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The effect on fracture resistance of Fibre-Reinforced composite on endodontically treated teeth:

Systematic Integrative review

Sara Chédotal

Dissertação conducente ao **Grau de Mestre** em **Medicina Dentária (Ciclo Integrado)**

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Trabalho realizado sob a Orientação de
Prof. Doutor Paulo Miller e a Co-Orientação de Dr. António Ferraz

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RESUMO

Introdução: A manutenção a longo prazo dos dentes endodonciados na cavidade oral depende da qualidade do tratamento endodôntico e dos materiais de restauração. Os compósitos reforçados com fibras, podem ter um efeito na melhoria do reforço da resistência à fratura e na capacidade de minimizar a taxa de fratura catastrófica em dentes posteriores que suportam um elevado nível de stress.

Objetivo: Avaliar e comparar o efeito das fibras, no reforço do compósito, na resistência à fratura de dentes endodonciados.

Materiais e Métodos: Pesquisa através das bases de dados Pubmed, ScienceDirect e Scielo, entre 2010-2023. A estratégia de pesquisa seguiu as diretrizes Cochrane utilizando a estratégia PICO. Foram incluídos 26 artigos.

Resultados: Dos artigos selecionados, os dados relevantes foram organizados numa tabela: Estudo, Objetivo, Métodos, População, Resultados e Conclusão.

Discussão: Embora não exista uma concordância total entre os vários autores, a utilização de fibras de vidro ou de polietileno não só aumentaria a resistência da restauração como também afetaria favoravelmente o tipo de fratura, permitindo um melhor prognóstico de sobrevivência.

Conclusão: A utilização de fibras para reforçar o compósito, em dentes endodonciados, parece ser uma escolha adequada para aumentar a resistência à fratura e proteção contra o desenvolvimento de fratura irreparável. É necessária investigação adicional para determinar os parâmetros ideais (compósito e adesivo utilizados em conjunto, posição e quantidade de fibras) e estudos adicionais in vivo para demonstrar a eficácia a longo prazo dessas fibras no caso de restauração pós-endodôntica.

Palavras-Chaves: *"Tooth fractures", "Fibre-reinforced composite", "Composite resins", "Tooth, nonvital", "EverX posterior".*

ABSTRACT

Introduction: The long-term maintenance of endodontically treated teeth in the oral cavity depends on the quality of endodontic treatment and the restoration materials used. Fibre-reinforced composites, may have an effect on improving the reinforcement of fracture resistance and the ability to minimise the rate of catastrophic fracture in posterior teeth that bear a high level of stress.

Objective: To evaluate and compare the effect of fibres, in composite reinforcement, on the fracture resistance of endodontically treated teeth.

Materials and methods: Research through Pubmed, ScienceDirect and Scielo databases, between 2010-2023. The search strategy followed Cochrane guidelines using the PICO strategy. 26 articles were included.

Results: From the selected articles, relevant data were organised into a results table: Study, Purpose, Methods, Population, Results and Conclusion.

Discussion: Although there is not complete agreement among the various authors, the use of glass or polyethylene fibers would not only increase the strength of the restoration but also favourably affect the type of fracture, allowing a better survival prognosis.

Conclusion: The use of fibers to reinforce composite, in endodontically treated teeth, seems to be a suitable choice to increase fracture resistance and protection against the development of irreparable fracture. Further research is needed to determine the optimal parameters (composite and adhesive used together, position and amount of fibres) and additional in vivo studies to demonstrate the long-term efficacy of these fibres in the case of post-endodontic restoration.

Keywords: *"Tooth fractures", "Fibre-reinforced composite", "Composite resins", "Tooth, nonvital", “EverX posterior”.*

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LIST OF ABBREVIATIONS

Bis-GMA: Bisphenol A-Glycidyl Methacrylate

CEC: Conservative Endodontic Cavity

CEJ: CementoEnamel Junction

CP: Cavity Preparation

DEJ: DentinoEnamel Junction

ETC: Endodontic Treatment Classification

Fb: Fibre

FCR: Flowable Composite Resin

FP: Fibre Post

FR: Fracture Resistance

FRC: Fibre-Reinforced Composite

GIC: Glass Ionomer Cement

GPa: Gigapascals

MOD: Mesio-Occluso-Distal

PM: PreMolars

PMMA: Polymethylmethacrylate

RC: Resin Composite

RCT: Root Canal Treatment / Root Canal-Treated

TEC: Tradicional Endodontic Cavity

TEGMA: Triethylene Glycol Dimethacrylate

1 Introduction

Among the causes of root canal-treated teeth extraction, 13.4% are due to vertical root fractures (1). In other words, the fragility of endodontically treated teeth represents a challenge in dental science (2). In effect, root canal treatments are frequently caused by previous caries, fractures or restoration infiltration resulting in a decreased residual wall (3,4). Moreover, the sacrifice of a substantial amount of sound tissues such as ridges, pulp chamber wall and dentin lead to the reduction of the structural integrity (4–8). Since the structural integrity of the crown is necessary for the resistance of the tooth under mechanical loads, a decrease in support can cause a decline in fracture toughness(9). For this reason, the long-term maintenance of the devitalised tooth in the oral cavity depends not only on the quality of the root canal treatment but also on the restorative materials used (7).

Consequently, restorative material is a crucial factor in dentistry; it should ensure integrity, adequate properties, and durability of the damaged tooth (2,6,8,10).
For this purpose, numerous materials for restoration exists, such as indirect restorative materials (full crow coverage), glass ionomer cement (GIC), and amalgam (7,8). However, those materials have some limits, such as a greater lack of follow-up by patients for full crown coverage due to the need for several consultations to complete the protocol (7,8). As well as a lack of adhesion to the tooth structure of the amalgam, which can lead to microcrack propagation under a high load level (7,8). Furthermore, the composite resin is the most used material for restoration of posterior teeth (11). This material is recommended due to its suitable properties (esthetics, elasticity), affordable cost, easy handling, and rapid execution (2,12). Particularly, the use of composite resin is associated with the 2mm incremental layering technique (oblique or horizontal) (11,13). Indeed, this technique is recognised due to its ability to reduce polymerisation and develop mechanical properties (11,13).
Nevertheless, when using composite resins, essential characteristics must be taken into account, such as their shrinkage rate, long-term fatigue rate, and fragility to mechanical forces compared to natural tooth tissues. Indeed, the volumetric shrinkage, which

ranges from 1.5% to 6% during polymerisation contraction, generates internal stress that can lead to micro-cracks, cusp deflection and eventually result in secondary caries or tooth fractures in a long perspective(9,14,15). Therefore, by combining these factors and the fact that the tooth is weakened by the root canal treatment, it demonstrates the necessity to develop complementary products to the use of this restorative material to ensure the success of the root canal treatment (16,17).

In that regard, composites reinforced with fibres such as polyethylene and glass fibres may have an effect in the improvement of strengthening the fracture resistance and in its capacity to minimise the rate of catastrophic fracture in teeth that bears a high level of stress like posterior teeth (4,10,18). Those fibres reinforced composites are used to increase durability and damage tolerance; and would contribute to eliminate or help the integration of inter radicular posts in the restoration process. They are based on their abilities to mimic DEJ and dentin by reciprocally reproduce its stress absorption property and elasticity modulus (14-16 GPa) (11,19). At present, the capacity of fracture resistance of the fibre-reinforced composite varies according to Garroushi and Lassila (2011), with the *"quantity of fibres, length of fibres, form of fibres, orientation of fibres, adhesion of fibres to the polymer matrix and impregnation of fibres with the resin"* (16). It will also depend on fibres positions, types of fibres and product presentation format (20,21).

2 Objectives

The first aim of this study is to evaluate and compare the effect of different types of fibres, in the reinforcement of composite, on the fracture resistance of endodontically treated teeth: depending on wall thickness, retention systems, quantity and position of fibres.

3 Materials and methods

3.1 Protocol

This review protocol was realised based on PRISMA directives (Preferred Reporting Items for Systematic and Meta-Analyses).

3.2 Eligibility Criteria

This research was structured according to Cochrane's and based on a PICO strategy.

Table 1: PICO	
Product	- Premolars or Molar extracted for a periodontal or orthodontic reason (20 -60 years) unrestored and without cracks or fractures.
Intervention	- Root canal treatment - Fibre-reinforced composite as a post-restorative material
Comparison	- Compared to direct and indirect restoration without fibres.
Outcome	- Fracture resistance

The eligibility criteria were divided into two groups, the inclusion and exclusion criteria:

Table 2: Eligibility Criteria	
Inclusion criteria	**Exclusion criteria**
- Between 2010 and 2023 - Evaluation of the fracture resistance of FRC on RCT tooth - Evaluation of the impact of the cavities on the FR on RCT tooth - Impact of the root canal treatment on the FR - Case Reports, Clinical Study, Clinical Trial, Comparative Study, Controlled Clinical Trial, Observational Study, Randomized Controlled Trial	- Review / Systematic Review / Book and Documents - Studies before 2010 - Studies involving non-human RCT teeth - Studies that only cover the post

3.1 Selection of articles

Stage I - The *Pubmed, Science Direct,* and *Scielo* databases were used using those keywords:

- Mesh Term: *"composite resins", "tooth fractures", "tooth, nonvital", "EverX Posterior"*

- No Mesh Term: *"fiber reinforced composite"*

A filter was used in the survey: time frame (2010-2023).

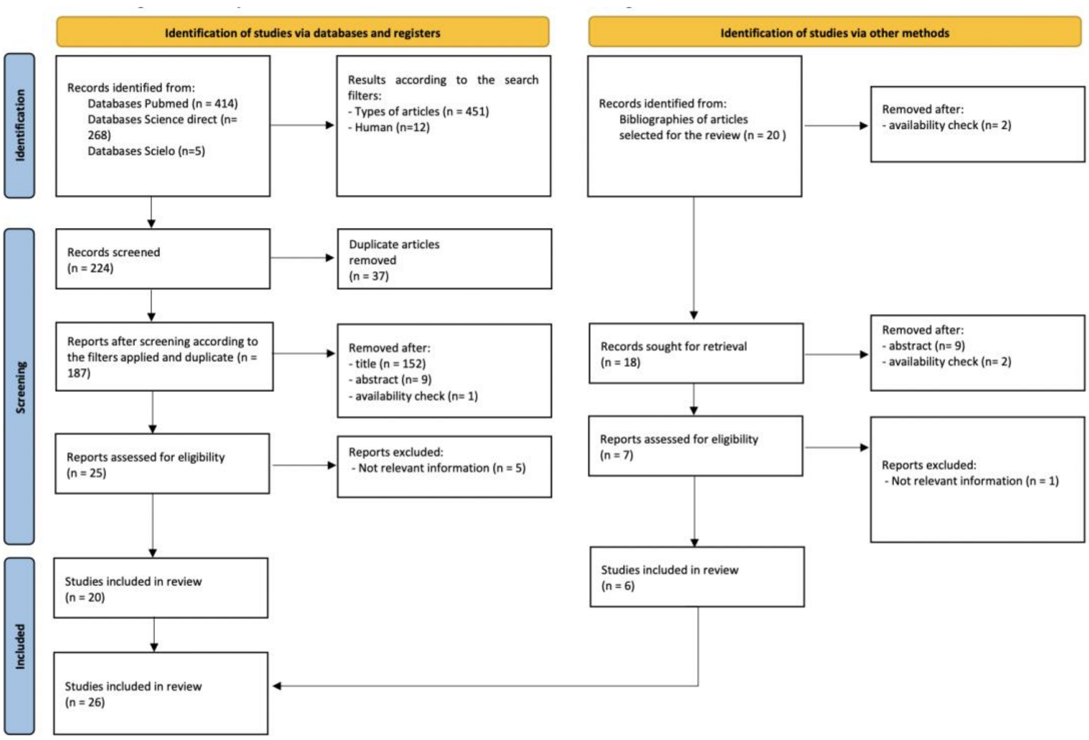
Stage II - The potential articles usable according to the titles were read through the abstract.

Stage III - Based on the articles assessed in Stage II, potentially eligible articles were read in their entirety to select those that meet the stated objective. From the articles evaluated in stage III, potentially eligible articles in the bibliographies of the selected articles were also read in full and selected.

Table 3: Search results

Database	Combination of keywords	Stage 1	Stage 2	Stage 3
Pubmed	*((composite resins[MeSH Terms]) AND (tooth fractures[MeSH Terms])) AND (tooth, nonvital[MeSH Terms])*	236	13	11
Pubmed	*(fiber reinforced composite) AND ((tooth fracture[MeSH Terms]) OR (tooth nonvital[MeSH Terms]))*	176	5	5
Pubmed	*"EverX Posterior" [Supplementary Concept]) AND "Tooth, Nonvital" [Mesh]*	2	1	1
Science Direct	*(composite resins) AND (tooth fractures) AND (tooth, nonvital)*	195	3	2
Science Direct	*(fiber reinforced composite) and (tooth fractures) and (tooth nonvital)*	73	1	1
Scielo	*(fiber reinforced composite)*	5	2	0
Bibliographies				6
			Total articles	26

Figure 1: Flow chart of study selection for the review (Prisma).



4 Results

Stage I - Database results

Based on the keywords and time limit (2010-2023), databases displayed a result of 687 articles. After the application of the search filter and the elimination of duplicates, 500 articles were excluded.

Stage II –Titles and Abstract reviewed

After reading the titles and abstracts and screening according to the selection criteria, 162 articles were excluded.

Stage III - Articles for inclusion

At this stage, 25 articles were reviewed to assess the eligibility of the article based on the full text. Among these, 5 have been excluded: 20 have been included in this systematic review.

From the articles evaluated at Stage III, the potentially eligible articles in the selected articles' bibliographies were also read in their entirety and selected. After reviewing the title and summary, the inclusion criteria and availability, 7 were selected. Of those, 1 excluded: 6 articles were included in this systematic review.

→ 26 articles were included in this systematic review (figure 1).

As indicated in methodology and methods, relevant and valuable data from selected articles were sorted and organised in a results table: Study, Purpose, Methods, Population Results, and Conclusion (Table 4).

Table 4: Results

Study	Purpose	Methods	Population	Results	Conclusion
(Aslan et al. 2018) (3)	Effects of different coronal restoration techniques on FR of RCT mandibular PM with MOD cavities.	Transillumination and recording as favourable and unfavourable + maximum pre-fracture loads of the different groups after application of a 45° oblique compressive load at the enamel/RC junction until fracture.	7n= 105 PM mandibular: - G1: intact teeth - G2: unfilled - G3: RC - G4: 10mm FP + RC - G5: 5mm FP + RC - G6: **Occlusal Ribbond**® + RC - G7: horizontal FP + RC	<u>FR:</u> G1, 6, 7 > G 3, 4, 5: $P < 0.05$. Among G1, 6, 7 and G 3, 4, 5 : $P > 0.05$ <u>Favourable and unfavourable:</u> No significant differences among the experimental groups in terms of the fracture types ($P > 0.05$).	Occlusal Ribbond® or Horizontal FP in RCT mandibular PM gives the tooth an FR-like intact teeth. + Greater resistance than the vertical posts (5mm or 10mm).
(Eapen et al. 2017) (10)	Compared the FR of RCT restored with 2 FRC resins and 2 conventional RC core reconstruction materials with MOD cavities.	Application of increasing load on the occlusal surface of the buccal and lingual cusps along the vertical axis of the tooth until the fracture (1 mm/min). Recording of the force required to fracture each tooth (Newton) and the localisation of the fracture.	6n= 60 maxillary PM: - G1: intact teeth - G2: unfilled - G3: dual-cure RC - G4: posterior RC - G5: **FRC (Interlig® Fiber Angelus)** - G6: **short FRC (EverX Posterior™)**	<u>The mean FR values:</u> group 1 > group 6 > group 4 > group 3 > group 5 > group 2. (Significant differences were found only in the posterior RC and short FRC groups) <u>Levels of fractures:</u> - Group 6: All the fractures occurred at the level of enamel. - Group 4 and 5: All the fractures occurred at the level of enamel or dentin. - Group 2: All the fractured at or below the CEJ.	FRC showed less FR compared with Short FRC resin. RC covers fibres during placement= formation of air gaps = can lower the FR. Short FRC under a posterior RC to mimic the enamel and dentin could reinforce RCT teeth.

(Özyürek et al. 2018) (18)	Compare the FR of mandibular molar prepared using TEC and CEC methods and restored using SDR (bulk-fill) and EverX Posterior™ based composite materials.	Application of a compressive load (1mm/min) on the central fossa in the lingual direction (15°) until the fracture. Recording in Newton of the load causing the fracture Classification of the types of fracture with a stereomicroscope.	5n= 100 mandibular first molar. - G1: intact teeth - G2: TEC + **everX Posterior™** + RC - G3: CEC + **everX Posterior™** + RC - G4: TEC + SDR + RC - G5: CEC + SDR + RC	No statistically significant difference in endodontic access cavities TEC and CEC and restored with the same material (P > 0.05). <u>The FR</u> increased as the dimensions of the BL, MD, and BL MD. FR Higher: G4 and G5. <u>More restorable fracture:</u> G3 (p<0,05) More non restorable fracture: G2 and 4 (p < 0,05)	The conservative method (CEC) did not differ from the traditional (TEC) when restored with the same base material except for their ability to be restored after a fracture. The fracture strength of SDR (bulk-fill) stands out as superior to that of EverX Posterior™ without considering the shape of the cavity.
(Monaco et al. 2016) (4)	Evaluate the FR and the failure mode of the RCT posterior teeth restored with Resin overlays with and without reinforcement with glass fibre in different cavity configurations.	Application of mechanical loading in a computer-controlled masticator (50N) in the occlusal surface in the central fossa (= 5 years of clinical service). Recording the fracture strength and the fracture patterns.	4n= 32 molars: - G1: No foundation + No FRC - G2: No foundation + **FRC (Vectris® Frame)** - G3: Foundation + No FRC - G4: Foundation + **FRC (Vectris® Frame)**	<u>Retention rate</u> of all groups: 100% <u>FR:</u> G2 < G3 < G1 < G4 Statistically significant difference: - G1 and G4 - G2 and G4 - G3 and G4 <u>Fracture Patterns:</u> - G1: Reparable < Radicular - G2: Radicular - G3: Reparable = Radicular - G4: Reparable	The presence of a foundation + the use of an FRC = increase in FR and allow the limitation to reparable fractures.

(Gokce and Basaran 2019) (5)	Compare the effect of different restoration techniques on FR of RCT teeth with varying thicknesses of wall (MOD)	Application of compressive force (1mm/min) vertically on the occlusal surface and touched buccal and lingual cusps. Recording the force (kN) Classification with catastrophic (non-reparable) and non-catastrophic fracture (reparable) with a stereomicroscope.	3n= 210 PM Groups: GA: 2mm GB: 1,5mm GC: 1mm Subgroups: - K: RC - KT**: Fibre on the cavity floor (EverStick® NET Stick)** + RC - KO: **Fibre on occlusal level (EverStick® NET Stick)** + RC - FP: FP + RC - L: Inlay - LT: **Fibre on the cavity floor (EverStick® NET Stick) +** Inlay - LO: **Fibre on the occlusal level (EverStick® NET Stick)** + Inlay	No statistically significant differences in groups A and C (p <0,05) but differences in group B (p <0,05). <u>Groupe B;</u> No statistically significant difference in subgroups K, KT, FP, LT, and LO (*P* > 0.05) but KO and L (p<0,05) FR: KO > K, KT, FP, LT, LO	- 2 mm or more was sufficient = no need to use additional material - 1 mm was insufficient = not enough - 1.5 mm = very useful to use FRC → improves the resistance and reduces the presence of catastrophic fractures.
(S. S. Oskoee et al. 2012) (14)	Evaluate the effect of composite fibre insertion along with low-shrinking RC on cuspal deflection of RCT maxillary premolars (MOD)	Measurement of intercuspal distance and cuspal deflection. Application of compressive force (0,5mm/min) on the occlusal surface, touched buccal and lingual cusps parallel to the long axis of the teeth. Recording of the force required to fracture each tooth (Newton).	4n= 60 PM maxillary G1: RC G2: Impregnated **glass Fb** at gingival third **(Interlig®) +** RC G3: Impregnated **glass Fb** at middle third **(EverStick® NET Stick)** + RC G4: Impregnated **glass Fb** at occlusal third **(EverStick® NET Stick)** + RC	<u>Cuspal deflection:</u> → statistically significant differences among the groups. (p<0,001mm) - G 1 vs G2, G3, G4: p< 0,001 - G2 vs G3; G2 vs G4; G3 vs G4: p>0,001 <u>FR:</u> → Among the groups (p<0,001mm) - G4 vs G1, G2, G3: p< 0,001 - G1 vs G2; G1 vs G3; - G2 vs G3: p>0,001	Using FRC in combination with silane-based composite reduces cusp deflection and increases the fracture resistance of RCT teeth. Deviation from the cuspal cannot be regarded as a predictor for FR.

(Khan et al. 2013) (6)	Compare the fracture resistance of RCT molars with MOD between teeth restored with polyethylene fibre and glass fibre with RC.	Application of compressive force (0,5mm/min) on the occlusal surface and touched buccal and lingual cusps parallel to the long axis of the teeth. Recording of the force required to fracture each tooth (Newton).	6n= 60 molars mandibular. G1: intact teeth G2: unfilled G3: hybrid RC G4: FCR + Hybrid RC G5: FCR + **FRC (Ribbond®)**+ hybrid RC G6: FCR + pre-impregnated translucent **glass fibre** mesh **(Vectris®, Ivoclar Vivadent)** + hybrid RC	FR: G1 vs others: FR significantly higher (p<0,001) G2 vs others: FR significantly lower (p<0,001) G3 VS G4: No statistically significant difference (p>0,001) G5 e G6 vs G3: Higher FR (p<0,001) G5 vs G6: No statistically significant difference (p>0,001)	FRC such as polyethylene fibre (Ribbond®) or bidirectional glass fibre mesh (Vectris®) significantly increase the FR compared to other materials (p>0,05) They both have inherent crack-stopping properties due to their ability to transmit forces and resist dimensional changes.
(Yasa et al. 2016) (13)	Evaluate the FR of RCT teeth restored with nano-hybrid RC, short FRC (everX Posterior™) and bulk-fill flowable in the absence or presence of retention slots (MOD)	Record of BL and MD dimensions at the most prominent point of the tooth (digital calliper) Application of compressive force (1 mm/min) on the occlusal surface and touched buccal and lingual cups in the mesiodistal direction. Recording of the force required to fracture each tooth (Newton) Classification of the fracture mode: restorable	2n= 110 molars mandibular Groups: G1: No retention slot G2: Dovetail retention slots 1.5 mm x 1.5 mm width and 2/3 of cavity wall height Subgroups: SG 1: No restoration SG2: Nano hybrid RC (Filtek) SG3: Bulk-fill FCR + Nano	Fracture resistance: - Presence/absence of retention: p < 0.05. - Restorative material type: p <0,001 - Presence/absence of retention x restorative material type: p >0, 05 G1 SG1 > G2 SG1: p> 0,05 G1 SG2 < G2 SG2: p> 0,05 G1 SG3 < G2 SG3: p> 0,05	Retentive slots and restorative material type increased the FR of restored tooth. Short FRC with retentive slot increases in a significant way the FR by comparing with other materials with retentive slots.

		(above the CEJ or 1 mm apical to the CEJ) or non-restorable (vertical root fractures or 1 mm apical to the CEJ)	hybrid RC (Filtek) SG4: **Short FRC (EverX Posterior^{TM})** + Nano hybrid RC (Filtek)	G1 SG4 < G2 SG4: p< 0,05 → Short FRC + retentive slot had significantly higher FR than the other groups (p < 0.05). <u>Fracture mode:</u> p>0,05	
(Rodrigues et al. 2010) (22)	Evaluate the FR molar teeth with MOD with or without RCT, either associated with or without glass fibres (woven or unidirectional).	Application of compressive force (0,5mm/min) on the occlusal surface and touched buccal and lingual cusps parallel to the long axis of the teeth. Recording of the force required to fracture each tooth (Newton), deformation/dislocation curves, and failure mode. Classification with the failure mode (pulp chamber floor or cusp fracture) and the fracture mode (unrestorable - vertical extension of the pulp chamber floor, or restorable- the fracture line was partial, either vertically or horizontally)	6n= 90 molars maxillary G1: intact teeth G2: MOD G3: MOD + RCT G4: MOD + RCT + RC G5: MOD + RCT+ RC + **Woven fibre (bidirectional)** G6: MOD + RCT + RC + **Unidirectional fibre**	<u>Fracture resistance:</u> G1: FR highest (p<0,05) G3: FR lowest (p<0,05) G5>G2> G6>G4: FR intermediate (p<0,05 with G1 e G3; p> 0,05 from each other) <u>Failure mode:</u> G1, G2: 47% restorable (cusp fracture) G3, G4, G5, G6 (60-93,3%): High prevalence of pulp chamber floor fracture	The presence of a pulp chamber roof is a determining factor in the resistance of MOD preparations. The use of glass fibres (woven or unidirectional) didn't significantly increase the FR but demonstrated an improvement.

(Sangwan et al. 2016) (7)	Compare and assess the FR of RCT tooth restored with silver amalgam, posterior RC, posterior GIC, and miracle mix as coronal restorative materials.	Application of compressive force on the occlusal surface and touched buccal and lingual cups parallel to the long axis of the teeth. Recording of the force required to fracture each tooth (Newton)	5n= 75 1° PM G1: Intact teeth G2: Amalgam G3: Posterior RC G4: Posterior GIC. G5: Miracle mix	FR: G1 >G3 > G2 > G5 > G4 - G1 vs G3 G2 G5 G4 = FR significantly higher (p< 0,05 - Significant difference among all the materials compared with the G1 (p<0.05). - G5 vs G4: p > 0.05	The RC has the highest FR rate in RCT teeth compared to other materials, followed closely by amalgam.
(P. A. Oskoee et al. 2011) (20)	Evaluate the effect of using FRC (glass and polyethylene) at the gingival third of MOD cavities on the FR of RCT.	Application of compressive force (0,5mm/min) on the occlusal surface touched buccal and lingual cusps at 90 degrees, parallel to the long axis of the teeth. Recording of the force applied (Newton). Classification with the fracture pattern: favourable (coronal to CEJ) and unfavourable (apical to CEJ)	3N= 35 PM maxillary G1: RC (Filtek) G2: FCR (Filtek) + **glass fibre (Interlig® Fiber)** + RC (Filtek) G3: FCR (Filtek) + **polyethylene fibre (NSI)** + RC (Filtek)	<u>Fracture resistance:</u> G1 vs G2 vs G3: significant differences (p <0,05) G1 vs G2: statistically significant differences (p<0,05) G2 vs G3: statistically significant differences (p<0,05) G1 vs G3: not significant (p>0,05) --> Mean of FR: G3 > G1 > G2 <u>Fracture patterns:</u> G1, G2e G3= unfavourable >70%	The use of polyethylene Fb shows a significant difference in FR compared to using or not glass fibre at the gingival third. The use or not of glass Fb shows no significant difference. The use of FRC can benefit the increase in resistance to the invoice of teeth with RCT.
(Monaco, Bortolotto, and Antonio 2015) (23)	Evaluation of the marginal adaptation before and after thermocycling and cyclic	Application of compressive force (1,0mm/min) on the centre of occlusal surface at 90 degrees, parallel to the long axis of the teeth.	32 PM maxillary G1: RC overlay (Adoro, Ivoclar, Vivadent) G2: RC + **3 horizontally FRC layers (Vectris® Frame)** (bottom)	<u>Marginal adaptation :</u> Tooth / RC: no significant difference before and after the loading (p>0,05) RC / overlay:	No limitation of the marginal adaptation. FRC affects the FR = variation according to thickness and

	mechanic loading.	Recording of the force applied (Newton) at IF (initial failure) and FF (final failure). Classification of the failure mode: restoration chipping; restoration fracture; restoration and coronal fracture; restoration and irreparable fracture (below CEJ)	G3: RC + **6 horizontally FRC layers (Vectris® Frame)** (base) G4: RC + **FRC (Vectris® Frame)** (anatomically designed)	- before loading: no significant difference (p>0,05) - after loading: significant difference between G1 vs G2 / G3; G1 vs G4 → G1 < G4 < G3<G2 FR: G1<G2<G3<G4 → G3 and G4 difference statistically significative compared to G1 and G2 Failure mode: - G1 and G4: higher number of catastrophic failures (p> 0,05)	location. FRC affect the failure mode (no difference significative) partially.
(J. Bijelic-Donova et al. 2022) (2)	Investigate the clinical performance and survival rate of direct short RFC and indirect glass-ceramic Endo crowns in restoring RCT molars.	Restorations between Nov 2012 and Jan 2015. Evaluation at baseline and after 4.0 years (modified USPHS criteria): - Number of visits required for fabrication and maintenance. - Anatomical form - Marginal adaptation - Color match - Surface texture - Gingival inflammation - Secondary Caries - Occlusion - Patient satisfaction	2n= 18 n= 11 - G1: **short FRC (everX Posterior™)** + RC (G-aenial Posterior) n= 7 - G2: indirect endocrown restorations (IPS empress CAD)	Population: age +/- 43.4 years Anatomical form: no statistical differ- height and thickness Survival of the restoration: G1: 90.9% / G2: 85.7% Clinical evaluation: G2 > G1 (p> 0,05) Biological complication:p>005 Technical complication: G1 (36.4%) and G2 (14.3%). Maintenance G1 +/- 36 m and G2+/- 55 m Visits to create G1 = 1,45 / G2= 2,14	Short FRC and endocrown = viable for restoring RCT molars. Short FRC = fewer visits to create but more maintenance Endocrown = more visits to complete but less maintenance + best anatomical form and surface texture. Marginal integrity is similar.

(Akman et al. 2011) (15)	Compare mean cusp movement in molar teeth with CP and MOD cavities before and after restoration with several FRC restoration techniques under loading and evaluate the effect of restoration technique on FR.	Application of compressive force (5,0mm/min) on the centre of occlusal surface at 90°, parallel to the long axis. Recording of the force required to fracture each tooth (Newton). Classification with a fracture pattern: - I: Cusp or RC above CEJ - II: Vertical - not extend to the root (restorable) - III: Vertical - extend to the root (non-restorable) - IV: Vertical longitudinal fracture crown + root (non-restorable)	4n= 40 G1: RC (Clearfil) G2: FCR (Protect liner) + **2 FRC (Ribbond® - 3mm)** + RC (Clearfil) G3: RC (incremental technique) + In a groove (3mm x 1mm) = FCR + **FRC** inserted on surface O from buccal to lingual + RC (Clearfil) G4: Walls with RC + inner axial wall with FCR and **FRC +** RC (Clearfil)	<u>Cusp movement:</u> - G1 >G2, G3, G4: G2, G3 and G4 decrease in inter-cuspal ($p<0,05$) - G4<G3<G2: $p>0,05$ <u>Fracture resistance:</u> No significant difference was found amongst the fracture strength values ($p>0,05$) <u>Fracture patterns:</u> G1: 90% non-restorable G2: 80% restorable G3: 100% restorable	According to this study, FRC does not affect fracture resistance but decreases the rate of non-restorable fractures and cusp movement.
(Fráter et al. 2014) (11)	Evaluate the efficiency of a short FRC material compared to RC when restoring MOD cavities in molar teeth with different layering techniques.	Application of increasing load at the centre of the occlusal surface along the vertical axis of the tooth until the fracture (2 mm/min). Recording of the force required to fracture each tooth (Newton). Classification with a fracture pattern: restorable (above the CEJ) / non-restorable (below the CEJ).	5n= 130 3° M G0: intact teeth G1h: Composite horizontal G1o: Composite oblique G2h: **short FRC (EverX Posterior™)** Horizontal G2o: **short FRC (EverX Posterior™)** Oblique	<u>Fracture resistance:</u> - G0: Higher FR →G0 > G2o > G2h> G1o > G1h - G1 and G2: not significantly different from G0 or from each other. <u>Fracture pattern:</u> G1h: 46% restorable G1o: 50% restorable G2h: 50% restorable G2o: 62 % restorable	The use of Short FRC doesn't significantly increase the FR. The short FRC with oblique layering technique seems to have a high potential to increase FR and induce restorable fractures.

(Nagas et al. 2010) (19)	Evaluate the effect of 3 different intraorifice barriers on the FR of RCT with Resilon or gutta-percha.	Application of increasing load at the centre of the canal opening (1 mm/min). Recording of the force required to fracture each tooth (Newton).	2n= 80 PM Groups: G1: gutta percha + AH plus sealer G2: Resilon + epiphany Sealer Subgroups: SG1: MTA (Dentsply) SG2: Vitremer (3M/ESPE) SG3: **FRC (Ever stick net)** SG4: No barrier	<u>Fracture resistance:</u> - Type of intraorifice barrier (P < 0,05) - Type of obturation system used (P > 0,05) → SG1: no significant reinforcing effect (p>0,05) → SG2 and SG3: increased the FR (p<0,05); SG3> SG2 (p>0,05).	FRC or Vitremer can be a viable choice to improve the FR and decrease the rate of occurrence of post-RCT fractures.
(Tekçe et al. 2017) (24)	Evaluate: - Effect of direct or indirect polymerisation of adhesive-impregnated Ribbon on FR - Compare Ribbon with short FRC - The effectiveness of fibres according to the restorative materials used (bulk-fill, FCR or RC).	Application of increasing load at the restoration's occlusal surface until the fracture (1 mm/min). Recording of the force required to fracture each tooth (Newton) Classification of the types of fracture with a stereomicroscope : Mode I: Small portion of coronal Mode II: Small portion of coronal / restoration cohesion failure. Mode III: Root and Crown/restoration cohesion and/or adhesive failure (restorable) Mode IV: Severe root and crown (non-restorable)	7n= 70 1°molar mandibular G1: FCR & **Ribbond**® + 4mm SDR + RC (G aenial post) * G2: FCR & **Ribbond**® & 4 mm SDR + RC (G aenial post) * G3: FCR & **Ribbond**® + 2 mm RC (G aenial flow) + 2 mm RC (G aenial flow) * G4: FCR & **Ribbond**® + 2 mm RC (G aenial post) + 2 mm RC (G aenial post) * G5: 3mm **FRC (EverX Posterior™)** + 2 mm RC (G aenial post) * G6: unfilled cavity G7: intact teeth	<u>Fracture resistance:</u> Statistically significant differences in FR between the groups (P < 0.05): - G7: higher FR (P < 0.05) - G6: lower FR (P < 0.05) - G1 > G2> G5>G3 >G4: p>0,05 <u>Fracture patterns:</u> Mode IV (48)> Mode III (18)> Mode II (4) > Mode I (0) * Polymerisation between each stage (+)	Ribbond® or short FRC increased the FR but not as well as the results demonstrated by the intact teeth. Polyethylene ribbon fibre-reinforced + SureFil SDR (low-viscous BF) or G Aenial Flo Flowable (high-viscous flow) or G Aenial Posterior (conventional) shows similar capabilities of FR (p>0,05).

(Jasmina Bijelic-Donova et al. 2020) (21)	Evaluate the chewing FR of compromised molars restored with RC, with and without a short FRC (MOD) and with or without RCT.	Application dynamic loading on VM VL and PM until the fracture or to a maximum of 120 000 cycles. Application of increasing load at the restoration's occlusal surface until the fracture (1 mm/min). Recording of the force required to fracture each tooth (Newton) Classification of the types of fracture: I: Restorable (superficial fracture of the restoration) II: +/- Restorable (fracture of the tooth above CEJ) III: Non-restorable/ catastrophic (below the CEJ)	5N= 60 molars G1- intact teeth G2- Without TEC + RC (Gænial Posterior) G3- TEC + RC G4- Without TEC + **short FRC (EverX Posterior™)** + RC G5- TEC + **short FRC (EverX Posterior™)** + RC → oblique layering technique	<u>Chewing simulator:</u> - G1,2,3,4,5 = resistance to the chewing simulator. - TEC: p> 0,05 - Restoration type: p<0,05 G4 >G2: p<0,05 G5 > G3: p> 0,05 <u>Fracture mode:</u> - Short FRC: higher percentage of restorable fracture (p=0,05); 25 and 33% of non-restorable (Not TEC / TEC) - Only RC: 75% of non-restorable (RCT or not)	FRCs allow for a significant increase in chewing FR compared to intact and RCT teeth restored with RC; they also allow for a decrease in the catastrophic fracture rate (stops the propagation of the fracture below the CEJ).
(Costa et al. 2014) (25)	Compare a new adhesive technique with other conventional methods in the FR of RCT PM (MOD)	Application of increasing load on the palatal cusp at 45 ° of the root long axis until the fracture. Recording of the force required to fracture each tooth (Newton) and classification of the types of fracture: the direction (longitudinal, transverse or oblique) and the localisation (crown or root).	5n= 50 PM maxillary G1: intact teeth G2: RC G3: Fibre post + RC G4: **Ribbond® fibre** + RC G5: Fibre post + **Ribbond®** + RC	<u>Fracture resistance:</u> - G1 > G5 > G4: statistically similar (p>0,05) - G5 > G4 > G3: statistically similar (p>0,05) - G2 < G3: statistically similar (p>0,05) - G2 < G4<G5: statistically different (p<0,05) <u>Fracture patterns:</u> G1: 100% Crown,	Exist significatively differences in the FR in teeth with RCT restored with different direct techniques and intact premolars. → FRC restorations provide superior FR of premolars compared to conventiona

				G2: 60 % Root G3: 100% crown; G4: 70% crown; G5: 100% crown; Non-restorable fractures → just in G2 and G4.	l direct restoration (RC alone and post)
(Shah et al. 2020) (8)	Evaluate the FR of RCT maxillary PM restored with three different core materials - Conventional RC, Ribbond® and EverX Posterior™ in different CP (O, MO, MOD).	Fracture resistance testing: Application of increasing load on the centre of the occlusal surface in contact with buccal, lingual cusps and the restoration surface until the fracture (1 mm/min). Recording of the force required to fracture each tooth (Newton) Classification of the types of fracture with a stereomicroscope : - Favorable: above the CEJ - Unfavorable: below the CEJ	11n= 110 PM maxillary G1/ G2/G3: **EverX Posterior™**+ Classe I (O) / Classe II (MO)/ Classe II (MOD) G4/G5/G6: **Ribbond®** + Classe I (O) / Classe II (MO)/ Classe II (MOD) G7/G8/G9: Hybrid composite + Classe I (O) / Classe II (MO)/ Classe II (MOD) G10: Intact teeth G11: No restoration (MOD)	<u>Fracture resistance:</u> G10> other groups: p<0,05 EverX Posterior™, Ribbond® and hybrid composite: No difference with cavity design (P > 0.05). <u>Types of fracture:</u> EverX Posterior™ > Ribbond® > Hybrid composite.	In different CP on RCT PM, the use of FRC shows similar results. The use of FRC shows a higher proportion of favourable fracture than the other groups due to the presence of multiple fibres that will allow the crack to propagate from one fibre to another (decrease the intensity of the energy and stress distribution.
(Kemaloglu et al. 2015) (12)	Evaluate the FR of RCT premolars restored with these Short FRC and bulk-	Application of increasing load at the restoration's occlusal surface and cusps parallel to the long axis of the tooth until the fracture (1 mm/min).	4n= 48 PM mandibular G1: Nano-hybrid RC (Filtek)	<u>Fracture resistance:</u> G2 > G3> G1 > G4 G1 and 4: P> 0,05 G2 and 3: p> 0,05 G1, 4 / G2, 3: p< 0,05	FRC increased the FR of teeth with MOD and RCT compared to bulk-fill and

	fill RC (MOD)	Recording of the force required to fracture each tooth (Newton) Classification of the types of fracture with a stereomicroscope : - Favorable: above the CEJ - Unfavorable: below the CEJ	G2: FCR+ **Ribbond**® + N-H RC (Filtek) G3: **Short FRC (EverX Posterior™)** + N-H RC (Filtek) G4: Bulk-fill + N-H RC (Filtek)	Types of failures: - G1: 50%/50% - G2: 91% favourable - G3: 67%favourablee - G4: 60 % unfavourable - G1, G2 and G3: p>0,05 - G4: p<0,05	nano-hybrid RC. Fibres could be beneficial in increasing protection against unfavourable fractures = increase FR significantly compared to the other.
(Luthria et al. 2012) (26)	Evaluate the FR of RCT maxillary PM with MOD cavities restored with either RC, FRC (glass and polyethylene)	Application of compressive force (0,5mm/min) on the occlusal surface and touched buccal and lingual cusps at 90 degrees, parallel to the long axis of the teeth. Recording of the force required (to fracture each tooth (Newton).	1n=5 – G0: intact teeth 3n= 45 PM maxillary G1: Nano-hybrid RC (Filtek) G2: FCR+ **impregnated glass fibre (Interlig® Fiber)** + N-H RC (Filtek) G3: FCR + **Ribbond**® + N-H RC (Filtek)	Fracture resistance: G0 > G2, G1, G3 = 0.01 < p ≤ 0.05 G2>G1>G3: p>0,1	RCT and MOD CP significantly reduced FR of maxillary PM ⍰ Despite the absence of a significant result, the FRC with glass (Interlig®) shows an increase in FR.
(Garoushi and Lassila 2011) (16)	Investigate the reinforcement effect of Short E-glass fibre filler on fracture-related mechanical properties	**Experimental Short FRC resin is prepared: 22,5 short E glass fibre + 22,5 IPN resin + 55% Silane** Each tooth was loaded in a material testing machine (N) = load-deflection curves → FR, Compressive strength, and load-bearing ability.	4 n= 32 specimens: - bar (6mm x 3mmx25mm^3) - cylindrical (6mm x 3mm) - cubic (9,5 x 5,5 x 3mm^3) + Conventional RC (Grandio)	Fracture toughness: Short FRC vs RC: 14 MNm^-1,5 (dry storage) vs 2 MNm^-1,5 (dry storage) : p <0,05 Compressive strength: Short FRC vs RC: 129 MPa vs 112 MPa : p <0,05 Static load bearing: Short FRC vs RC: 1584 N vs 1031 N : p <0,05	FRC shows improved data leading to increased fracture resistance (significant differences). +: Wet storage decreases the capacity of both materials.

(Garoushi et al. 2013) (9)	Determine the physical properties (flexural strength, modulus; fracture toughness; polymerisation shrinkage) and curing depth of EverX Posterior^{TM} vs different posterior RC	- Flexural strength and modulus: Each tooth was loaded in material testing machine (N) = load-deflection curves. - Fracture toughness: calculated - Depth of cure - Polymerisation shrinkage - Fibre length measurement	Bulk-fill: X-tra base, Venus Bulk fill SDR Nano Bulk-fill: Filtek superme, TetricEvoCeram Bulk-fill condensable: Filtek Bull-fill Alert Hybrid Bulk-fill: Filtek Z250 Sonicfill Reinforced base: **XENIUS (EverX Posterior^{TM})**	Xenius base composite: FR > others: - SDR, Alert, SonicFill : p>0,05 - Filtek , X-tra base, venus bulk fill, TetrisEvoCeram : p<0,05 Flexural strength > others: - Filtek, Tetric, SDR, Venus BF: p<0,05 - X-tra base, Alert: p>0,05 Polymerisation shrinkage: Lower % (0.17%) compared to other (p<0,05) Depth of cure: 4.6 mm → like others (except TetricEvoCeram, Sonic, Alert	Based on in vitro research, the everX Posterior^{TM} shows improved data leading to increased FR. The everX Posterior^{TM} is suitable for high-stress areas.
(Touré et al. 2011) (1)	Prospectively investigate the reasons for the extraction of permanent endodontically treated teeth.	Information: 120 practitioners (randomly selected) Questionnaires were sent to the included practitioners by mail with a stamped envelope. - Information about the practitioner (age, gender, seniority) - Motive for consultation	N=33 practitioners N= 119 patients with a permanent tooth extracted after RCT.	Mean age of patient: 37,5 +/- 13,22 years Sexes: 50.9% of women Level of education: 25% university / 32,8% elementary school Smoker: no = 76% Cause of consultation: - dental mobility: 10,9% - trauma: 8,5% - dental pain: 68,9%	The leading causes of exodontia following an RCT are periodontal disease, non-restorable teeth, fracture vertical of the root or non-restorable of the crown and recurrent cavity. These types

		- Tooth or teeth extracted - Reason for extraction		- esthetics: 2,5% Teeth involved: 1°M mand >, 2°M mand >3°M mand >... Restorations without post (67.2%): amalgam (58%), composite (6.7%) ... Reason for extraction: Periodontal disease (40.3%), endodontic treatment failure (19.3%), vertical root fracture (13.4%), non-restorable cuspid and crown fracture (15.1 %) ...	of failures appear mainly in the lower molars at the level of the 1st and 2nd ...
(Rahman et al. 2016) (17)	Compare the different techniques of placement of polyethylene FRC (Ribbond®) of RCT teeth with MODs.	Application of compressive force (0,5mm/min) on the occlusal surface restoration and touched buccal and lingual cups at 90 degrees, parallel to the long axis of the teeth. Recording of the force required (to fracture each tooth (Newton) and classification of the types of fracture with a stereomicroscope : - Favorable: higher than 1 mm below the CEJ - Unfavorable: lower than 1 mm below the CEJ	4n=40 PM maxillary G1: RC (Filtek Z250 Sonic Fill) G2: FCR+ occlusal **Ribbond**® + RC G3: FCR+ base **Ribbond**® + RC G4 FCR + occlusal and base **Ribbond**® + RC	Fracture resistance: G4 > G3>G2>G1 → G4 Vs others: p<0,001 Types of failures: G1: 60% unfavourable G2: 80% unfavourable G3: 70% favourable G4: 60% unfavourable	Inserting polyethylene FRC in the restoration can increase the fracture resistance of the RCT tooth. Moreover, to obtain a maximum of favourable fractures, fibre placement is essential. The results show that when they are placed near the base, there is a decrease in unfavourable fractures.

5 Discussion

5.1 Definition and types of fibres

5.1.1 Definition

During chewing, the forces applied to a vital and unrestored tooth propagate through the enamel and are stopped by the DEJ (11). During the opening of the access cavity to perform root canal treatment, a portion of the dentin and this junction disappears, leading to micro-fractures in conjunction with the chewing forces that can ultimately lead to fractures in the long term.

The aim of restorative dentistry today is to recreate, with specific materials, the properties of an intact tooth (11).

5.1.2 Types of fibres

For this purpose, fibres have been introduced not only as inter radicular posts but also as fibres reinforced composite in the endodontic access cavity.

Firstly, the principle of fibre reinforced can be defined in two different ways:

- The primary way is the association between a first layer of fibre that serves as a cavity base with or without a flowable composite resin (FCR) and a second layer composed of a classical composite resin: nanohybrid or micro-hybrid (21).
- The second way is the incorporation of fibres directly into the composite resin; the product will be presented as a resin which will also be placed as a base in the cavity and covered by a standard composite resin as the first way (18).

The fibres used in modern dentistry today are primarily composed of glass and polyethylene.

On the one hand, glass fibres have a polymerisation shrinkage limit depending on the direction of the fibre, allowing the polymerisation source, i.e. light, to be transferred throughout the restoration (2,21). Furthermore, Fb glass has high reinforcement capacity, aesthetics, tensile strength, and percentage of elongation (11,26). However, as it is stiffer, it does not easily adapt to the walls of the cavity (10).

On the other hand, polyethylene fibres have a very high modulus of elasticity, similar to dentin and a low modulus of flexibility, which allows for easy bonding with the dentin and the restorative material (3,6).

In this study, different types of fibres with varying forms of presentation or brands have been used:

Table 5: Types of materials

Types of fibres	Materials	Composition	Protocols	Properties	Studies
Glass fibres	Vectris®, Ivoclar Vivadent ➔ Pre - impregnated translucent glass fibre mesh = Several layers of continuous bidirectional wafers and woven bundles based in an E-glass fibre system + embedded in an organic polymer matrix → Fibre orientation: braided.	-Dimethyl-acrylate (44 to 46 wt%) - Glass Fb (49 to 51 wt %) - Silicon dioxide (5 to 6wt %) E- glass fibre system = SiO2-Al2-O3-CaO-MgO	1. 3mm x10 mm of fibres over the FCR to the buccal, lingual walls and floor. + polymerisation (20s) 2. Hybrid composite (incremental technique) + polymerisation 40s	- Fibres bindles maintain orientation and don't separate from each other - Adapts to the shape of the cavity - PMMA: increases the capacity to connect the glass to the RC. Increases the capacity to connect the glass to the RC. - Orthotropic behaviour (mechanical properties are different in all directions) - Favourable elastic modulus	*(Monaco et al. 2016; Monaco, Bortolotto, and Antonio 2015; Khan et al. 2013)* (4,6,23)
	Interlig®, Angelus ➔ Glass Fibres pre-impregnated in light curable RC → Fibre orientation: braided	- 3 mm glass Fibres (60 +/- 5 wt %) - Nanohybrid FCR (40 +/- 5 wt %): BisGMA, diurethane, barium glass, silicon dioxide, catalysts.	1. FCR + glass Fb (10mm) on the floors + vestibular and lingual walls + polymerisation (20s) 2. Hybrid composite (incremental technique) + polymerisation 40s	- Good bond with the RC - Contain interlaced glass → increase the impact strength	*(Eapen et al. 2017; P. A. Oskoee et al. 2011; S. S. Oskoee et al. 2012; Luthria et al. 2012)* (10,14,20,26)

	EverStick® NET, Stick Tech Ltd => Fibre network pre-impregnated in a resin. → Fibre orientation: bidirectional.	- E-glass Fb - Bis-GMA - PMMA	1. FCR + 10mm long and 4 mm wide glass Fb + polymerisation 40s 2. Hybrid composite (incremental technique) + polymerisation 20s	- High flexural strength - Elastic modulus similar to dentin (high modulus) - Good adhesive properties on the surface	*(Gokce and Basaran 2019; Nagas et al. 2010)* (5,19)
	EverX Posterior™ (GC company) ➔ Short FRC resin = multitude and randomly oriented short E-glass (0,3-1,9mm) and inorganic particulate Fb incorporated in a resin matrix. → Fibre orientation: woven.	Resin matrix: Semi-interpenetrating network: Bis-GMA, TEGMA, PMMA Fillers: 74.2wt%/53.6vol % Particle: E-glass (8,6 wt%/ 7,2 vol %), barium borosilicate, silicon dioxide, photoinitiator.	1. Product added until 1,5-2mm below the occlusal level (incremental technique) + polymerisation 20s 2. Hybrid RC (1mm) + polymerisation 40s	- Isotropic reinforcement in multiple directions. - The load bearing and the thickness layer work proportionally - Capacity of polymerisation: 4-5 mm thick - Easy handling - Good bonding properties - High viscosity - Short fibres reduce polymerisation contraction (0,17%) - Excellent biomimetic properties	*(Eapen et al. 2017; Özyürek et al. 2018; Yasa et al. 2016; J. Bijelic-Donova et al. 2022; Jasmina Bijelic-Donova et al. 2020; Fráter et al. 2014; Tekçe et al. 2017; Shah et al. 2020; Kemaloglu et al. 2015; Garoushi et al. 2013)* (2,8–13,18,21,24)

Polyethylene fibres	Ribbond®, Ribbond Inc. → Spectrum of 215 fibres →Arrange in lock stitch design. → Fibre orientation: woven.	Leno woven ultrahigh molecular weight polyethylene fibre – homopolymer ((H-CH2-CH2)n-H) → Treated with cold plasma	1. FCR + 10mm long and 3 mm large Ribbond® on the pulpal floor, buccal and lingual walls of the cavity + polymerisation 40s 2. Hybrid composite (incremental technique) + polymerisation 20s	- Ultrahigh elasticity - Low flexural modulus - High strength - High adhesion to the structure (cold plasma) - Micro tensile bond strength - Load transfer to sound part (multitude paths) - High concentration of nodal intersection (integrity) - Orthotropic reinforcement - Excellent aesthetics -Biocompatible	*(Aslan et al. 2018; Khan et al. 2013; Akman et al. 2011; Tekçe et al. 2017; Costa et al. 2014; Shah et al. 2020; Kemaloglu et al. 2015; Luthria et al. 2012; Rahman et al. 2016)* (3,6,8,12,15,17,24–26)
	Ribbon, NSI Dental PTY, Hornsby, → Fibre orientation: braided.	Fibre braided pre-impregnated polyethylene fibre	1. FCR + 0,3 mm thickness on the pulpal floor, buccal and lingual walls of the cavity + polymerisation 40s 2. Hybrid composite (incremental technique) + polymerisation 20s	- High modulus of elasticity - Low flexural modulus	*(P. A. Oskoee et al. 2011)* (20)

5.2 Fracture resistance and types of fractures with fibre-reinforced composite according to the types of fibres.

In his 2016 study, Sangwan demonstrated that composite resin, among all direct restoration materials in the case of endodontically treated teeth, exhibits the highest fracture resistance rate, followed by amalgam (7). On average, in this author's study, the composite resin exhibits a fracture resistance rate of 845.46 ± 47.36 N (7). Despite this favourable property compared to indirect restorations, the composite resin is still considered a material with low fracture resistance under high stress (14). Furthermore, according to Bijelic Donova in 2020, direct composite resin restorations often lead to catastrophic fractures despite exhibiting a rather satisfactory fracture resistance (21). These fractures are not reparable and, in most cases, would result in the extraction of the devitalised tooth.

5.2.1 Polyethylene fibres

Fracture resistance:

Most studies included in this systematic review suggest that Ribbond®, which was previously introduced, has a significantly higher rate of fracture resistance compared to standard composite resin (3,6,25). Furthermore, Ribbond® has been found to have a similar fracture resistance to intact, non-endodontically treated teeth, possibly due to its ability to reduce cuspal deflection (3,6,25).

Fracture patterns:

This polyethylene fibre would not only enhance the restoration's strength but also affect the type of fracture. Indeed, the fracture pattern will not only determine where the fracture takes place when it took place but will help define its ability to be restored and thus preserve the tooth. For example, teeth with horizontal coronal or vertical fractures above the CEJ are considered restorable, while vertical or horizontal fractures below the CEJ reaching the root are non-restorable (15). According to Akman's 2011 study, the RCT tooth restored with an unreinforced composite resin has just 10% post-restorability fracture, whereas polyethylene fibre-reinforced teeth have a much higher rate of restorability (80%-100%)(15).

5.2.2 Glass fibres

Fracture resistance:

In their respective studies, conducted in 2017, 2014, 2010 and 2010, the scientists Eapen, Fráter, Rodrigues, and Nagas have demonstrated that short or impregnated glass fibres present in the reinforced composite have a significant or non-significant resistance enhancement capability when compared with non-reinforced endodontic cavities (10,11,19,22).

The effect of using EverX Posterior™ compared to standard RC on tooth strength has been investigated by several authors, including Fráter (2014), Eapen (2017), and Bijelic Donova (2020), with mixed results (10,11,21). While Fráter found a non-significant increase in tooth strength, Eapen and Bijelic Donova demonstrated a significant improvement, suggesting a potential benefit of using EverX Posterior™ in dental restoration (10,11,21).

In 2018, Özyürek compared a posterior composite resin (SDR) and EverX Posterior™ and obtained contradictory results; he observed that SDR had a higher fracture resistance than EverX Posterior™ (18). He lends these results to the fact that EverX Posterior™ has a higher viscosity rate, a layering technique different from the other studies, and difficulty handling the resin (18).

Resin-impregnated glass fibres, such as Everstick® net and Vectris®, demonstrate a significant increase due to their ability to diffuse much of the stress received to the intact areas of the crown before diffusing the remaining load to the root (6,19).

A non-significant increase in non-impregnated glass fibres was observed when comparing woven or unidirectional glass fibres with non-reinforced composite resins by Rodrigues in 2010 and in pre-impregnated glass fibres when comparing Interlig®, EverX Posterior™ and standard resins by Eapen in 2017 (10,22).

According to these authors, this decrease in the reinforcement capacity of the pre-impregnated and non-impregnated glass fibres compared to EverX Posterior™ is due to the flowable composite resin (10,22). This FCR has an elastic modulus of 6 mgA, which is lower than the elastic modulus of dentin, which would result in the creation of porosity at the fibre/restoration interface and a lack of dispersion of masticatory charges (10,22). In addition, EverX Posterior™, which is not only a fibre but a pre-incorporation of tiny fibres into a composite resin to create an entirely new restorative material, would allow for better adaptation to the walls and resin of the fibres (10).

Fracture patterns:

According to Eapen in 2017, EverX Posterior™ shows an improvement in the type of fracture, i.e., its ability to be repaired after its occurrence; this resin would allow going from a fracture that reach the enamel and the dentin (Interlig® and standard RC) to a fracture that would reach only the enamel (10). In addition, Bijelic Donova, in 2020, demonstrated that EverX Posterior™ reduces the 75% non-restorable fracture rate in standard techniques to 33% (21).

5.2.3 Polyethylene fibres vs Glass fibres

Fracture resistance:

Several of the authors included in this study compared and analysed the effects of polyethylene fibres and glass fibres on the fracture resistance of root canal-treated teeth. In 2013, Khan and his co-authors used various products such as Ribbond® (polyethylene fibre) and Vectris® (glass fibre) (6). The result of this study shows that there is no significant difference between fibre-using groups (6). Ribbond® has a high modulus of elasticity and a low modulus flexural compensating the effect of Vectris®, a pre-impregnated fibre in PMMA that will increase its ability to link its fibres and resin incremental composite (6). These properties reduce the shrinkage rate of the composite and thus increase the stress tolerance threshold (6).

In 2012 and 2017, the authors Luthria and Tekçe obtained similar results by comparing Interlig® and Ribbond; short glass FRC (EverX Posterior™) and polyethylene fibre (Ribbond®)(24,26), respectively. In 2012 Luthria's research, despite this lack of significant difference, Interlig® has a higher rate of FR due to the impregnation, which allows a better adhesion compared to the Ribbond®, which due to its complex handling because of its cold plasma treatment that makes it difficult to imbibition of FCR during the placement in the cavity (26). Moreover, the polyethylene fibre, compared to the glass fibre, presents a higher elongation density and low tensile strength (26).

In 2011, Oskoee had previously compared polyethylene fibres (NSI) to glass fibres (Interlig®), both pre-impregnated in resin (20). In contradiction with the results of Luthria, he had analysed, in 2012, a significant difference between NSI and Interlig®, polyethylene being more resistant than glass (20,26). This analysis would show that the pre-impregnation of polyethylene fibres by the manufacturer would allow better adhesion and thus increase the resistance of the restoration (20).

5.3 Fracture resistance and types of fractures with fibre-reinforced composite according to other factors

5.3.1 Comparison with intra-radicular posts

Vertical intra-radicular post is a metal or fibre-based dental material used in the case of endodontic teeth to help retain restoration by anchoring in the root. These vertical intra-radicular posts are placed inside the root canal, which will lead to the additional removal of dentin, further reducing the strength of the tooth (3). There is agreement among the researchers that the post is not installed to increase fracture resistance but to improve restoration retention.

This is why some authors included in this study have compared the fibres and the vertical posts of the FR; they all concluded a significant increase in the groups possessing the FRC (3).

In 2018, it has been demonstrated by Aslan that there is a notable distinction between Ribbond® and the vertical post, but not between Ribbond® and the horizontal posts (3). This difference may be attributed to the fact that the vertical post conceals the removal of a greater amount of tissue (3).

Furthermore, Gockce and Basaran's research, published in 2019, indicated a marked contrast between Evert Sick Net (glass fibre) only when it had an occlusal placement (5). On the contrary, when these fibres are placed at the base of the cavity, they produce post-like results (5).

Meanwhile, in 2014, Costa and his colleagues demonstrated that using Polyethylene Ribbond® fibres alone or in combination with posts significantly reinforces composite resin compared to using standard composite resin alone (25). However, when comparing the results of Ribbond® and posts, Ribbond® exhibits a non-significant superiority (25).

5.3.2 According to the wall thickness and retention

During endodontic treatment, reducing healthy tissues and walls can have significant implications for the future of endodontically treated teeth. As a result, many researchers have examined the thickness of walls and retention systems that could reduce the rate of restoration movement (13).

5.3.2.1 Wall thickness

In 2019, Gockce and Basaran demonstrated in their study that when the reminiscent walls are 2mm or 1mm thick, it is not necessary to use additional material (5). In the case of 2mm walls, sufficient dental structure, fibre addition or posts are not required to decrease the fracture rate (5). In the case of the 1mm, which has shown a substantial decrease in resistance, adding additional material will not be necessary because the dental structure is so thin that the effect of such materials will not be sufficient (5). In the same study, they also demonstrated that the 1.5 mm reminiscent walls and additional materials cause significant differences (5).

5.3.2.2 Access cavity

In the same vein as Gockce and Basaran, Özyürek, in 2018, studied a method for opening access to root canals called the conservative endodontic cavity (CEC); this technique would preserve a part of the floor of the pulp chamber (18). The CEC, compared to TEC, demonstrates in Özyürek’s 2018 study an ability to raise the restorable fracture rate (18). This research shows no significant difference in the strength of the fracture between a CEC and a TEC but that combining fibres with the CEC would lead to a capacity of post-restoration upper fracture than with a conventional access cavity (18).

5.3.2.3 Retention systems

The addition of retention systems, such as foundations, with fibres will lead to a decrease in the rates of irreparable fractures; a significant increase in the FR reducing coronal deflection (4). In addition, slot placement in the cavity would allow the creation of a mechanical interlocking, significantly increasing the transfer surface of forces between the tooth and the composite resin (13). In Yasa's study achieved in 2016, the use of slot in combination with EverX Posterior^{TM} shows a significant increase in fracture resistance compared to other groups (13).

5.3.3 According to the position in the cavity and the quantity

5.3.3.1 Position

The technique of positioning the fibres, as well as their quantities, can create variations in the working capacity of the fibres and an increase in the resistance of the tooth with a root canal treatment (5).

In the 2019 Gokce and Basaraan study, the position of the glass fibres in occlusal causes an increase in this resistance (5). It previews the formation of catastrophic fractures while the placement on the ground of the cavity does not cause any significant difference (5). In a separate study completed in 2016 by Rahman et al., the incorporation of Ribbond® (polyethylene fibre) in occlusal, basal, and both locations demonstrated an increase in resistance (17). Nevertheless, using both occlusal and basal sites led to the greatest increase in resistance (17). Rahman (2016) further observed that using fibres at the base would significantly reduce the catastrophic fracture rate (17). These findings align with the 2012 SS Oskoee investigation (14,17). His investigation shows that the fibres of glasses placed at 1/3 occlusal increase the resistance, due to the position of the fibres at a close position to the point where the force is applied and its ability to keep cups close; while when placed in 1/3 gingival position; the results were not significant (14).

5.3.3.2 Quantity

In 2015, Monaco and his co-authors combined the position of the fibres and analysed the number of fibres in the same study. (23). In their research, these researchers found that teeth with glass fibres adapted to occlusal show an excellent resistance rate, followed by the six horizontal fibres placed on the cavity floor (23). These two groups demonstrated a significant difference compared to the absence of fibres and the use of only three horizontal fibres. Furthermore, there was a tendency towards a higher rate of restorable fractures with the help of six FRC, with 62.5% exhibiting restorable condition (23).

5.4 Limits

5.4.1 Methods of research

Research for this study resulted in the loss of some relevant articles, such as limitations until 2010 or keywords used. This limit has been reduced thanks to the internal searches of the bibliographies of the selected articles.

5.4.2 The study protocols of the integrated articles

The theme of this systematic review leads to the presence of different limits, such as the various fibres used, the presence of impregnation or not, the placement of fibres, the restoration techniques, the resins used, and the storage of the material. In addition, the variation in the root canal treatment depends on the professionals applying the protocol and factors such as moisture effect, irrigation, loss of structure, anatomical variation of teeth and handling of materials.

5.4.3 Long-term studies

In addition, the force on the teeth during in vitro tests varies enormously with the forces applied in vivo; these studies do not perfectly replicate the oral condition. Mastication and occlusion forces in vivo will depend on the position of adjacent teeth, of the dynamic or static occlusion, as well as external factors such as bruxism. The presence of a unique in vivo study shows that there are still very few studies demonstrating the long-term effectiveness of these fibres in the case of post-endodontic restoration. Further, in vivo studies should be used to estimate whether composite-reinforced fibres are the additive materials of choice.

6 Conclusions

To achieve a restoration that increases fracture resistance and makes it more durable over time, type of fibres, amount of retentive walls, retention systems, as well as position and quantity of fibres, have proven to be essential factors that cannot be ignored:

- Comparing the capacities of different fibres, glass fibres and standard resin composite produce a minor reinforcement than EverX Posterior^{TM} (short glass FRC) and pre-impregnated polyethylene fibres.
- Using fibres on walls smaller than 1 mm and larger than 2 mm is reciprocally insufficient or unnecessary but can be helpful with 1,5 mm walls. The conservative method (CEC) could be a method to limit this decrease in the dental structure.
- The restoration retention would reduce the rate of dental fracture but not only in the case of fibre use.
- The placement and the quantity of the fibres in the cavity showed a significant variation in strengthening capacities.

Despite some discrepancies, the case of fibres for composite reinforcement of root canal-treated teeth may be an interesting choice to increase fracture resistance and/or protection against the development of unrepairable fractures.

That's why it's necessary to have additional research to determine the ideal parameters (composite and adhesive used jointly, position and quantity of fibres) and further in vivo studies to demonstrate those fibres' long-term effectiveness in the case of post-endodontic restoration.

7 References

1. Touré B, Faye B, Kane AW, Lo CM, Niang B, Boucher Y. Analysis of reasons for extraction of endodontically treated teeth: A prospective study. J Endod. 2011;37(11):1512–5.

2. Bijelic-Donova J, Myyryläinen T, Karsila V, Vallittu PK, Tanner J. Direct Short-Fiber Reinforced Composite Resin Restorations and Glass-Ceramic Endocrowns in Endodontically Treated Molars: A 4 -Year Clinical Study. Eur J Prosthodont Restor Dent. 2022 Nov 30;30(4):284–95.

3. Aslan T, Sagsen B, Er O, Ustun Y, Cinar F. Evaluation of fracture resistance in root canal-treated teeth restored using different techniques. Niger J Clin Pract. 2018 Jun 1;21(6):795–800.

4. Monaco C, Arena A, Scotti R, Krejci I. Fracture Strength of Endodontically Treated Teeth Restored with Composite Overlays with and without Glass-fiber Reinforcement. 2016;18(2).

5. Gokce Y, Basaran ET. Evaluation of the influence of various restoration techniques on fracture resistance of endodontically treated teeth with different cavity wall thicknesses. Niger J Clin Pract. 2019 Mar 1;22(3):328–34.

6. Khan SI, Anupama R, Deepalakshmi M, Kumar KS. Effect of two different types of fibers on the fracture resistance of endodontically treated molars restored with composite resin. J Adhes Dent [Internet]. 2013 Apr;15(2):167–71. Available from: http://www.ncbi.nlm.nih.gov/pubmed/23534017

7. Sangwan B, Rishi R, Sea M, Jain K, Dutt P, Talukdar P. An in vitro evaluation of fracture resistance of endodontically treated teeth with different restorative materials. Journal of Contemporary Dental Practice. 2016;17(7):549–52.

8. Shah S, Shilpa-Jain DP, Velmurugan N, Sooriaprakas C, Krithikadatta J. Performance of fibre reinforced composite as a post-endodontic restoration on

different endodontic cavity designs— an in-vitro study. J Mech Behav Biomed Mater. 2020 Apr 1;104.

9. Garoushi S, Säilynoja E, Vallittu PK, Lassila L. Physical properties and depth of cure of a new short fiber reinforced composite. Dental Materials. 2013;29(8):835–41.

10. Eapen AM, Amirtharaj LV, Sanjeev K, Mahalaxmi S. Fracture Resistance of Endodontically Treated Teeth Restored with 2 Different Fiber-reinforced Composite and 2 Conventional Composite Resin Core Buildup Materials: An In Vitro Study. J Endod. 2017 Sep 1;43(9):1499–504.

11. Fráter M, Forster A, Keresztúri M, Braunitzer G, Nagy K. In vitro fracture resistance of molar teeth restored with a short fibre-reinforced composite material. J Dent. 2014;42(9):1143–50.

12. Kemaloglu H, Emin Kaval M, Turkun M, Micoogullari Kurt S. Effect of novel restoration techniques on the fracture resistance of teeth treated endodontically: An in vitro study. Dent Mater J. 2015 Oct 5;34(5):618–22.

13. Yasa B, Arslan H, Yasa E, Akcay M, Hatirli H. Effect of novel restorative materials and retention slots on fracture resistance of endodontically-treated teeth. Acta Odontol Scand. 2016 Feb 17;74(2):96–102.

14. Oskoee SS, Oskoee PA, Navimipour EJ, Ajami AA, Zonuz GA, Bahari M, et al. The effect of composite fiber insertion along with lowshrinking composite resin on cuspal deflection of root-filled maxillary premolars. Journal of Contemporary Dental Practice. 2012;13(5):595–601.

15. Akman S, Akman M, Eskitascioglu G, Belli S. Influence of several fibre-reinforced composite restoration techniques on cusp movement and fracture strength of molar teeth. Int Endod J. 2011 May;44(5):407–15.

16. Garoushi S, Lassila L. Fracture Toughness, Compressive Strength and Load-bearing Capacity of Short Glass Fibre-reinforced Composite Resin [Internet]. 2011. Available from: https://www.researchgate.net/publication/51472835

17. Rahman H, Singh S, Chandra A, Chandra R, Tripathi S. Evaluation of fracture resistance of endodontically treated teeth restored with composite resin along with fibre insertion in different positions in vitro. Australian Endodontic Journal. 2016 Aug 1;42(2):60–5.

18. Özyürek T, Ülker Ö, Demiryürek EÖ, Yılmaz F. The Effects of Endodontic Access Cavity Preparation Design on the Fracture Strength of Endodontically Treated Teeth: Traditional Versus Conservative Preparation. J Endod. 2018 May 1;44(5):800–5.

19. Nagas E, Uyanik O, Altundasar E, Durmaz V, Cehreli ZC, Vallittu PK, et al. Effect of different intraorifice barriers on the fracture resistance of roots obturated with resilon or gutta-percha. J Endod. 2010;36(6):1061–3.

20. Oskoee PA, Chaharom MEE, Kimyai S, Oskoee JS, Varasteh S. Effect of two types of composite fibers on fracture resistance of endodontically treated maxillary premolars: An in vitro study. Journal of Contemporary Dental Practice. 2011;12(1):30–4.

21. Bijelic-Donova J, Keulemans F, Vallittu PK, Lassila LVJ. Direct bilayered biomimetic composite restoration: The effect of a cusp-supporting short fiber-reinforced base design on the chewing fracture resistance and failure mode of molars with or without endodontic treatment. J Mech Behav Biomed Mater. 2020 Mar 1;103:103554.

22. Rodrigues FB, Paranhos MPG, Spohr AM, Oshima HMS, Carlini B, Burnett LH. Fracture resistance of root filled molar teeth restored with glass fibre bundles. Int Endod J. 2010 May;43(5):356–62.

23. Monaco C, Bortolotto T, Antonio /. Restoring Nonvital Premolars with Composite Resin Onlays: Effect of Different Fiber-reinforced Composite Layers on Marginal Adaptation and Fracture Load. J Adhes Dent. 2015;17(6):567–74.

24. Tekçe N, Pala K, Tuncer S, Demirci M, Serim ME. Influence of polymerisation method and type of fibre on fracture strength of endodontically treated teeth. Australian Endodontic Journal. 2017 Dec 1;43(3):115–22.

25. Costa S, Silva-Sousa Y, Curylofo F, Steier L, Sousa-Neto M, Souza-Gabriel A. Fracture resistance of mechanically compromised premolars restored with polyethylene fiber and adhesive materials. Int J Adhes Adhes. 2014 Apr;50:211–5.

26. Luthria A, Srirekha A, Hegde J, Karale R, Tyagi S, Bhaskaran S. The reinforcement effect of polyethylene fibre and composite impregnated glass fibre on fracture resistance of endodontically treated teeth: An in vitro study. Journal of Conservative Dentistry. 2012 Oct;15(4):372–6.