ceramic immersed in hydrochloric acid with pH 3 for 24 hours has a loss of 0.0015 gm, while Hjerppe et al. (5) shows a weight loss in the same material of 0.00009 mg, thus evidencing that this material has a high resistance to wear compared to nanoceramic resins. Therefore, Zirconia-reinforced Lithium Silicate ceramic is ideal for posterior indirect restorations in patients with GERD or bulimia in any of its clinical forms because it presents minimal weight loss compared to natural teeth (18). In contrast, Sulaiman et al. (25) conclude that lithium disilicate has a weight loss three times greater than monolithic zirconium.

Authors such as Cruz et al. (15) analyzed the VHM of lithium disilicate, zirconia reinforced with lithium disilicate, nanoceramic resin, and ceramic network infiltrated with polymers before and after being immersed in hydrochloric acid for 18 hours, finding the absence of significant changes in the VHM. However, the material governed microhardness order: VITA Suprinity > IPS e.max CAD > VITA Enamic > Lava Ultimate. In contrast, Pîrvulescu et al. (26) reveal that ceramic materials and CAD/CAM hybrids do present changes in VHM. Similarly, Hjerppe et al. (5) and Gülakar et al. (1) show that there are also changes in feldspathic vitreous ceramics, lithium disilicate, and feldspathic ceramics, but this is due to the longer exposure time (96 hours).

For their part, Pîrvulescu et al. (26) share that VHM is not affected in CAD/CAM nanoceramic materials, such as

Cerasmart™ (GC Corporation, Tokyo, Japan). Although Backer et al. (17) found a decrease in VHM in two nanoresin systems, the ceramic nanoresin CAD/CAM presented greater VHM compared to the conventional nanoresin. Finally, the authors who use artificial saliva as a control medium, Gil-Pozo et al. (6) and Deste et al. (7), reveal that VHM decreases as the exposure time is prolonged in conventional resin with nanofiller, nanohybrid conventional resin composite, resin nanoceramic, reinforced composite, leucite-reinforced glass ceramic, present in two of the groups; lithium silicate ceramic infiltrated with zirconia and monolithic zirconia.

Clinical Implications

These findings suggest that material selection should consider initial strength, and also its ability to maintain structural integrity in the face of prolonged acidic challenges, especially in patients with diseases such as gastroesophageal reflux (GERD) or eating disorders.

The research of Elraggal et al. (3), Gülakar et al. (1), and Gil-Pozo et al. (6) highlights that the flexural strength of CAD/CAM restorative materials tends to decrease the longer they are exposed to acidic media (from 24 to 96 hours).

However, the literature shows us that it is dependent on restorative material. The studies of Elraggal et al. (3) and Gülakar et al. (1) highlight zirconia as a preferred restorative material if flexural strength has to be prioritized in a patient, since it presents greater flexural strength before and after being immersed in solutions that vary in pH from 1.2 to 7. Elraggal et al. also state that lithium disilicate ceramic, IPS e.max CAD, is the material of choice for patients with GERD or eating disorders, as it responds in the same way as zirconia (3). Similarly, Al-Thobity et al. (27) show that the use of zirconia or lithium disilicate-reinforced feldspar has greater flexural strength compared to feldspathic porcelain. (27)

In addition, Gil-Pozo et al. (6) reveal in their study that there is a lower flexural strength in conventional resinous materials compared to CAD/CAM resinous materials, results that agree with those of Alnsour et al. (28) and Ille et al. (29), where it is stated that in erosive media, such as hydrochloric acid or a carbonated beverage, they do not significantly affect the flexural strength or elastic modulus in CAD/CAM composites.

Considering that the average masticatory strength in healthy adults ranges from 70 to 150 N, Yeslam et al. evaluated the resistance of different CAD/CAM materials after 48 hours of immersion in deionized water (pH 7), Coca-Cola (pH 2.6), and artificial gastric acid (pH 1.3). Nanoceramic resin reached a strength of up to 1333 N, followed by glass ceramic (1313 N) and composite resin (1135 N). Although all materials far exceeded the physiological values of masticatory load, composite resin-based materials exhibited a greater loss of strength after exposure to acidic media, suggesting a greater susceptibility to chemical degradation, especially in patients with a history of GERD, bariatric surgery, or eating disorders. However, no statistically significant differences were found in flexural strength between the groups, indicating adequate stability under maximum loads in simulated acidic environments. Despite this, the flexural modulus was significantly reduced ($p < 0.001$), from 13.15 GPa to 8.84 GPa, suggesting a loss of stiffness attributable to water absorption or hydrolysis of the polymeric matrix (30).

Independent data on load-bearing confirm the material-dependence of performance: earlier work on full-coverage ceramics under dynamic fatigue showed fracture resistance varies with material and prep design (Clausen et al., 2010), while occlusal veneers in CAD/CAM materials under lateral loading demonstrate higher capacity for LDS and zirconia than resin-based options (Zamzam et al., 2021). These trends accord with our findings under acidic aging (31, 32).

Aesthetic Outcomes (color stability, translucency)

An important parameter highlighted by this review is the color change of the restorative materials, evaluated by means of a spectrophotometer according to the parameters of the CIELab system. The ΔE value obtained allows quantifying the perceived color difference between the initial and post-exposure state of simulated media. This indicator allows us to assess susceptibility to staining and its aesthetic impact on clinical practice (15).

Cruz et al. (15) assessed how several CAD/CAM materials changed color after being exposed to an acidic media with a pH of 1.2, which is the same as gastric juice. They found that there was a statistically significant difference ($p<0.01$) between the comparison groups. Nevertheless, neither IPS e.max CAD nor Vita Suprinity, nor Lava Ultimate and Vita Enamic, were found to vary significantly. Lava Ultimate was the least susceptible to staining, in contrast to Vita Suprinity, which was the most susceptible. Despite these variations, all materials presented color changes considered clinically undetectable. The immersion protocol was designed to simulate a cumulative exposure equivalent to two years of contact with gastric juice, based on the average of three daily purging episodes in patients with bulimia and an estimated duration of 30 seconds per episode (15).

While Da Cruz et al. (14) evaluated extrinsic acidic substances such as deionized water, coffee, or cola at a pH, simulating up to a fifth year of exposure. Treatment had no effect on the staining susceptibility of all staining solutions for Lava Ultimate (resin nanoceramic), Vita Enamic (polymeric infiltration ceramic), IPS Empress CAD (leucite-reinforced feldspathic porcelain), IPS e.max CAD (lithium disilicate ceramic), and Vita Suprinity (lithium disilicate-reinforced zirconia) ($p > 0.05$). However, in the gastric juice test with brushing, there was no significant difference between The Coca-Cola Co. and coffee ($p > 0.05$), whereas Lava Ultimate and Vita Suprinity had higher coffee staining ($p < 0.001$) and

Vita Enamic and IPS Empress CAD had higher glue staining ($p < 0.016$). However, the only material that was not significantly impacted by the three treatments was IPS e.max CAD (14). These findings are consistent with the most recent research by Makkeyah et al. (33), who found statistically significant differences in color stability, highlighting that IPS e.max CAD showed the lowest susceptibility to staining against Vita Suprinity, which obtained higher values after being immersed in acidic media with staining capacity.

The findings of Alharbi et al. (32) partially complement what was reported by Cruz et al., by demonstrating that the resin-based materials, Vita Enamic and Lava Ultimate, have good resistance to staining even in chromogenic media such as coffee, tea, and even in red wine, showing a behavior comparable to that of feldspathic ceramic blocks, Vitablocs Mark II. Although Alharbi did not include gastric exposure or clinical purging simulation, its results reinforce the chromatic stability of these materials in extrinsic staining scenarios. Unlike Cruz, Alharbi also evaluated direct resin compounds, among which Filtek Silorane showed superior staining resistance, comparable even to some CAD/CAM materials (34). On the other hand, the study conducted by Theocharidou et al. (16) demonstrated that the yield of lithium disilicate was marginally lower than that of monolithic zirconia samples, as they displayed notable and clinically discernible variations for the parameter of translucency and color change following acid storage and aging.

The main limitations of the studies analyzed include their in vitro study framework; this allows the conditions of the oral cavity to be partially reproduced, such as pH dynamics, saliva, variation in temperature, and masticatory forces. One of the main limitations noted in this review was the lack of uniformity in the properties assessed between the included studies. In addition, important variations were identified in the methodologies used to evaluate the same property, evidencing an absence of standardized criteria. Nor was unification found in the acid simulation protocols. There were differences in the types of media used, their pH levels, and exposure times. In addition, few studies evaluated medium-term simulations, most of which were short-term, which compromises the comparability of the results obtained. This methodological variability limits the possibility of reliable clinical extrapolations, since there is no consensual experimental model that faithfully reproduces real intraoral conditions.

Additionally, it was identified as a limitation that a few studies did not systematically group and compare materials within the same category. While comparisons between different categories of CAD CAM restorative materials can provide an overview, they make it difficult to accurately assess the relative behavior within each subgroup of materials. Therefore, it is considered that future research should focus on unifying methodological criteria, both in accelerated aging protocols and in techniques for measuring physical, mechanical, and aesthetic properties. Only through standardized methodologies will it be possible to generate solid, comparable, and clinically applicable evidence for the rational selection of CAD/CAM restorative materials.

Only two authors managed the risk of BIAS, while the other authors, readers of the full articles, and those responsible for collecting the data, verified and corroborated the risk of BIAS information. Still, none of these methodological limitations could lead to changes in the conclusions of this review.

In addition, some of the articles were not collected in a complete way, despite having made an attempt to contact the authors through their email. However, we are grateful to the authors who did collaborate with us. Understanding the effect of experimental pH variations on CAD/CAM indirect restorative materials should be aligned with clinical needs and is considered key to choosing the right material.

Implications: For patients with GERD, bulimia or post-bariatric reflux, prioritize zirconia or lithium disilicate; apply glazing to limit roughening; schedule maintenance for polished surfaces; avoid feldspathic and resin-matrix materials in high-acid exposure zones or expect faster wear and roughness.

4. CONCLUSIONS

Most CAD/CAM restorative materials exhibited color changes within clinically undetectable limits after acidic exposure, with IPS e.max CAD (lithium disilicate) demonstrating the highest chromatic stability. Zirconia and lithium disilicate consistently retained superior flexural strength and surface stability compared to feldspathic ceramics and resin-matrix composites, which showed greater microhardness loss and susceptibility to acidic degradation. Surface roughness (Ra) increased as pH decreased; however, zirconia and lithium disilicate experienced smaller losses than other materials, while glazing effectively reduced surface deterioration. For patients with recurrent acid exposure, such as those with GERD, bulimia, or post-bariatric reflux, zirconia or lithium disilicate should be preferred, and glazing should be applied to minimize surface degradation, whereas feldspathic and resin-based options should be used cautiously.

Nevertheless, the available studies lack methodological standardization regarding exposure times and acid solutions, limiting comparability and clinical extrapolation. Future research should aim to standardize acid exposure protocols and the evaluation of specific properties, which would enable more reliable comparisons and contribute to the development of accurate clinical guidelines for the selection of CAD/CAM restorative materials in patients with recurrent acid exposure.

Provide the revision registration information, including the name and registration number, or declare that the revision has not been registered.

The review has not been registered

Indicate where the protocol can be accessed, or state that no protocol has been drafted.

No protocol has been drafted

Describe and explain any amendments to the information provided in the registry or protocol.

Not applicable

Describe the sources of financial or non-financial support for the review and the role of funders or sponsors in the review.

This review has not received financial support.

Declare the conflicts of interest of the authors of the review.

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