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Application of one-piece endodontic crowns fabricated with CAD-CAM system to molars

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ABSTRACT

Computer-aided design-computer-aided manufacturing (CAD-CAM) systems have been widely used as a fabrication method for restorations because of their high efficiency and accuracy, which significantly reduces fabrication time. However, molars with insufficient clearance or short clinical crown lengths require retention holes or grooves on the preparation, making it difficult to replicate the shapes with the CAM milling system. In these cases, restorations using the lost-wax method are selected. This article focuses on one-piece endodontic crowns (endocrowns) fabricated with a CAD-CAM system (CAD-CAM endocrowns), in which their posts and crowns are integrated. Articles from July 2012 to August 2023 were searched in PubMed with the keyword "endocrown". This review discusses the application of CAD-CAM endocrowns to molars from the viewpoint of model experiment (fracture resistance, adaptation) and clinical research. This technique, which allows margins and internal gaps to be set within the clinically acceptable range, is reported to be an effective way of restoring molars with high survival rates in clinical research.

1. Introduction

Along with their high efficiency and accuracy, computer-aided design-computer-aided manufacturing (CAD-CAM) systems have the advantage of a significant reduction in fabrication time, which enables dentists to provide their patients with high-quality restorations at the chairside [1]. Restorations using CAD-CAM resin composites have been covered by National Health Insurance in Japan since 2014, and are currently provided to many patients for anterior teeth, premolars and molars [2]. In actual clinical dentistry, however, dentists often find cases with insufficient clearance between maxillary and mandibular teeth or short clinical crown lengths, especially in second molars. Therefore, in order to prevent fracture and debonding, retention holes or grooves are provided on the preparation to secure the thickness of the restoration and to expand the bonding area between the preparation and the restoration. In cases requiring such complex preparation, milling with CAD-CAM systems is difficult, and dental metal restorations fabricated with the lost-wax casting method are still the mainstream.

In 1999 Bindl and Mörmann suggested an one-piece endodontic crown (endocrown) as an alternative to the post-and-core-supported restoration [3]. In molars, indirect restorations have been reported to have better clinical survival rates than direct restorations [4]. This review searched for articles from July 2012 to August 2023 to focus on the application of endocrowns fabricated with a CAD-CAM system (CAD--CAM endocrowns) to molars. Currently, no review on endocrowns that summarizes the morphology of restorations or preparations and multiple materials has been reported. Therefore, this manuscript investigated the effectiveness of CAD-CAM endocrowns on molars by examining fracture resistance and adaptation from model experiments and survival rate from clinical research.

2. Methods

A literature search was conducted in PubMed using the terms

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"endocrown" and "molar", "post-and-core crown" and "molar", and "endocrown" and "clinical performance", followed by a two-step screening process (Fig. 1). The eligibility criteria were "including molars" and "CAD-CAM system as the fabrication method". The exclusion criteria were "anterior teeth and premolars", "material: metal only", "fabrication method: direct method", "fabrication method: without CAD-CAM system", "pediatric patients", "article type: review, commentary, protocol", and "retracted article".

The primary screening eliminated duplicated articles, those which were not in English, and whose title or abstract did not meet the criteria. The secondary screening verified the body of the text and removed articles which did not meet the criteria. A total of 68 articles were then included for fracture resistance, adaptation, and clinical performance. The materials used for endocrowns were classified by their types: resin composite, silica-based ceramics (ceramic), zirconia ceramics (zirconia), and polyether ether ketones (PEEK).

3. Results

3.1. Fracture resistance and fracture mode

The classification of CAD-CAM endocrown materials by their types is shown in Table 1 [5–42]. Comparing each material, the maximum and minimum fracture resistance against a load to CAD-CAM endocrowns was the highest in resin composite, followed by ceramic and zirconia.

Table 2 shows the fracture modes for axial and lateral loading on each material type [5,6,8–10,12,16–18,20,22,24–37,40,42]. The resin composite type was the most frequently reported as repairable in terms of fracture mode [5,6,8,10,18,20,24–29,31,34,35].

3.2. Marginal and internal gap

Marginal and internal gaps were not related to restoration form, margin, or material type, and were within the clinically acceptable range in many reports (Table 3) [11,21,24,38,43–55]. Marginal gaps were reported to be larger than the clinically acceptable range for some resin composites and ceramic material types [43–45]. The highest values of internal gap were observed in the pulp floor for all material types [43, 47,50].

3.3. Clinical performance

A comparison by material type showed that CAD-CAM endocrowns fabricated with ceramics (81.8–100%) and zirconia (82.4–100%) reported higher survival rates (Table 4) [56–72], although the duration of observation varied among the articles. On the other hand, survival rates for CAD-CAM endocrowns fabricated with resin composite were reported to be 62.5–80.0% at 5 years [69] and 89.5% at 2 years [67]. Almost all of the cases reported as complications were repairable regardless of material type.

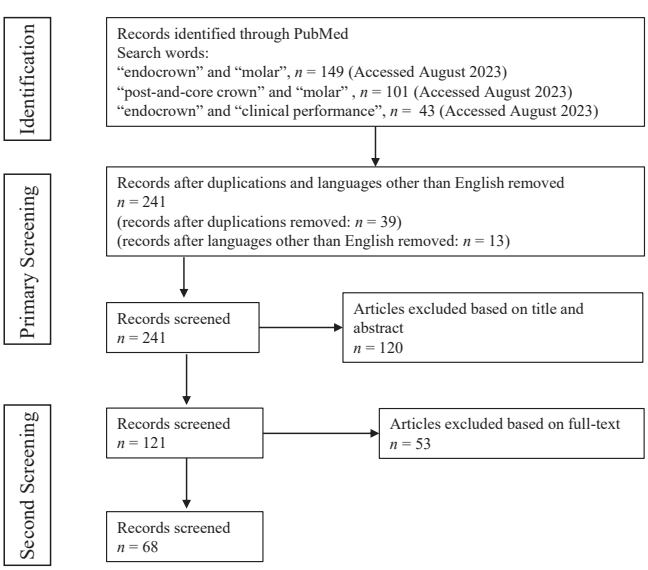

Fig. 1. Flowchart of study selection.

4. Discussion

In this research, more articles on model experiment were surveyed than those of clinical research. The fact that only papers describing the clinical follow-up period were targeted for clinical research may be one of the reasons for this.

On account of their fabrication process, CAD-CAM endocrowns require preparations that meet certain conditions; occlusal preparation with at least 2.0 mm in the axial direction and parallel to the occlusal plane, finish line placed on the gingival margin, and enamel walls less than 2.0 mm thick being removed. Axial preparation requires removal of undercuts, an inclination angle of 7°, preservation of the pulp floor, and a cavity depth of at least 3.0 mm [73].

Although the CAD-CAM endocrown forms set in the research varied, the minimum endocrown thickness was 1.5 mm, which was thick enough to resist the average fracture load by human mastication with molars (approximately 600–900 N) [14,19,34,74–76]. CAD-CAM endocrowns were also reported to have higher fracture resistance than inlays and onlays [28,29]. CAD-CAM endocrowns are the integration of the post and crown restoration. This structure ensures the thickness of the area where the load is put, enabling the CAD-CAM endocrowns to be applied to cases with short clinical crown length or insufficient clearance between maxillary and mandibular teeth.

The extension of the CAD-CAM endocrown in the direction of the pulp chamber (pulp chamber extension) increases the bonding area and fracture load values, but also increases the risk of putting the surrounding tooth structure under a bigger stress at the same time. In addition, such forms of CAD-CAM endocrowns increase the risk of irreparable fractures as a result of the lateral load being concentrated in the cervical area without being dispersed toward the axial direction [39]. According to reports of 1.0–5.5 mm pulp chamber extension (Table 1), which is higher than the average masticatory force fracture load in molars, extension is considered clinically to be up to 5.5 mm as the maximum value.

Adding a ferrule to the preparation was reported to increase the fracture resistance of the CAD-CAM endocrown, but did not affect the ratio of unrepairable fracture morphology [12]. However, it was also reported that a design with a 2.0 mm ferrule may cause a large gap between the CAD-CAM endocrown and preparation due to milling limitations in fabrication [15]. Although adding a ferrule structure contradicts the principle of minimal invasiveness, it also has the ability to increase the dentin surface area available for bonding. The data from the researched articles showed that the average fracture load was higher than the average masticatory force in human molars. Therefore, the ferrule should be used in cases with a small bonding area, such as severely damaged teeth in CAD-CAM endocrowns.

Grooves should be added to prevent debonding in restorations. Placing grooves on the prepararions of CAD-CAM endocrowns increases the adhesive area and improves the retention of the restoration, but increases the rate of vertical fracture of the preparation below the cement enamel junction under axial loads [22], resulting in irreparable fractures. Preparations of CAD-CAM endocrowns should not be proactively grooved, considering their long-term survival.

In order to improve the long-term success rate with a low number of irreparable fracture patterns[31,32], the preparation of the endocrown should have at least three walls and an occlusal surface covering the functional occlusal cusp.

The clinically acceptable ranges of marginal and internal gaps were

Table 1
Comparison of fracture resistances for CAD-CAM endocrowns.

Type	Material type	Materials	Restoration (mm)			Cavity base material	Additional Conditions	Load direction	Fracture resistance (N) (Fracture load)	Reference
			Thickness	Chamber extension	Height from CEJ (finish line)					
Composite resin	nano-ceramic hybrid CAD-CAM composite resin block	Cerasmart	2.0	4.0	-	-	-	axial load	1508.5	[11]
			-	4.0	-	composite resin	-	axial load lateral load	2752.0 1210.0	[18]
			6.0 (from central groove to pulp chamber extension)		2.0	composite resin	-	axial load	2220.0	[21]
			2.0	1.0	1.0	-	-	angled load (30°)	1300.5	[29]
			2.0	2.0	1.0	composite resin	mesio-occlusal-distal-lingual cavities	axial load	387.4	[31]
							-	axial load	500.4	
			-	2.0	1.0	-	-	axial load lateral load	1406.6 391.0	[26]
			2.0	1.0	-	-	-	-	2300.0	[28]
			5.2 ± 0.1	2.1 ± 0.1	1.0	composite resin	-	axial load	1254.5	[30]
			2.0	3.0	2.0	glass ionomer cement special polyethylene fiber + composite resin	-	axial load	2303.1 2920.7	[35]
		Grandio blocs	2.0	2.0	-	composite resin	-	axial load	3808.0	[27]
			1.5	5.0	-	composite resin	-	axial load	1315.0	[34]
	polymer-infiltrated ceramic network resin block	Vita Enamic	2.0	4.0	-	-	without ferrule with ferrule	axial load	880.0 1140.0	[12]
			3.5	2.5			without ferrule with ferrule		1240.0 1270.0	
			2.0	4.0	-	-	-	axial load	1241.5	[11]
			1.5 (lingual: 3.5)	-	1.0 ± 0.5	composite resin	-	angled load (45°)	1025.0	[10]
			2.0	2.0	-	composite resin	-	axial load	1952.0	[27]
			2.0	2.0	1.0	composite resin	mesio-occlusal-distal -lingual cavities	axial load	340.0	[31]
							-		439.6	
			2.0 4.5	5.0-5.5 3.0-3.5	-	-	- - distal root canal extension (2.0 mm)	axial load	1598.6 2685.9 1936.6	[20]
			-	4.0	2.0	composite resin	-	angled load (45°)	578.8	[24]
			5.5-6.0	3.0	1.0	-	-	axial load	1201.5	[25]
			-	2.0	1.0	-	-	axial load lateral load	1369.5 496.6	[26]
			2.0	2.0 (mesio-occlusal-distal cavities)	-	- composite resin (visible light cured bulk-fill flowable based resin composite) composite resin (nanohybrid bulk-fill composite material) composite resin (short fiber-reinforced resin composite)	-	axial load	1282.6 1445.6 1236.1 1605.3	[36]
			2.0	3.0-5.0	2.0	composite resin	-	axial load	1232.1	[41]
	hybrid ceramic CAD-CAM	Lava Ultimate	3.5	1.5	1.0	glass ionomer cement	-	axial load	2606.0	[5]

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Table 1 (*continued*)

Type	Material type	Materials	Restoration (mm)			Cavity base material	Additional Conditions	Load direction	Fracture resistance (N) (Fracture load)	Reference
			Thickness	Chamber extension	Height from CEJ (finish line)					
	composite resin block		-	2.0	2.0	composite resin	-	angled load (35°)	1582.3	[6]
			2.5	2.3	1.0	composite resin	-	axial load lateral load	1118.0 838.0	[8]
			2.0	2.0	-	composite resin	-	axial load	2484.0	[27]
			2.0	2.0	1.0	composite resin	mesio-occlusal-distal-lingual cavities	axial load	659.4	[31]
							-		606.2	
		Shofu	-	2.0	1.0	-	-	axial load lateral load	1068.4 543.4	[26]
		Brilliant Crios	-	2.0	1.0	-	-	axial load lateral load	2072.8 615.6	
	ceramic-based composite resin block	Ceramill COMP	6.0 (from central groove to pulp chamber extension)		2.0	composite resin	-	axial load	2420.0	[21]
Ceramic	lithium disilicate glass-ceramic block	IPS e.max CAD	-	2.0	2.0	composite resin	-	angled load (35°)	1368.8	[6]
			3.5	1.5	1.0	glass ionomer cement	-	axial load	3265.0	[7]
			2.5	2.3	1.0	composite resin	-	axial load lateral load	2428.0 2675.0	[8]
			4.0	2.0 3.0 4.0	-	composite resin	-	angled load (45°)	843.4 762.8 943.5	[9]
			6.0	4.0	2.0	glass ionomer cement	-	axial load	3320.4	[13]
			2.0	4.0	-	-	-	axial load	1478.9	[11]
			1.5	5.0 3.0 1.0	2.0	glass ionomer cement	-	axial load	2008.6 1795.4 1268.1	[14]
			2.0	2.0	2.0	composite resin	without ferrule ferrule 1.0 mm ferrule 2.0 mm	angled load (45°)	638.5 1101.0 956.3	[15]
			1.5 3.0 4.5	4.5 3.0 1.5	-	resin cement	-	axial load	1570.0 1813.0 1759.0	[19]
			-	3.0	1.5	-	-	angled load (45°)	584.5	[16]
			-	4.0	-	composite resin	-	axial load lateral load	2914.0 1516.0	[18]
			-	extension extension - extension	- 1.0 - 1.0	- composite resin composite resin	-	axial load	1546.3 1634.4 1821.5 1924.1	[17]
			-	4.0	2.0	composite resin	with grooves	axial load lateral load	3329.0 2914.0	[22]
							without grooves	axial load lateral load	1871.0 1516.0	
			2.0	2.0	-	composite resin	-	axial load	2349.0	[27]
			-	5.0	2.0	glass ionomer cement	-	axial load	1935.0	[23]
			-	4.0	2.0	composite resin	-	angled load (45°)	714.8	[24]
			5.5-6.0	3.0	1.0	-	-	axial load	1209.4	[25]
			-	2.0	1.0	-	-	axial load lateral load	1913.8 670.8	[26]
			-	3.0 ± 0.3	2.0	-	-	axial load	1760.0	[37]
			5.0	5.0 ± 0.2	1.0	composite resin	-	axial load	1693.4	[38]
			-	1.42-2.17 2.25-3.17 3.33-5.17	1.5	-	-	angled load (45°)	1084.6 1103.7 1893.8	[39]
			2.0	3.0-5.0	2.0	composite resin	-	axial load	1505.5	[41]

(*continued on next page*)

Table 1 (*continued*)

Type	Material type	Materials	Restoration (mm)			Cavity base material	Additional Conditions	Load direction	Fracture resistance (N) (Fracture load)	Reference
			Thickness	Chamber extension	Height from CEJ (finish line)					
			5.0	2.0	2.0	composite resin	-	angled load (45°)	4169.0	[42]
	leucite-reinforced glass ceramic	IPS Empress CAD	1.5 3.0 4.5	4.5 3.0 1.5	-	resin cement	-	axial load	1556.0 1313.0 1070.0	[19]
			-	5.0	2.0	glass ionomer cement	-	axial load	1178.0	[23]
	zirconia-reinforced lithium silicate ceramic	Vita Suprinity	1.5 (lingual: 3.5)	-	1.0 ± 0.5	composite resin	-	angled load (45°)	1058.3	[10]
			-	4.0	-	composite resin	-	axial load lateral load	2279.0 1074.0	[18]
			2.0	2.0	-	composite resin	-	axial load	1814.0	[27]
			-	5.0	2.0	glass ionomer cement	-	axial load	1859.0	[23]
			-	4.0	2.0	composite resin	-	angled load (45°)	569.4	
			2.0	2.0	-	composite resin	mesiobuccal cuspal coverage coverage of all buccal cusps mesiolingual cuspal coverage coverage of all lingual cusps mesiobuccal and mesiolingural cuspal coverage coverage of all cusps	axial load	1324.0 1627.0 1130.0 1346.0 1096.0 1639.0	[32]
			2.0	3.0-5.0	2.0	composite resin	-	axial load	1488.4	[41]
		Celtra Duo (unfired)	2.0	4.0	-	-	-	axial load	886.9	[11]
		Celtra Duo	-	4.0	2.0	glass ionomer cement	-	axial load	1618.3	[33]
	feldspathic glass-ceramic	Cerec Blocs	-	2.0	2.0	composite resin	-	angled load (35°)	1340.9	[6]
			-	4.0	2.0	composite resin	-	angled load (45°)	493.2	[24]
		Vitablocs Mark II	1.5 (lingual: 3.5)	-	1.0 ± 0.5	composite resin	-	angled load (45°)	1035.1	[10]
Zirconia	monolithic zirconia (4Y-TZP)	Ceramill Zolid HT	2.0 4.5	5.0-5.5 3.0-3.5	-	-	- distal root canal extension (2.0 mm)	axial load	3533.3 1066.9 2951.8	[20]
	monolithic zirconia (Y-TZP)	ZirkOM Si	-	5.0	2.0	glass ionomer cement	-	axial load	6333.0	[23]
		Superfect Zir HT	2.0	4.0	-	glass ionomer cement	-	axial load	5374.7	[40]
	monolithic zirconia (5Y-TZP, 3Y-TZP)	IPS e.max Zir CAD Multi	5.0	2.0	2.0	composite resin	-	angled load (45°)	2312.3	[42]
	monolithic zirconia (Y-PSZ)	Katana Zirconia STML	5.5-6.0	3.0	1.0	-	-	axial load	1810.2	[25]
	monolithic zirconia (3Y-TZP)	DD Bio ZX2	-	4.0	2.0	glass ionomer cement	-	axial load	7395.1	[33]
PEEK	polyether ether ketones	BioHPP	5.5-6.0	3.0	1.0	-	-	axial load	579.5	[25]

less than 120 μm and 150–220 μm [77,78], respectively. Numerous articles reported that they were within these ranges regardless of the material types of CAD-CAM endocrowns (Table 1). One of the causes of the clinically unacceptable range may have been the influence of setting of the space between restoration and cement when fabricated with the CAD-CAM system [79].

The margin design of CAD-CAM endocrowns should be made with a consideration of the thickness of the margin to improve bond strength by preserving more enamel and to ensure the edge strength of the restoration. Therefore, the selection of a butt margin has been reported in

Table 2
Comparison of fracture modes for CAD-CAM endocrowns.

Type	Material type	Materials	Restoration (mm)			Cavity base material	Additional Conditions	Load direction	Fracture mode (%)		Reference
			Thickness	Chamber extension	Height from CEJ (finish line)				Repairable	Irreparable	
Composite resin	nano-ceramic hybrid CAD-CAM composite resin block	Cerasmart	-	4.0	-	composite resin	-	axial load	60.0	40.0	[18]
								lateral load	80.0	20.0	
			2.0	1.0	-	-	-	-	52.4	47.6	[28]
			2.0	1.0	1.0	-	-	angled load (30°)	96.7	3.3	[29]
			2.0	2.0	1.0	composite resin	mesio-occlusal-distal-lingual cavities	axial load	20.0	80.0	[31]
							-	axial load	100.0	0.0	
			5.2 ± 0.1	2.1 ± 0.1	1.0	composite resin	-	axial load step stress (1250,000 cycles)	30.0	70.0	[30]
			-	2.0	1.0	-	-	axial load	60.0	40.0	[26]
								lateral load	75.0	0.0	
			2.0	3.0	2.0	glass ionomer cement	-	axial load	74.6	15.4	[35]
						special polyethylene fiber + composite resin			92.3	7.7	
		Grandio blocs	2.0	2.0	-	composite resin	-	axial load	62.0	38.0	[27]
			1.5	5.0	-	composite resin	-	axial load	100.0	0.0	[34]
	polymer-infiltrated ceramic network resin block	Vita Enamic	2.0	4.0	-	-	without ferrule	axial load	25.0	75.0	[12]
							with ferrule		25.0	75.0	
			3.5	2.5			without ferrule		35.0	65.0	
							with ferrule		37.5	62.5	
			1.5 (lingual: 3.5)	-	1.0 ± 0.5	composite resin	-	angled load (45°)	75.0	25.0	[10]*
			2.0	5.0-5.5	-	-	-	axial load	60.0	40.0	[20]
			4.5	3.0-3.5			-		50.0	50.0	
							distal root canal extension (2.0 mm)		100.0	0.0	
			2.0	2.0	-	composite resin	-	axial load	62.0	38.0	[27]
			2.0	2.0	1.0	composite resin	mesio-occlusal-distal-lingual cavities	axial load	0.0	100.0	[31]
							-	axial load	80.0	20.0	
			-	4.0	2.0	composite resin	-	angled load (45°)	70.0	30.0	[24]
			5.5-6.0	3.0	1.0	-	-	axial load step stress (600,000 cycle)	60.0	40.0	[25]*
			-	2.0	1.0	-	-	axial load	85.0	15.0	[26]
								lateral load	80.0	20.0	
			2.0	2.0 (mesio-occlusal-distal cavities)	-	-	-	axial load	0.0	100.0	[36]*
						composite resin (visible light cured bulk-fill flowable based resin composite)			50.0	50.0	
						composite resin (nanohybrid bulk-fill composite material)			37.5	62.5	

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Table 2 (*continued*)

Type	Material type	Materials	Restoration (mm)			Cavity base material	Additional Conditions	Load direction	Fracture mode (%)		Reference
			Thickness	Chamber extension	Height from CEJ (finish line)				Repairable	Irreparable	
						composite resin (short fiber-reinforced resin composite)			75.0	25.0	
	hybrid ceramic CAD-CAM composite resin block	Lava Ultimate	3.5	1.5	1.0	glass ionomer cement	-	axial load step stress (185,000 cycle)	100.0	0.0	[5]*
			-	2.0	2.0	composite resin	-	angled load (35°)	100.0	0.0	[6]*
			2.5	2.3	1.0	composite resin	-	axial load lateral load	70.0 80.0	30.0 20.0	[8]
			2.0	2.0	-	composite resin	-	axial load	48.0	52.0	[27]
			2.0	2.0	1.0	composite resin	mesio-occlusal-distal-lingual cavities	axial load	60.0	40.0	[31]
							-		80.0	20.0	
		Shofu	-	2.0	1.0	-	-	axial load lateral load	80.0 80.0	20.0 20.0	[26]
		Brilliant Crios	-	2.0	1.0	-	-	axial load lateral load	70.0 80.0	30.0 20.0	
Ceramic	lithium disilicate glass-ceramic block	IPS e.max CAD	-	2.0	2.0	composite resin	-	angled load (35°)	30.0	70.0	[6]*
			2.5	2.3	1.0	composite resin	-	axial load lateral load	70.0 50.0	30.0 50.0	[8]
			4.0	2.0 3.0 4.0	-	composite resin	-	angled load (45°)	33.3 8.3 26.7	66.7 91.7 83.3	[9]*
			-	3.0	1.5	-	-	angled load (45°)	33.3	66.7	[16]*
			-	4.0	-	composite resin	-	axial load lateral load	50.0 40.0	50.0 60.0	[18]
			-	extension extension - extension	- 1.0 - 1.0	- composite resin composite resin	-	axial load	0.0 0.0 10.0 0.0	100.0 100.0 90.0 100.0	[17]* *
			-	4.0	2.0	composite resin	with grooves without grooves	axial load lateral load axial load lateral load	20.0 20.0 50.0 40.0	80.0 80.0 50.0 60.0	[22]
			2.0	2.0	-	composite resin	-	axial load	48.0	52.0	[27]
			-	5.0	2.0	glass ionomer cement	-	axial load	90.0	10.0	[23]*
			-	4.0	2.0	composite resin	-	angled load (45°)	60.0	40.0	[24]
			5.5-6.0	3.0	1.0	-	-	axial load step stress (600,000 cycle)	40.0	60.0	[25]*
			-	2.0	1.0	-	-	axial load lateral load	65.0 80.0	35.0 20.0	[26]
			-	3.0 ± 0.3	2.0	-	-	axial load	90.0	10.0	[37]
			5.0	2.0	2.0	composite resin	-	angled load (45°)	16.7	83.3	[42]
	leucite-reinforced glass ceramic	IPS Empress CAD	-	5.0	2.0	glass ionomer cement	-	axial load step stress (140,000 cycle)	62.5	37.5	[23]*
	zirconia-reinforced lithium silicate ceramic	Vita Suprinity	1.5 (lingual: 3.5)	-	1.0 ± 0.5	composite resin	-	angled load (45°)	0.0	100	[10]*
			-	4.0	-	composite resin	-	axial load lateral load	60.0 80.0	40.0 20.0	[18]
			2.0	2.0	-	composite resin	-	axial load	30.0	70.0	[27]
			-	5.0	2.0	glass ionomer cement	-	axial load step stress (140,000 cycle)	15.0	85.0	[23]*

(*continued on next page*)

Table 2 (*continued*)

Type	Material type	Materials	Restoration (mm)			Cavity base material	Additional Conditions	Load direction	Fracture mode (%)		Reference
			Thickness	Chamber extension	Height from CEJ (finish line)				Repairable	Irreparable	
			-	4.0	2.0	composite resin	-	angled load (45°)	60.0	40.0	[24]
			2.0	2.0	-	composite resin	mesiobuccal cuspal coverage	axial load	60.0	40.0	[32]
							coverage of all buccal cusps		80.0	20.0	
							mesiolingual cuspal coverage		40.0	60.0	
							coverage of all lingual cusps		50.0	50.0	
							mesiobuccal and mesiolingual cuspal coverage		40.0	60.0	
							coverage of all cusps		80.0	20.0	
		Celtra Duo	-	4.0	2.0	glass ionomer cement	-	axial load step stress (500,000 cycle)	50.0	50.0	[33]*
	feldspathic glass-ceramic	Cerec Blocs	-	2.0	2.0	composite resin	-	angled load (35°)	70.0	30.0	[6]*
			-	4.0	2.0	composite resin	-	angled load (45°)	80.0	20.0	[24]
		Vitablocs Mark II	1.5 (lingual: 3.5)	-	1.0 ± 0.5	composite resin	-	angled load (45°)	58.3	41.7	[10]*
Zirconia	monolithic zirconia (4Y-TZP)	Ceramill Zolid HT	2.0	5.0-5.5	-	-	-	axial load	90.0	10.0	[20]
			4.5	3.0-3.5					80.0	20.0	
							distal root canal extension (2.0 mm)		10.0	90.0	
	monolithic zirconia (Y-TZP)	ZirkOM Si	-	5.0	2.0	glass ionomer cement	-	axial load step stress (140,000 cycle)	20.0	80.0	[23]*
		Superfect Zir HT	2.0	4.0	-	glass ionomer cement	-	axial load step stress (50,000 cycle)	20.0	80.0	[40]
	monolithic zirconia (5Y-TZP, 3Y-TZP)	IPS e.max Zir CAD Multi	5.0	2.0	2.0	composite resin	-	angled load (45°)	0.0	100.0	[42]
	monolithic zirconia (Y-PSZ)	Katana Zirconia STML	5.5-6.0	3.0	1.0	-	-	axial load step stress (600,000 cycle)	20.0	80.0	[25]*
	monolithic zirconia (3Y-TZP)	DD Bio ZX2	-	4.0	2.0	glass ionomer cement	-	axial load	50.0	50.0	[33]*
PEEK	polyether ether ketones	BioHPP	5.5-6.0	3.0	1.0	-	-	axial load step stress (600,000 cycle)	100.0	0.0	[25]*

As definitions, Repairable: fracture above CEJ; Irreparable: fracture below CEJ; * Irreparable: catastrophic fracture; * * Irreparable: presence of a crack in the remaining tooth structure

many reports (Tables 3, 4). However, butt margins located near the gingival margin cause a thinner remaining enamel. Therefore, flexible selections should be made in designing the margins, depending on the condition of the prepararion [66].

In the increasingly digitalized dentistry, not only extraoral scanners for scanning dental casts, but also intraoral scanners have been developed [80]. Comparisons of the margin gap between different intraoral and extraoral scanners in the fabrication of endocrowns reported no significant difference [46,51]. Marginal and internal discrepancies have been reported to increase in dependence on the extension of the

Table 3
Comparison of marginal and internal gaps for CAD-CAM endocrowns.

Type	Material type	Materials	Preparation	Restoration			Margin design	Marginal gap	Internal gap	Reference
				Thickness (mm)	Chamber extension (mm)	Cavity wall angle (°)				
Composite resin	nano-ceramic hybrid CAD-CAM composite resin block	Cerasmart	teeth	2.0	4.0	8	butt	39.4	-	[11]
			teeth	-	4.0	8	butt	143.0	116.1	[45]
			model teeth	-	6.0	8	butt	before: 47.7* after: 45.9*	-	[21]
	polymer-infiltrated ceramic network material	Vita Enamic	teeth	2.0	4.0	8	butt	47.0	-	[11]
			model teeth	3.0-5.0 (buccal: 5.0, lingual: 3.0)	3.0 (from lingual walls)	8-10 (mesial-distal) 22 (buccal) 11 (lingual)	butt	71.0	axial: 77.2 floor: 93.9	[47]
			teeth	-	4.0	8-10	butt	74.3	-	[24]
			teeth	5.5-6.0 (nonfunctional occlusion: 6.0, functional occlusion: 5.5)	3.0	8	butt	37.7	cervical: 61.4 axial: 70.4 pulpal: 121.1 internal: 83.5	[50]
			teeth	2.0-3.0	3.0-5.0	7	butt	26.6	-	[55]
	hybrid ceramic CAD-CAM composite resin block	Lava Ultimate	model teeth	2.0	2.0	-	butt	88.9	axial: 139.9 occlusal: 158.0	[44]
	ceramic based composite	Ceramill COMP	model teeth	-	6.0	8	butt	before: 45.4* after: 40.8*	-	[21]
	Techno-polymer, fiber-reinforced composite	Trilor	teeth	-	4.0	8	butt	196.7	161.6	[45]
Ceramic	lithium disilicate glass-reinforced ceramic	IPS e.max CAD	teeth	-	2.0	8	shoulder	98.9 * *, 107.8 * **	line angle: 112.7 * **, 134.1 * ** * cavity wall: 118.2 * **, 185.3 * ** * pulp floor: 228.8 * **, 278.2 * ** *	[43]
					4.0			120.2 * *, 90.2 * ***	line angle: 123.4 * **, 115.7 * ** * cavity wall: 151.7 * **, 136.7 * ** * pulp floor: 250.2 * **, 327.7 * ** *	
			teeth	2.0	4.0	8	butt	36.9	-	[11]
			teeth	-	4.0	8	butt	104.8	105.3	[45]
			model teeth	3.0-5.0 (buccal: 5.0, lingual: 3.0)	3.0 (from lingual walls)	8-10 (mesial-distal) 22 (buccal) 11 (lingual)	butt	69.2	axial: 70.2 floor: 102.6	[47]
			teeth	-	4.0	8-10	butt	78.7	-	[24]
			model teeth	2.0	3.0	-	shoulder	56.5	158.1	[48]
			teeth	-	-	-	butt	intraoral scanner: 120.0 extraoral scanner: 120.0	-	[51]
			teeth	5.5-6.0 (nonfunctional occlusion: 6.0, functional occlusion: 5.5)	3.0	8	butt	45.2	cervical: 67.7 axial: 76.5 pulpal: 128.3 internal: 90.8	[50]
			teeth	5.0	5.0 ± 0.2	8-10	butt	54.7	-	[38]
			teeth	2.0	-	8	butt	109	127	[54]

(*continued on next page*)

Table 3 (*continued*)

Type	Material type	Materials	Preparation	Restoration			Margin design	Marginal gap	Internal gap	Reference
				Thickness (mm)	Chamber extension (mm)	Cavity wall angle (°)				
			teeth	2.0-3.0	3.0-5.0	7	butt	29.2	-	[55]
	lithium disilicate glass-reinforced ceramic	Rosetta SM	model teeth	2.0	-	10	butt	69.0	84.8	[53]
			model teeth	2.0	-	5	butt	77.5	84.0	
	zirconia-reinforced lithium silicate ceramic	Vita Suprinity	teeth	-	4.0	8	butt	114.7	110.9	[45]
			model teeth	3.0-5.0 (buccal: 5.0, lingual: 3.0)	3.0 (from lingual walls)	8-10 (mesial-distal) 22 (buccal) 11 (lingual)	butt	77.5	axial: 73.4 floor: 100.0	[47]
			teeth	-	4.0	8-10	butt	80.4	-	[24]
			teeth	2.0-3.0	3.0-5.0	7	butt	34.6	-	[55]
		Celtra Duo (unfired)	teeth	2.0	4.0	8	butt	45.8	-	[11]
		Celtra Duo	model teeth	2.0	2.0	-	butt	131.0	axial: 177.0 occlusal: 182.3	[44]
			teeth	-	3.0-5.0	6	butt	80.6 * ** *	99.8 * ** *	[49]
			model teeth	2.0	-	10	butt	84.8	86.1	[53]
			model teeth	2.0	-	5	butt	89.3	90.8	
	feldspathic glass-ceramic	Cerec Blocs	model teeth	-	-	-	butt	maxillary: 91.0 mandibular: 110.0	maxillary: 215.0 mandibular: 182.0	[52]
Zirconia	monolithic zirconia (3Y-TZP)	DD Bio ZX2	teeth	-	3.0-5.0	6	butt	78.5 * ** *	113.8 * ** *	[49]
	monolithic zirconia (5Y-TZP)	Zolid Fx multilayer	teeth	-	5.0-7.0	8-10	butt	intraoral scanner: 70 extraoral scanner: 74	-	[46]
	monolithic zirconia (Y-PSZ)	Katana Zirconia STML	teeth	5.5-6.0 (nonfunctional occlusion: 6.0, functional occlusion: 5.5)	3.0	8	butt	64.0	cervical: 73.7 axial: 89.4 pulpal: 172.4 internal: 111.5	[50]
PEEK	polyether ether ketones	BioHPP	model teeth	2.0	3.0	-	shoulder	81.3	199.1	[48]
			teeth	5.5-6.0 (nonfunctional occlusion: 6.0, functional occlusion: 5.5)	3.0	8	butt	83.0	cervical: 121.1 axial: 137.7 pulpal: 153.4 internal: 138.2	[50]
		Ceramill	teeth	2.0	-	8	butt	87	104	[54]

* after thermo-mechanical; * * chairside CAD-CAM systems (CEREC AC); * **chairside CAD-CAM systems (E4D Sky); * ** *maximum value

preparation into the pulp chamber [43], for which reason it is considered that extension should be less than 4.0 mm for CAD-CAM endocrowns. In addition, since increasing the cavity wall angle of the pulp chamber facilitates scanning and milling [46], 8–10° on each side is recommended for fabricating a well-fitting CAD-CAM endocrown.

Survival rates by material type were lower for resin composite than for ceramic and zirconia. Resin composite types showed the rate of 89.5% at 2 years [67] and 62.5% minimum at 5 years depending on the material [69], with all of the follow-up cases within 2 years reported to be restorable [63,67,69]. Ceramic types had a 100% survival rate at 2 years [65,67,70], with endocrown fracture as the most common complication at about 5 years, most of which were classified as repairable. [66]. Zirconia types were reported only for desorption [67]. Based on reports of clinical cases, the CAD-CAM endocrown should have an occlusal surface thickness of at least 1.5 mm, a chamber extension of at least 2.0 mm, a butt margin for margin design, and a wall thickness of at least 2.0 mm.

Belleflamme MM et al. [81] reported a survival rate of 99.0% and a success rate of 89.9% with an average of 44.7 ± 34.6 months in 99 cases, including heat-pressing and direct methods of fabrication. Furthermore, endocrowns were shown to be a reliable approach for restoring severely damaged molars and premolars, even with extensive crown defects (Class 3) and occlusal risk factors such as bruxism and unfavorable occlusal relationships.

Zou Y et al. reported that the average time for tooth preparation in molars for endocrowns was 22 min 32 s, approximately 10 min less than the mean time for restorations with post and core [68]. Although both direct and indirect methods are effective for endocrowns in terms of fabrication, the direct method is considered to require fewer visits but better maintenance [71]. Therefore, the indirect method is recommended as a technique that reduces the burden on the patient in view of the treatment progress.

5. Conclusion

CAD-CAM endocrowns require a restoration covering the functional cusp, at least 1.5 mm restoration thickness, 1.0–4.0 mm pulp chamber extension, and removal of remaining tooth structure less than 2.0 mm in width. The marginal and internal fit of CAD-CAM endocrowns on molars can be fabricated within clinical acceptability, according to many basic

Table 4
Clinical performance of CAD-CAM endocrowns.

Type	Material type	Materials	Preparation (mm)					Period (year)	Outcome		Reference
			Teeth: *n*	Thickness (Reduction in the axial direction)	Chamber extension	Margin design	Wall thickness		Survival rate (%)	Complications	
Composite resin	nano-ceramic hybrid CAD-CAM composite resin block	Cerasmart	molar: 9	1.5	3.0	butt or shoulder with 2.0 ferrule	-	6 months 12 months 5 years	77.8 66.7 66.7	chipping: 2 (repairable) debonding: 1 (repairable) dropout: 3 (irrepairable) debonding: 1 (irrepairable)	[69]
	polymer-infiltrated ceramic network material	Vita Enamic	molar: 6	≧ 2.0	≧ 3.0	butt	≧ 2.0	12 months	100.0	-	[65]
			molar: 20	-	-	butt	-	2 years	89.5	chipping: 2 teeth (repairable)	[67]
			molar: 6	1.5	3.0	butt or shoulder with 2.0 ferrule	-	6 months 12 months 5 years	100.0 100.0 80.0	- - extraction: 2 (second caries, root fracture)	[69]
	hybrid ceramic CAD-CAM composite resin block	Lava Ultimate	molar: 1 (26 [FDI])	≧ 1.5	-	-	-	1 month	-	-	[57]
			molar: 5 (maxillary: 1, mandibular: 4)	-	-	butt	-	12 months	-	-	[60]
			molar: 10	1.5	3.0	butt or shoulder with 2.0 ferrule	-	6 months 12 months 5 years	80.0 70 62.5	chipping: 2 (repairable) fracture: 2 (repairable) dropout: 2 (irrepairable) fracture: 1 (irrepairable)	[69]
	hybrid ceramic CAD-CAM composite resin block	Shofu Block HC	molar: 1 (16 [FDI])	1.0-1.2	-	butt	1.0-1.2	18 months	-	partial fracture of non-functional occlusal cusp (5 months later, repairable)	[63]
Ceramic	lithium disilicate	IPS e.max CAD	molar: 2	≧ 2.0	≧ 3.0	butt	≧ 2.0	12 months	100.0	-	[65]
	glass-reinforced ceramic	IPS e.max CAD / IPS Empress CAD	molar: 225	≧ 2.0	≧ 2.0	butt	≧ 2.0	56.1 ± 25.9 months	81.8 (9 years, n = 112: 71.8)	endocrown fracture: 14 (repairable), 3 (irrepairable) debonding: 5 (repairable) periodontal failure: 1 (repairable), 1 (irrepairable) recurrent carious lesion: 1 (repairable), 2 (irrepairable) endodontic retreatment: 3 (repairable) operator's mistake: 1 (repairable) dental fracture: 1 (repairable) tooth fracture: 2 (irrepairable)	[66]
		IPS e.max CAD	molar: 20	-	-	butt	-	2 years	100.0		[67]
			molar and premolar: 20	1.5-2.0	-	2.0 round cervical chamfer	-	2 years	100.0	-	[70]

(*continued on next page*)

Table 4 (*continued*)

Type	Material type	Materials	Preparation (mm)					Period (year)	Outcome		Reference
			Teeth: *n*	Thickness (Reduction in the axial direction)	Chamber extension	Margin design	Wall thickness		Survival rate (%)	Complications	
		IPS Empress CAD	first molar: 7 (maxillary: 3, mandibular: 4)	nonfunctional occlusion: ≧ 2.0 functional occlusion: ≧ 1.5	2.0	butt	-	4 years	85.7	extraction: 1 (apical periodontitis)	[71]
		IPS e.max CAD	molar: 36		5.0	chamfer	-	12 months	97.3	dentinexposure: 1	[72]
	feldspathic glass-ceramic	CEREC Block PC	molar: 1 (46 [FDI])	2.0	-	butt	1.0-1.2	10 months	-	-	[63]
		Vita Mark II	molar: 11	≧ 2.0	-	butt	≧ 2.0	6 months	-	second caries: 1 (repairable)	[58]
			molar: 20 (maxillary: 9, mandibular: 11)	-	-	butt	-	12 years	90.5	debonding: 1 bulk fracture: 1	[59]
			molar: 235	≧ 2.0	-	butt	≧ 2.0	55 months	99.6	fracture (38 [FDI]) (3 months later): 1	[61]
Zirconia	monolithic zirconia (Y-TZP)	Metoxit AG	molar: 1 (36 [FDI])	2.0	-	butt	-	28 months	-	-	[56]
		YZ HT 40/19	molar: 321 (16, 26 [FDI]: 86, 36, 46 [FDI] 94, 17, 27 [FDI]: 71, 37, 47 [FDI]: 70)	≧ 2.0	2.0-4.0	butt	≧ 1.0	3 years	100.0	-	[62]
			molar: 334	≧ 2.0	-	butt	≧ 1.0	5 years	100	-	[68]
		Cercon	molar: 20	-	-	butt	-	2 years	82.4	debonding: 3 (repairable: 1, conventional crowns: 2)	[67]
	monolithic zirconia (N/A)	-	molar: 1 (16 [FDI])	-	-	-	-	12 months	-	-	[64]

studies. High survival rates have been reported in clinical research, but further reports, including clinical outcomes, are needed to validate this technology for clinical application. In terms of mechanical strength, dental metals such as titanium [82], which can be fabricated with CAD-CAM systems, may also be used. The advantages of endocrowns include preservation of remaining tooth structure, reduced risk of root fracture and perforation of the root canal, handling of insufficient clearance, fewer patient visits, and reduced financial burden. Therefore, CAD-CAM endocrowns are a beneficial restoration for both dentists and patients.

Conflict of interest

All authors declare that they have no conflicts of interest in regard to this work.

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