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Relationship between tooth type and material used in the construction of endocrowns and fracture force values: a systematic review

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Abstract. – OBJECTIVE: The aim of this study was to summarize the results of the endocrown (EC) studies that compared tooth preparation designs, tooth types, and ceramic material types in relation to fracture force values.

MATERIALS AND METHODS: A full literature search was conducted in Web of Science, PubMed/Medline, EMBASE, Scopus, Cochrane Library, Google Scholar, and ProQuest electronic databases. The following keywords: Endocrown [(molar(s)) or (premolar(s) or (posterior teeth)] and Ceramic materials as (Lithium disilicate glass-ceramic; Zirconia; Lava Ultimate) and (fracture strength) or (fatigue) were used. Articles were manually searched utilizing their reference lists. Study selection was not restricted or limited to the time of publication, type of tested tooth, ceramic material, and EC design.

RESULTS: A total of 34 laboratory studies published between 2008 and 2023 were included in this systemic review. Twelve studies were published in the last 3 years, the mandibular molar was examined by 14 studies, and premolars in both arches were investigated, followed by premolars in both arches. Lithium disilicate glass-ceramic (LDGC) was the most used material for EC testing, followed by LAVA Ultimate and zirconia materials. The EC design with a 2 mm extension inside the pulp (14 studies) was the most used. Fracture forces of maxillary molars or premolars were nearly equal and lower than those of mandibular molars. Differences among the fracture forces of the tested ceramic materials were marginal. EC with 2 mm deep inside the pulp showed the highest fracture force.

CONCLUSIONS: Mandibular EC molars showed the highest fracture forces, followed by maxillary premolars and molars. No differences among the EC materials in the 2- and 4-mm pulpal extension designs were found, which had higher fracture forces than other designs.

Key Words:
Endocrown, Ceramic materials, Molar tooth, Premolar tooth, Fracture forces.

Introduction

Endocrown (EC) is a novel restoration with comparable or higher performance than conventional post-core-crown treatments using intraradicular posts, direct composite resins, inlays, onlays, and traditional metal posts and cores[1,2]. EC was first used and described by Bindl and Mörmann[3] in 1999 and is used as an indirect monoblock restoration that uses the pulp chamber of the endodontically treated teeth (ETT) for retention[4]. They described an adhesive monolithic ceramic restoration anchored in the pulp chamber, utilizing the micromechanical retention assets of the pulp-chamber borders. EC, with a certain preparation strategy and a rigorous adhesion protocol, is a reliable substitute to post-retained conventional prostheses for ETT with widespread loss of tooth structure through adequate long-term survival for ET in the posterior zones in certain patients[4-6]. It performed better in molars or teeth with larger pulp chambers[1,7-11] than maxillary[12-15] or mandibular premolars[16-18].

Compared with posts, cores, and crowns, ECs are easier to prepare and apply and require less clinical time and fewer visits, and their esthetic

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properties are excellent[19]. Adhesive restorations can inhibit microorganisms from infiltrating coronal and apical parts, thus improving the clinical success of endodontic treatment[2,7,19]. Additionally, they present a great benefit in cases where posts are contraindicated due to small or limited canals[7]. Apart from the superior anatomic properties provided by a computer-aided design, and computer-aided manufacturing (CAD/CAM) unit, a one-appointment treatment that requires less time is preferable.

Specific guidelines for a tooth preparation design for an EC have not been defined. An overall reduction of 2-3 mm in height is necessary. A 90-degree butt-joint margin of 1-1.2 mm is suggested but not always needed. All cervical margins should be placed as supragingival as possible and smoothly and internally transitioned with the flat pulpal floor. Besides, an occlusal divergence of 5°-7° is obligatory for the coronal pulp cavity and endodontic access hole to be nonstop, pulp chamber depth should be sufficient to allow retention and/or resistance[2,3,20-22]. Nevertheless, alterations can be made depending on material-oriented influences, aesthetic, and biomechanical. For example, the axial height of the cusps can be reduced when a specific material is used[13-15,23,24], and uniform or nonuniform ferrule in the restoration can be used to increase fracture resistance[9,12,22,25,26]. Notably, using different EC designs inside a pulp chamber improves and increases fracture forces[8,10,13,14,16,23,27].

During the last 35 years, computer-aided design, and computer-aided manufacturing (CAD/CAM) technology has played an increasing role in dentistry, allowing restoration design and fabrication by mechanized and computer-assisted techniques. In addition, different materials have been allowed for the fabrication of EC prostheses, including LDGC, zirconia-reinforced lithium disilicate (zirconia), hybrid ceramics (LAVA Ultimate), and polymer-infiltrated ceramic (Vita Enamic)[28-35].

LDGC ceramics are preferred in EC fabrication because of their high mechanical strength, durable bonding strength to the tooth structure, and good esthetic appearance[12,13,16,22,29-36]. To date, a wide range of ceramic materials with different esthetic and mechanical properties and advanced clinical performance have been established. Monolithic zirconia eliminates persistent problems, such as bone-white opaqueness and porcelain veneer fracture. It has a high flexural strength (600-800 Mpa)[36]. Different fracture forces in zirconia have been reported[8,9,12,13,16,37], and the material is suitable for EC manufacturing because it improves optical properties. LAVA Ultimate shows[14,17,23,25,37,38] improvements in fracture forces when used as an EC restoration irrespective of the design, depth inside a pulp chamber, and presence or absence of ferrule. Polymer-infiltrated ceramics combining the mechanical properties of ceramic and polymers and demonstrating the compatible modulus of elasticity to dentin have been developed[39]. For example, VITA ENAMIC comprises 86% wt ceramic and 14% wt polymer. It has a flexural strength of 130 MPa, fracture toughness of 1.4 MPa, and the same Vickers hardness as that of enamel[40]. It shows a relabel amount of fracture forces that can withstand the forces of mastication during oral functioning[8,14,28,37,41,42].

Hence, this current systematic review summarizes the results of the EC studies comparing tooth preparation designs, tooth types, and ceramic material types in relation to fracture forces and failure types. Moreover, the included papers will be evaluated for their overall quality and risk of bias.

Materials and Methods

Review Question

Applying the Participants, Intervention, Control and Outcomes principle described in the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines[43], we formulated a focused question: "In patients who require a prosthesis to replace a missing coronal portion of the tooth (maxillary or mandibular either in anterior or posterior areas) (participants), are the mechanical and physical properties (outcomes) of restorative materials used for ECs (intervention) adequate to withstand the forces of mastication that minimize the durability in comparison to post-and-core-crowns?"

Selection Criteria

The following inclusion criteria were used: 1) use of maxillary teeth (molars, premolars, and central incisors) or mandibular teeth (molars or premolars); 2) use of any type of all-ceramic material; and 3) English papers that focus on evaluating of fracture forces and type of EC failures. Clinical studies, such as case reports or case series, letters to the editors, commentaries, and finite-element analysis studies, were excluded. Studies recording the fracture forces in MPs were omitted.

Literature Search

Medical Subject Headings (MeSH) terms and the following keywords were used: Endocrown, [(molar(s)) OR (premolar(s) OR (central incisors) OR (posterior teeth)] and ceramic materials as (Lithium disilicate glass ceramic; Zirconia; Lava Ultimate; Vita Enamic; Feldspathic Porcelain) AND (fracture strength) OR (fracture resistance) OR (fatigue) AND (failure) OR (mechanical strength)]. An electronic search was performed using PubMED, Medline, Scopus, Embase, and ISI Web of Science.

Study Selection

The entire search process was carried out by two investigators (M. Al M and F.A) independently. Any disagreements were solved by discussion, and an inter-examiner reliability score was calculated. A third investigator was consulted (B.M). The titles of the articles were scanned for eligibility in the primary search. Any unrelated papers or duplicates were eliminated. Then, the abstracts of the remaining papers were evaluated for eligibility, and ineligible papers were excluded. The full texts of potentially eligible papers were copied and read systematically, and the reference lists of these papers were evaluated.

Data Extraction and Analysis

Using a calibrated data extraction form design, we extracted general data from the included studies: publication year, type of teeth restored, all-ceramic material used, and tooth preparation details. Then, the following outcomes data were extracted: aging or thermocycling processes, including using dynamic loading, fracture resistance values, and failure patterns and percentages. Data extraction was carried out by the two investigators independently. The third investigator was consulted to resolve any disagreement between the two investigators.

Quality Assessment

The risk of bias in the included studies was assessed using the Quality Assessment Tool For In *Vitro* Studies (QUIN) developed by Sheth et al[44]. The aims and objectives, sampling techniques, comparison group details, detailed explanation of methodology, operator details, randomization details, outcome measurements, outcome assessor details, and blinding and statistical analysis methods were assessed, and the studies were scored as follows: high (1-4), medium (5-8), and low (9-12) quality.

Results

Literature Search and Studies Selection

The primary search resulted in 452 items. After removing 348 irrelevant and duplicate items and titles, we read the abstracts of 104 studies to exclude ineligible studies. A total of 58 studies were excluded, and 46 studies were selected for full-text retrieval. Another 12 studies were dismissed as they did not identify whether the teeth used were maxillary or mandibular arches or did not use Newton (N) as a unit for fracture forces or because of other reasons. Finally, 34 studies[8-18,22,23,25-35,37,38,41,42,45-50] were included in the present review. The literature process is illustrated in Figure 1.

General Characteristics of the Studies

All included studies were laboratory or in *vitro* studies[8-18,22,23,25-35,37,38,41,42,45-50]. Most publications were found from 2016 to 2019 (14; 44%), while 12 of the studies (38%) were published between 2020 and 2023[8-10,12-16,23,27,41,45,46]. The maxillary arch was reported in: two studies[33,38] for maxillary molars, seven for premolars[12-15,26,41,49], and four[23,25,42,48] for central incisors. While mandibular arch included 15 studies[8-11,22,27-3135,37,42,45] for molars, and the remaining 6 studies[16-19,32,50] were for mandibular premolars. LDGS was the most frequently used (28 times) and had been used as a single material or compared with other ceramic materials, followed by LAVA Ultimate (10 times) and zirconia materials (eight times). The highest design of EC preparation was with a 2 mm extension inside the pulp (14 studies),[8,10,12-14,17,23,27,29,31,33,38,42,49] followed by a 4 mm extension in 8 studies[8-10,15-16,29,42,47]. Most of the studies used an axial direction of forces during their tests with thermocycling, and only 13 studies used dynamic loading during fracture tests. The details of the involved laboratory studies are presented, along with other characteristics of studies, in Table I. Figure 2 represents the descriptive statistics of the demographic data of the included papers.

Fracture Forces Strength Outcomes

Figure 3 shows the descriptive statistics of fracture forces in (N) in relation to tooth type, material used, and EC design for the 34 studies. In relation to tooth type, maxillary molars[33,38] and premolars[12-15,26,41,49] have almost equal fracture forces (1,195 and 1,215 N, respectively), which were considerably lower in studies[23,25,42,48] examining maxillary central incisors (mean value 492

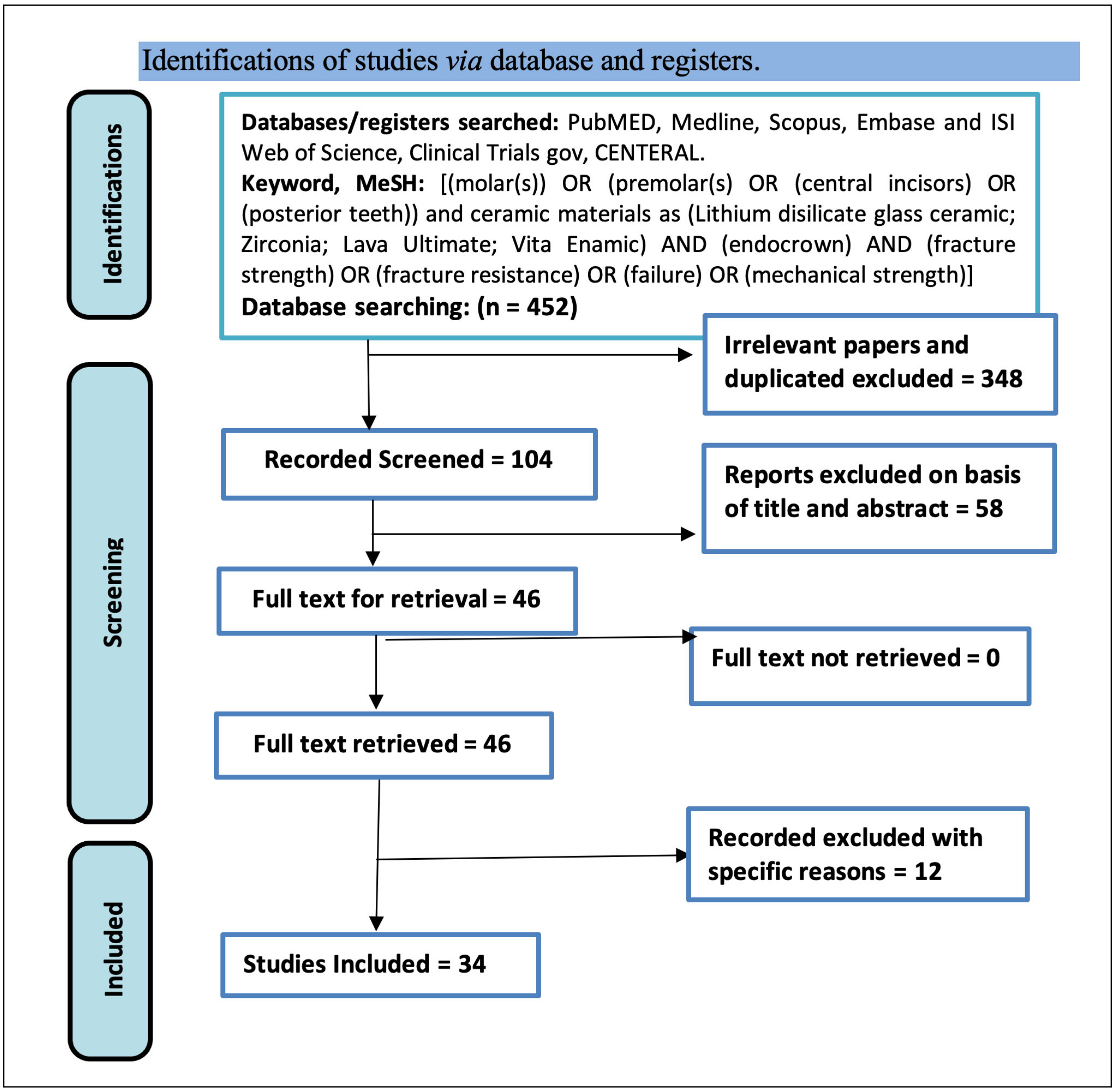

Figure 1. PRISMA Flowchart of the study selection process[43].

N). Mandibular molars had markedly higher values than premolars (1,528 and 862 N, respectively). Differences in fracture forces among all EC ceramic materials tested were marginal, which showed values between 1,286 and 1,133[8-18,22,23,25-34,38,41,42,45-50]. However, some materials had lower values. The highest fracture force was found in the cavity with 2 mm EC depth inside the pulp (1,329 N)[8,12,13,29,31,38], followed by that in the cavity with 4 mm EC depth[9,15,16]. The EC design with 3 mm depth had the lowest fracture force (877 N).

Results of Bias Assessment

The 34 studies defined aims and objectives, type of the tested tooth (either maxillary or mandibular arch), and materials used, except the study of Dartora et al[47], who mentioned the ceramic material used but did not specify the brand or category of the EC restorative material. Further parameters, for example, outcome measurements, statistics, results, and overall quality, were adequately described. None of the published papers[8-18,22,23,25-35,37,38,41,42,46-50] offered sample size calculation or operator details, except a study published by Alzahrani et al[45]. Randomization was not described in four studies[14,33,34,45], and some of the studies[14,27,34,37,41,47] did not mention the types of fractures after the application of fracture forces. Nine studies[8,9,12-16,23,45] were supposed to have a medium quality bias, and the remaining studies had high bias quality. Table II represents the quality bias assessment of the included papers in the current review.

Table I. Summary of *in vitro* endocrown studies on extracted teeth arranged descending (n=34).

Researchers/ Year	Restored Teeth Type and Arch	Used Materials	Tooth preparation details	Direction of Applied Forces/Aging	Fracture Forces Strength (N)
Koosha et al[46]/2023	Mandibular Molars	LDGC	Lingual wall removed up to 1 mm above CEJ with butt joint	Axial/Thermocycling	1,287
			Lingual wall removed up to 1 mm above CEJ with shoulder finish line		1,273
			Mesial & distal walls were removed up to 1 mm above CEJ with butt joint		1,045
			Mesial & distal walls were removed up to 1 mm above CEJ with shoulder finish line		1,050
Alzahrani et al[45]/2023	Mandibular Molars	LDGC	3 mm inside pulp as conventional EC	Axial/Aging	1,197.0
			3 mm inside pulp/ mesial& distal extension		1,019.8
Demachkia et al [12]/2023	Maxillary Premolars	LDGC	2 mm inside pulp & 2 axial walls	Axial/Thermocycling & dynamic loading	1,000.0
			2 mm inside pulp & 3 axial walls		940.0
			2 mm inside pulp & 4 axial walls		1,060.0
		Zirconia	2 mm inside pulp & 2 axial walls		1,533.3
			2 mm inside pulp & 3 axial walls		1,426,7
			2 mm inside pulp & 4 axial walls		1,486.7
Ahmed et al[13]/2022	Maxillary Premolars	LDGC	2 mm inside pulp /No ferrule	Axial/Thermocycling & dynamic loading	870.0
			2 mm inside pulp /1.5 mm circumferential ferrule		1,225.0
			2 mm inside pulp /1.5 mm buccal ferrule		661.0
		Zirconia	2 mm inside pulp /No ferrule		1,391.0
			2 mm inside pulp /1.5 mm circumferential ferrule		1,165.0
			2 mm inside pulp /1.5 mm buccal ferrule		857.0
Barallat et al[14]/2022	Maxillary Premolars	LAVA Ultimate	2 mm above simulated alveolar crest	Axial/Aging	859.6
			1 mm under CEJ in mesial & distal walls, 1 mm above alveolar crest		1,053.9
			1.5 mm under CEJ in mesial& distal walls, 0.5 mm above alveolar crest		1,124.6
			2 mm under CEJ in mesial & distal walls, at level of alveolar crest		780.7
Shams et al[15]/ 2022	Maxillary Premolars	LDGC	4 mm inside pulpal with 2mm ferrule	Axial/Thermocycling & Dynamic loading	1,433.5
		PEKK			1,831.4

Continued

Table I ***(continued).*** Summary of *in vitro* endocrown studies on extracted teeth arranged descending (n=34).

Researchers/ Year	Restored Teeth Type and Arch	Used Materials	Tooth preparation details	Direction of Applied Forces/Aging	Fracture Forces Strength (N)
Badr et al[23]/ 2022	Maxillary Central Incisors	LAVA Ultimate	Short extension with No ferrule	Oblique Axial/Aging	439.5
			Short extension with ferrule		306.5
			Long extension with No ferrule		516.3
			Long extension with ferrule		242.0
Haralur et al[8]/ 2021	Mandibular Molars	LDGC	2 mm occlusal reduction	Axial/Thermocycling	2,863.6
			4.5 mm occlusal reduction		3,770.3
			2 mm inside pulp & 4.5 mm occlusal		3,877.4
		Vita Enamic	2 mm occlusal reduction		1,598.6
			4.5 mm occlusal reduction		2,685.9
			2 mm inside pulp & 4.5 mm occlusal		1,936.6
		Zirconia	2 mm occlusal reduction		3,533.3
			4.5 mm occlusal reduction,		1,066.9
			2 mm inside pulp & 4.5 mm occlusal		2,951.8
Hassouneh et al1[6]/2020	Mandibular Premolars	Resin-based composite	4 mm Retention depth	Axial/Thermocycling & dynamic loading	758.1
		LDGC			547.4
		Zirconia			460.0
El Ghoula et al[9]/2020	Mandibular Molars	LDGC	4 mm retention depth, 1 mm chamfer, 2 mm ferrule, 2 mm occlusal reduction	Axial/Thermocycling & dynamic loading	2,914.0
		Zirconia			2,279.0
		LAVA Ultimate			2,752.0
de Kuijper et al[10]/2020	Mandibular Molars	LDGC	Control (No treatment)	Axial/Thermocycling & dynamic loading	1,080.0
			0 mm inside the pulp		796.0
			2 mm inside the pulp		977.5
			4 mm inside the pulp		979.5
Foad et al[41]/2020	Maxillary Premolars	LDGC	Horizontal butt joint preparation	Axial/Thermocycling & dynamic loading	856.5
			Anatomical occlusal preparation		905.6
		Vita Enamic	Horizontal butt joint preparation		957.5
			Anatomical occlusal preparation		1,108.8
Sedrez-Porto et al[27]/2020	Mandibular Molars	LDGC	2 mm distal root depth, 1 mm depth for other roots	Axial/Thermocycling	1,748.5
Rayyan et al[11]/2019	Mandibular Molars	LDGC	3 mm depth	Axial/Thermocycling & dynamic loading	491.1

Continued

Table I ***(continued).*** Summary of *in vitro* endocrown studies on extracted teeth arranged descending (n=34).

Researchers/ Year	Restored Teeth Type and Arch	Used Materials	Tooth preparation details	Direction of Applied Forces/Aging	Fracture Forces Strength (N)
Taha et al[37]/2018	Mandibular Molars	LDGC	Occlusal reduction: 2 mm, Cavity depth: 6 mm from central groove	Axial/Thermocycling & dynamic loading	1,478.9
		LAVA Ultimate			1,508.5
		Zirconia			886.9
		Vita Enamic			1,241.5
Aktas et al[28]/ 2018	Mandibular Molars	Alumina silicate	Central cavity to support EC	Axial/Aging	1,035.1
		Zirconia			1,058.3
		Vita Enamic			1,025.0
Dartora et al[47]/2018	Mandibular Molars	Ceramic	1 mm inside the pulp	Axial/Thermocycling & dynamic loading	1,268.1
			3 mm inside the pulp		1,795.4
			5 mm inside the pulp		2,008.6
Einhorn et al[22]/2017	Mandibular Molars	LDGC	No ferrule	Axial/Aging	638.5
			1 mm ferrule		1,101.0
			2 mm ferrule		956.3
Lise et al[17]/2017	Mandibular Premolars	LAVA Ultimate	2.5 mm deep, 1 mm wide margin	Axial/Thermocycling & dynamic loading	230.0
			5.0 mm deep, 1 mm wide margin		140.0
		LDGC	2.5 mm deep, 1 mm wide margin		125.0
			5.0 mm deep, 1 mm wide margin		220.0
Güngör et al[25]/2017	Maxillary Central Incisors	LAVA Ultimate	2 mm ferrule	Oblique Axial/Aging	869.0
		LDGC			915.9
Kanat-Ertürk et al[42]/2017	Maxillary Central Incisors		Long prep (6 mm) Short Prep (3 mm)	Oblique Axial/ Thermocycling	*Long* *Short*
		Zirconia			610.5 533. 0
		LDGC			225.1 244.0
		VITA Enamic			182.3 172.0
		LAVA Ultimate			99.8 81.0
		Feldspathic Porcelain			71.4 47.0
Atash et al[18]/2017	Mandibular Premolars	LDGC	2 mm ferrule	Axial/Aging	1,717.2
Al-shibri and Elguindy [26]/2017	Maxillary Premolars	LAVA Ultimate	2 mm ferrule	Axial/Aging	1,522.6
		LDGC			717.3
Hayes et al[29]/2017	Mandibular Molars	LDGC	2 mm depth	Axial/Aging	843.4
			3 mm depth		762.8
			4 mm depth		943.5

Continued

Table I *(continued)*. Summary of *in vitro* endocrown studies on extracted teeth arranged descending (n=34).

Researchers/ Year	Restored Teeth Type and Arch	Used Materials	Tooth preparation details	Direction of Applied Forces/Aging	Fracture Forces Strength (N)
Gresnigt et al[30]/ 2016	Mandibular Molars	Sound teeth	1 mm above CEJ with ferrule	Axial/Thermocycling & dynamic loading	2,151.0.
		LDGC			2,428.0
		LAVA Ultimate			2,675.0
Carvalho et al [31]/2016	Mandibular Molars	LDGC	2 mm inside pulp with 5 mm height	Axial/Thermocycling & dynamic loading	3,265.0
Guo et al[32]/ 2016	Mandibular Premolars	LDGS	1.5 mm ferrule, Depth 5 mm	Axial/Aging	997.1 (No treatment) 479.1
Hamdy[33]/2015	Maxillary Molars	LDGC	Intact tooth	Axial/Thermocycling	985.0
			2 mm inside pulp		989.0
Abdel-Aziz and Abo-Elmagd[34]/2015	Mandibular Premolars	LDGC	No ferrule	Axial/Aging	725.7
			2 mm ferrule		1,139.7
El-Damanhoury et al[38]/2015	Maxillary Molars	Feldspathic Porcelain	2-mm intra-coronal extensions and cavity wall thickness of 2.0 mm	Axial/Thermocycling	1,340.9
		LDGC			1,368.8
		LAVA Ultimate			1,583.3
Ramírez- Sebastià et al[48]/2014	Maxillary Central Incisors	LDGC	2 mm ferrule	Oblique Axial/	552.4
Biacchi and Basting[35]/2012	Mandibular Molars	LDGC	Margins ↔2.2 & 2.7 mm and crown height 7 mm from gingival margin	Axial/Aging	674.8
Chang et al[49]/2009	Maxillary Premolars	Feldspathic Porcelain	1.5 mm ferrule and 5 mm inside pulp	Axial/Thermocycling	1,446.7
Forberger and Gohring[50]/2008	Mandibular Premolars	LDGC	0.8 mm Shoulder and 2 mm Axial dentine	Axial/Thermocycling	849.0 (No treatment) 1,107.3

Lithium disilicate glass ceramic as (IPS e. max CAD) or (IPS e.max Press) = LDGC; High translucency zirconia or zirconia reinforced lithium disilicate ceramic as Vita Suprinity = Zirconia; Resin Nanoceramic = LAVA Ultimate; Feldspathic ceramic = Vita Mark II; Polymer infiltrated ceramic = Vita Enamic; Poly-ether-ketone-ketone = PEKK.

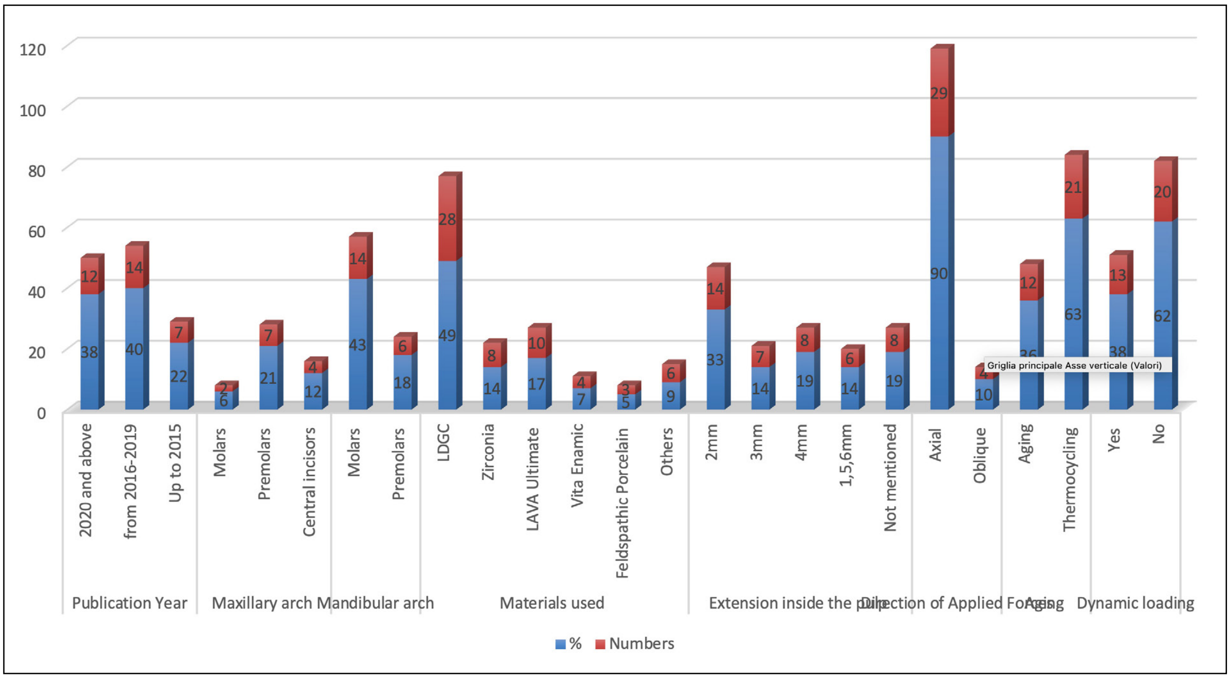

Figure 2. Descriptive statistics of demographic data of the included studies (n=34).

Discussion

ETT are more susceptible to breakdown or fracture than vital teeth because tooth structures are damaged by caries, access cavity, canal preparation, aggressive irrigation solutions, and intracanal medicaments[51,52]. Furthermore, in anterior and posterior teeth with extensive coronal loss, tooth structures that weaken the peri cervical dentin and are predisposed to vertical root fracture should be removed before a post that can retain the core is positioned[51]. Being less susceptible to fracture, ECs have been considered alternatives to post-core-retained crowns in premolars and molars[1,5-7]. The concept of EC was first introduced by Pissis[2] in 1995 and was known as the "monobloc porcelain technique", and the term endocrown was first coined by Bindl and Mormann[3] in 1999. ECs are minimally invasive prostheses and suitable for teeth with one or more of these features: short clinical crowns, inadequate interocclusal clearance, curved roots, small roots, and calcified root canals[2,3]. The biomechanical properties of prosthetic material show a critical role in the success of post-endodontic restorations and the persistence of the ETT[8-15,30,45,46]. Hence, this systematic review aimed to summarize, assess, and compare the results of studies that had compared the teeth preparation designs, tooth types, and ceramic material types (LDGC, zirconia-reinforced lithium disilicate, hybrid ceramics, and polymer infiltrated ceramic) used for ECs in relation to fracture force and failure mode or type. Moreover, the overall quality of the included papers was evaluated, and the risk of bias was assessed. All ECs in the involved studies were made by the CAD/CAM milling system.

EC can be considered an alternative to conventional treatments, such as post-core-crown or pin-supported crowns[4,6,7,21]. Regarding the recorded fracture forces in relation to tooth type, maxillary molars had almost equal fracture forces (between 985.0 to 1,583.3 with mean of 1,195 N)[33,38]. The highest fracture force for maxillary premolars was 1,831.4 N[15], the lowest was about 856.5 N[41], and the average value was 1,215 N (Figure 3). The fracture forces in relation to maxillary molars and premolars were nearly equal in other reviews[5,6,19,35]. The fracture forces for mandibular molars below and over 1,000 N were recorded in some studies[10,22,27,29,35,47] but ranged from 2,000 N to 3,000 N in other studies[8,9,30,31,46]. The forces in published studies or systematic reviews[5,20,53,54] were nearly equal. Moreover, the fracture resistance of ECs increased with the degree of occlusal reduction and cavity depth[11,17,29,32,35,41,42] but remained higher than the normal clinical force range[21,53-54].

Table II. Quality assessment of the *in vivo* involved studies (n=34)[44].

Research (S)/ Year	Aims and objectives	Sample size	Comparison group	Metho-dology	Operator details	Randomi-zation	Outcomes measure-ment	Blinding	Statistical analysis	Results	Overall quality
Koosha et al[46]/2023	Yes	No	Yes	Yes	No	No	Yes	Yes	Yes	Yes	High
Alzahrani et al[45]/2023	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Medium
Demakis et al[12]/2023	Yes	No	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Medium
Ahmed et al[13]/2022	Yes	No	Yes	Yes	No	No	Yes	No	Yes	Yes	Medium
Barallat et al[14]/2022	Yes	No	Yes	Yes	No	No	Yes	No	Yes	Yes	Medium
Shams et al[15]/2022	Yes	No	Yes	Yes	No	No	Yes	No	Yes	Yes	Medium
Badr et al[23]/2022	Yes	No	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Medium
Haralur et al[8]/2021	Yes	No	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Medium
Hassouneh et al[16]/2020	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	Medium
El Ghoul et a[9]/2020	Yes	No	Yes	Yes	No	No	Yes	No	Yes	Yes	Medium
de Kuijper et al[10]/2020	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	High
Foad et al[41]/2020	Yes	No	Yes	Yes	No	No	Yes	Yes	Yes	Yes	High
Sedrez-Porto et al[27]/2020	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	High
Rayyan et al[11]/2019	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	High
Taha et al[37]/2018	Yes	No	Yes	Yes	No	yes	Yes	Yes	Yes	Yes	High
Aktas et al[28]/2018	Yes	No	Yes	Yes	No	No	Yes	Yes	Yes	Yes	High
Dartora et al[47]/2018	Yes	No	Yes	Yes	No	No	Yes	Yes	Yes	Yes	High
Einhorn et al[22]/2017	Yes	No	Yes	Yes	No	No	Yes	Yes	Yes	Yes	High
Lise et al[17]/2017	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	High
Güngör et al[25]/2017	Yes	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	High
Kanat-Ertürk et al[42]/2017	Yes	No	Yes	Yes	No	yes	Yes	Yes	Yes	Yes	High
Atash et al[18]/2017	Yes	No	Yes	Yes	No	No	Yes	Yes	Yes	Yes	High
Al-shibri and Elguindy[26]/2017	Yes	No	Yes	Yes	No	No	Yes	Yes	Yes	Yes	High
Hayes et al[29]/2017	Yes	No	Yes	Yes	No	No	Yes	Yes	Yes	Yes	High
Gresnigt et al[30]/2016	Yes	No	Yes	Yes	No	No	Yes	Yes	Yes	Yes	High
Carvalho et al[31]/2016	Yes	No	Yes	Yes	No	No	Yes	Yes	Yes	Yes	High
Guo et al[32]/2016	Yes	No	Yes	Yes	No	No	Yes	No	Yes	Yes	High
Hamdy et al[33]/2015	Yes	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	High
Abdel-Aziz and Abo-Elmagd[34]/2015	Yes	No	Yes	Yes	No	No	Yes	Yes	Yes	Yes	High
El-Damanhury et al[38]/2015	Yes	No	Yes	Yes	No	No	Yes	Yes	Yes	Yes	High
Ramírz-Sebstià et al48/2014	Yes	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	High
Biacchi and Basting35/2012	Yes	No	Yes	Yes	No	No	Yes	Yes	Yes	Yes	High
Chang et al49/2009	Yes	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	High
Forberger and Goring50/2008	Yes	No	Yes	Yes	No	No	Yes	Yes	Yes	Yes	High

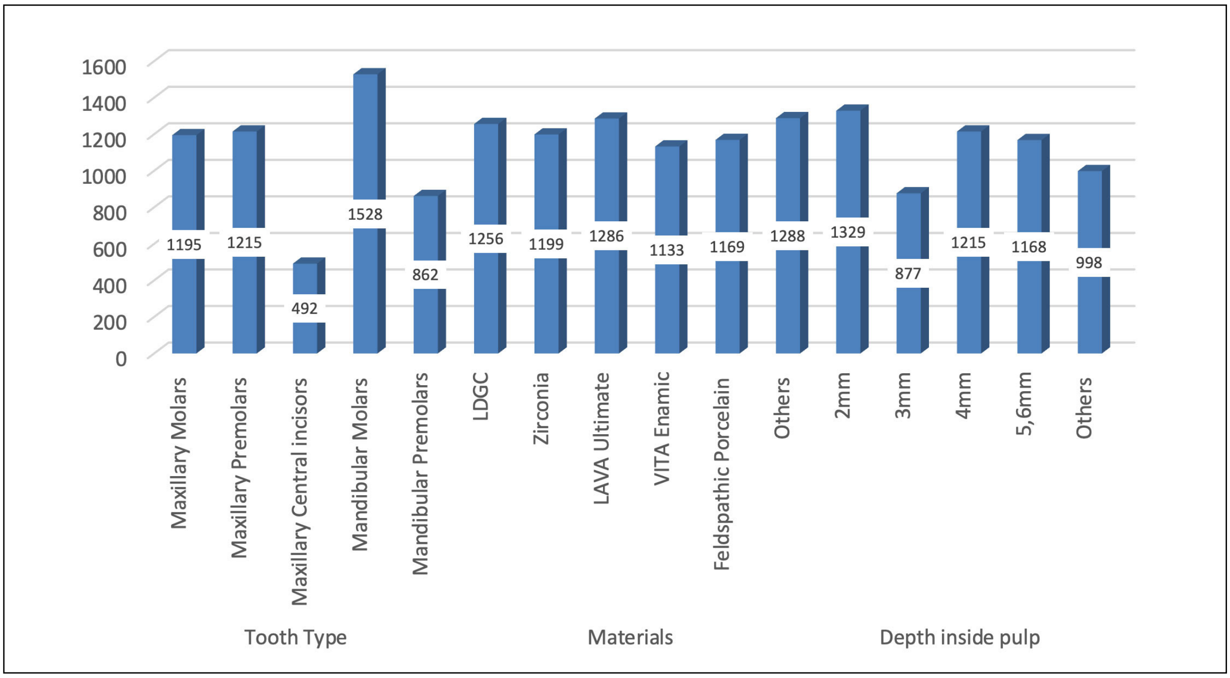

Figure 3. Descriptive statistics of fracture forces (N) in relation to tooth type, material used, and depth of EC inside the pulp chamber (n = 34).

Nanocomposite resins and lithium disilicate seemed to benefit the fabrication of ECs[5,15,45,46]. Zirconia might be the best material for EC because it preserves the tooth-restoration complex by absorbing stress, and it has low displacement within the complex and in dental tissues[8,12,13,16]. Lithium disilicate ceramic and zirconia-reinforced lithium silicate can be used in manufacturing ECs as they have acceptable ranges of stress, Mohr-Coulomb ratio, and displacement in ECs and dental structures[8,12,37,42]. In terms of stress distribution and levels of stress and displacements, dental materials with high elastic moduli provide higher protection for dental structures and EC-tooth complexes under occlusal load than materials with low elastic moduli[46,55,56]. Vita Enamic RCs show greater fracture resistance values than IPS e max cases. Zirconia has been used in restoring maxillary central incisors since 2017 and in restoring mandibular molars since 2018[28,37,42]. In 2022 and 2023, ECs have been used in maxillary premolars teeth[12,13] owing to developments in bonding systems, colors, biocompatibility and mechanical properties of materials, and fabrication of novel generations of zirconia materials with improved composition. Given these improvements, zirconia has been recommended for all fields of prosthetic dentistry, especially EC cases.

One of the inclusive criteria of this review is the inclusion of molars and premolars only because they are subjected to occlusal forces in the posterior region in maxillary and mandibular arches. According to the present findings, EC restorations seemed to resist occlusal forces and generate good fracture forces, the most reasonable explanations are related to the material used, distinctive design, thickness, and elastic moduli of ECs[1].

Tooth fractures have a direct relationship with the surface areas of pulp chambers. Forces in molars are higher than those in premolars[54,55]. The traditional design of EC is modified by adding grooves or boxes in the mesial and distal sides of teeth and shoulder finish lines to increase surface areas. Different designs for EC were tested by the included studies in this review. The design most used was 2 mm EC inside the pulp chamber with a ferrule. Most published reviews[8,10,12,13,26,38] mentioned that a 2 mm-deep EC design is preferred irrespective of tooth type and position. The fracture resistance of standard and ECs with modified design is higher than the normal masticatory force range. Therefore, excessive preparation (occlusal reduction and cavity depth) that increases fracture resistance is not recommended[53]. Moreover, no significant differences in fracture resistance were observed among EC designs[14,41,45].

The fracture loads of ECs manufactured with LDGC blocks by CAD/CAM are superior to those of leucite-based blocks after mechanical fatigue[57]. In 2023, Jalali et al[55] showed that preserving at least one of the axial walls can reduce the level of axial discrepancy and did not improve fracture resistance. The LDGC materials are the most used materials for EC constructions[58].

However, ECs seem to be a promising, conservative, and reasonable restorative choice with adequate long-term survival for posterior ETT in selected patients undergoing standardized clinical procedures[6]. ECs are reliable substitutes for post-retained restorations for molars and suggesting materials for premolars. A specified preparation shape and a rigorous adhesion protocol must be recognized. LDGC and nanofilled composite resin have attracted considerable interest[5]. ECs are promising materials for restoring molars that are treated endodontically and have extensive loss of tooth structure[5,6]. Material fracture forces increased sharply because of many factors, such as improvements in the mechanical properties of EC materials, as shown in Table I and Figure 3. Medium to high degree of bias was observed, although the introduction of recently published studies in this review minimized the bias. Journals that published *in vitro* laboratory studies had high impact factors and indexes.

This review has some drawbacks. First, different EC designs were used (pulp chamber extension, presence or modification or extension, axial wall height of remaining tooth above CEJ, presence or absence of butt joint, and degree of internal wall variance). Future in *vitro* studies must decrease the chance of bias, especially on sample size calculation and tooth randomization. The moderate quality of the implicated articles and the descriptive technique of analysis can be the limits of this systematic review, which must consequently be taken with caution. Additionally, papers published in English were reviewed, and thus the scope of this review was limited.

Conclusions

Mandibular molars and maxillary premolars were the most frequently used type in laboratory studies, and LDGC was the most used ceramic material. EC design with a 2 mm extension was the most frequently used, followed by the design with a 4 mm extension. In relation to fracture force, mandibular molars had the highest values, followed by maxillary premolars and molars. All the ceramic materials used for EC constructions recorded nearly have the same fracture forces. The EC with extension depths of 2 and 4 mm had higher values than other designs.

Ethics Approval
Not applicable.

Informed Consent
Not applicable.

Availability of Data and Materials
All data are provided in this study, and raw data can be requested by the corresponding author.

Conflict of Interests
The authors do not have anything to disclose and declare no conflict of interest.

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Authors' Contributions
NMAlA, MMAlM, MS, TSG: concepts, design, data analysis, statistical analysis, manuscript preparation, manuscript review. SYW, AAN, YFA, AlaMS, NQYD, MAHA. WYS, AAT: definition of intellectual content, literature search, experimental studies, data acquisition, guarantor.

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