Les facteurs influençant la formation de fissure et de fracture des dents traitées endodontiquement: une revue

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" LES FACTEURS INFLUENCANT LA FORMATION DE FISSURE ET DE FRACTURE DES DENTS TRAITEES ENDODONTIQUEMENT : UNE REVUE "

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RESUME

Objectif: Les buts de cette étude étaient de (1) procéder à une analyse des facteurs influençant l'initiation et la propagation de fissures ainsi que de la susceptibilité à la fracture des dents traitées endodontiquement, (2) isoler et quantifier les facteurs les plus cités.

Matériel et méthodes: Une revue systématique de littérature a été éffectuée en utilisant MEDLINE via PubMed, la bibliothèque Cochrane et Google Scholar. Des publications suggérées par des collègues ont également été integrées. Les termes de recherche ont été déterminés à l'aide du navigateur MeSH, puis combinés à l'aide d'opérateurs Booléens. 612 références ont été identifiées et 44 articles ont été retenus en fonction de leurs résumés et des critères de sélection préétablis pour l'analyse qualitative (nombre et type de facteurs). Une analyse quantitative a été effectuée sur 10 articles afin de déterminer lequel des facteurs les plus cités (càd preparation et obturation canalaire) contribuait le plus à la formation de fissures. Les articles pour cette analyse ont été selectionnés par deux examinateurs indépendants en se basant sur des critères d'admissibilité préétablis. Les données ont été extraites à l'aide d'une fiche d'extraction de données puis soumises à une analyse du «taux d'évenément» et à une analyse de «rapport des cotes». L'hypothèse nulle était qu'il n'y avait pas de différence significative entre la formation de fissures due à la préparation canalaire et la formation de fissures due à l'obturation canalaire. Le logiciel SPSS/PC version 13 a été utilisé pour les analyses.

Résultats: Huit facteurs de risque ont été identifiés et classifiés comme contrôlables ou non-contrôlables. Les facteurs les plus cités étaient la préparation et l'obturation canalaire. L'analyse quantitative a montré que 24.9% de dents présentaient une fissure après la préparation et que 43.7% de dents en présentaient après l'obturation. Cependant, la différence n'était pas significative (p=0.055). L'hypothèse nulle n'a pas été rejetée.

Conclusions : L'analyse qualitative a montré que l'étiologie est multifactorielle. L'analyse quantitative a également montré que les procédures endodontiques (préparation et obturation) contribuaient considérablement à l'initiation de fissures. Il ressort de cette étude l'importance de différencier le phénomène d'initiation de

fissure à celui d'affaiblissement global de la dent, qui est souvent mesuré par la résistance à la fracture. En effet, l'initiation à la fissure est une mesure cliniquement et biologiquement plus pertinente que la résistance à la fracture dans la mesure où l'action préventive se fait en amont et que le pronostic de dents fracturées est très défavorable. Cette étude montre également l'importance pour le praticien de prendre en compte les facteurs non-contrôlables et d'agir sur les facteurs contrôlables pour une approche thérapeutique cohérente.

Mots clés : Fissures, traitement de racine, traitement endodontique, fractures, défauts dentinaires

INTRODUCTION

La fracture dentaire est un problème majeur en dentisterie. En effet, elle représente la troisième cause la plus fréquente d'extraction après la carie et les maladies parodontales[1,2]. L'Association Américaine d'endodontie a défini 5 types de fissures dentaires en fonction de la localisation, l'étendue et la direction[3]. Cette terminologie, qui est généralement acceptée par les cliniciens et les scientifiques, ne fait pas de distinction claire entre fissures et fractures car elle considère la fracture comme étant une «conséquence ultime» de la propagation d'une fissure.

Les dents présentant des fissures ou des fractures peuvent être asymptomatiques ou symptomatiques. Lorsque des symptômes sont présents, les patients se plaignent de douleurs d'intensité variable dont l'origine est souvent difficile à identifier tant pour le patient que pour le clinicien[4]. De plus, les images radiographiques ne permettent pas une détection précoce des fissures[5]. Par conséquent, un diagnostic tardif et/ou erroné de fissure dentaire est un problème courant qui peut conduire à une fracture et à une extraction de la dent en question.

Des études montrent que les dents traitées endodontiquement sont plus sujettes aux fractures, notamment aux fractures radiculaires verticales (FRV), que les dents vivantes[6,7]. Les FRV sont généralement complètes, irreversibles et présentent une longueur variable originant de la racine généralement dans le sens bucco-lingual et pouvant s'étendre jusqu'à la couronne[8-11]. La très grande majorité du temps, une dent présentant une FRV est condamnée à l'extraction. Il est évident que les dents endodontiques sont souvent structurellement compromises, cependant, à l'heure actuelle, il n'y a pas de consensus scientifique pouvant expliquer la prévalence de

fractures dans ce groupe. En effet, les proprietés mécaniques des dents endodontiques ne peuvent que partiellement expliquer ce phénomène[12,13].

La gestion d'une fracture est souvent difficile, invasive et agressive. Il s'agit donc de prévenir plutôt que de traiter la fracture. Cependant, avant de prendre des mesures de prévention, il faudrait avoir une meilleure compréhension des facteurs de risque de fissures/ fractures des dents endodontiques, afin d'aider le praticien à faire un choix thérapeutique cohérent. Dans cette optique, cette étude a cherché à valider certains facteurs et à en identifier d'autres.

L'objectif de cette étude était (1) d'effectuer une revue systématique des études antérieures concernant cette problèmatique afin d'en identifier l'étiologie, (2) d'éffectuer une analyse quantitative comparant et contrastant les facteurs les plus cités dans la revue systématique. Pour ce faire, des analyses du taux d'événement et de rapport des cotes ont été effectuées.

L'hypothèse nulle de l'analyse quantitative était qu'il n'y avait pas de différence significative dans l'initiation de fissure quelque soit le facteur cité.

MATERIEL ET METHODE

Formulation de la question clinique

Cette étude a porté sur l'étiologie des fissures et des fractures des dents traitées endodontiquement. Nous avons tenté de déterminer les facteurs de risques, ainsi que le facteur de risque le plus important. Le résultat de cette étude était donc indésirable (fissure/fracture). Nous avons utilisé l'approche « PICO » (participants, intervention, comparateur et "outcome" ou résultat) suggérée par la revue Cochrane pour formuler la question clinique[49]. Dans notre cas, les participants étaient les dents, l'intervention était le traitement endodontique, le comparateur était l'absence de traitement endodontique et le résultat était la fissures/fracture.

Question d'étude

Pour quelle(s) raison(s) les dents endodontiques sont-elles plus susceptibles aux fissures et aux fractures que les dents non-endodontiques?

Combinaison de recherche

		AND
	Concept 1	Concept 2
	root canal therapy	dental fissure
Subject Heading (MeSH Terms)		tooth fracture
	OR	OR
Text Words	endodontic*.tw. (éliminé)	dent* defect*.tw.
		OR
		dent* crack*.tw.

Recherche littéraire

La recherche de literature a été effectuée en anglais, en utilisant MEDLINE via PubMed, la bibliothèque Cochrane et Google scholar. Des articles ont également été suggerés par des collègues. Les termes de recherches ont été determinés en utilisant l'explorateur « MeSH » et ensuite combinés en utilisant des opérateurs Booléens.

La recherche a été effectuée de la façon suivante:

1- Recherche des « MeSH headings » pour une recherche explosée: Root canal therapy, Dental fissure et Tooth fracture

Recherche des « text words » (tronqué): endodontic*, dent* defect*, dent* crack*

2- Combinaison en utilisant « OR » a mené au Concept 1 (# 1) et au Concept 2 (# 2)

3- Combinaison avec « AND » des deux concepts: # 1 AND # 2

4- Filtres additionels: Human + Dental journals

5- Résultats: 1302 citations

Le ratio sensibilité/precision étant trop grand, le mot « endodontic » a donc été supprimé.

6- Augmentation de la précision en utilisant la combinaison suivante:

Root canal therapy [mh:exp]= concept 1

Dental fissure [mh:exp] OR Tooth fracture [mh:exp] "dent* defect*".tw. OR "dent* crack*".tw. = concept 2

Concept 1 AND Concept 2 = 987 citations

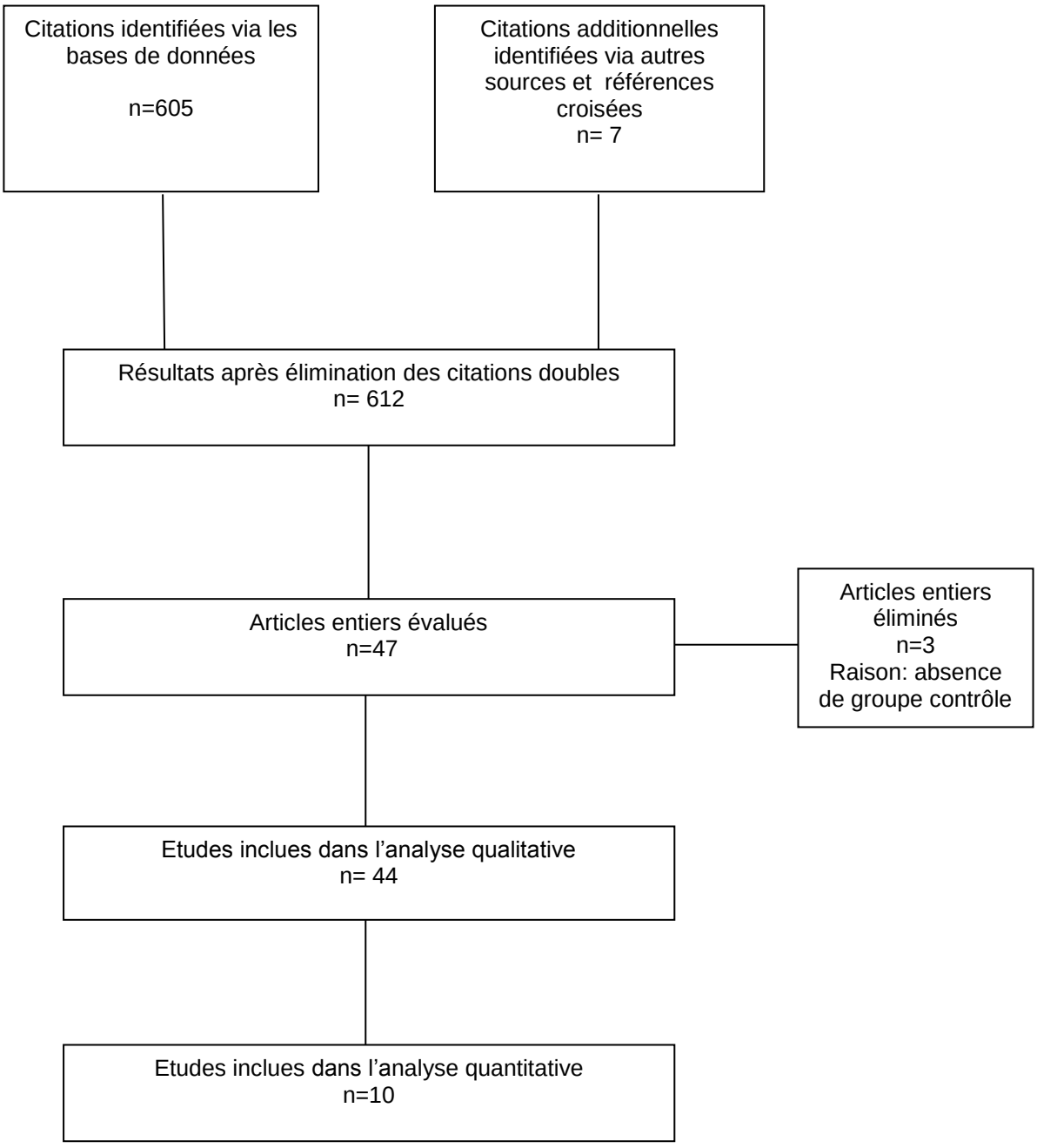
7- Filtre Additionel: publication de 1993-2013 ce qui a mené a une augmentation de la precision et à 605 citations.

Un nombre de 605 citations a été jugé acceptable en termes de ratio sensibilité/précision**.**

Critères de selection pour l'analyse qualitative

Critère	**Inclusions**	**Exclusions**
Langue	AUCUNES RESTRICTIONS	
Type de publication		
Considérations géographiques		
Période	20 ans (1993-2013)	
Participants	Dents adultes (>16 ans)	Dents restaurées
	Maxillaire et mandibulaire	
Intervention	Traitement endodontique	
Résultats	Fissures/fractures	
Types d'études	Etudes aléatoire contrôlée comparant les dents traitées endodontiquement aux dents non traitées (groupe contrôle) In vitro In vivo Ex vivo	Etudes croisées, quasi aléatoire, non-aléatoires Résumés, travail non publié

Diagramme de sélection



RESULTATS

Analyse qualitative

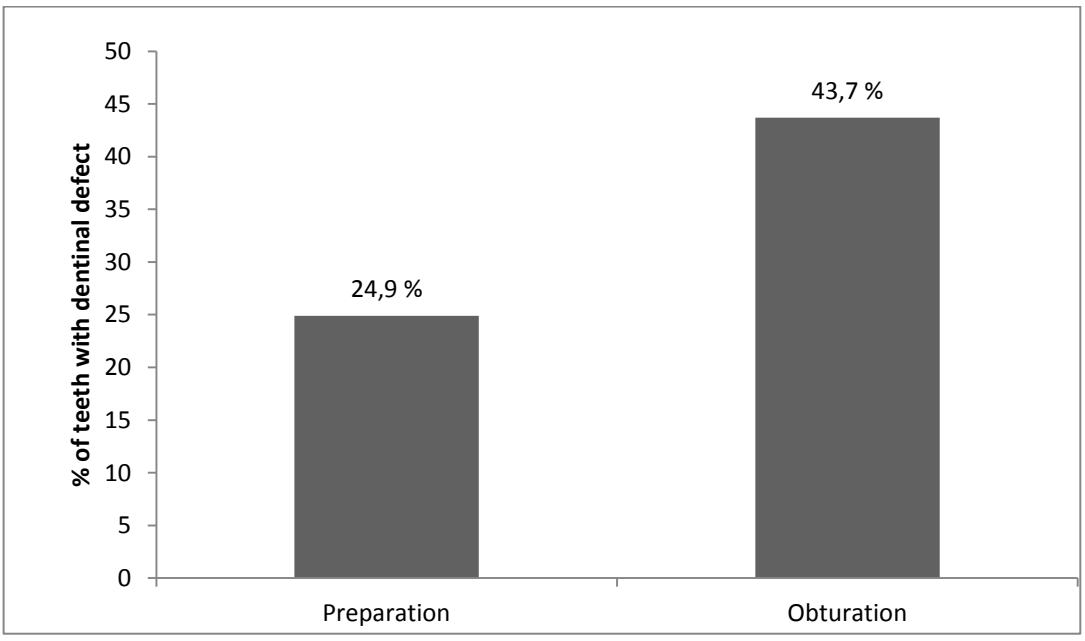
Les procédures les plus citées comme facteurs de risque sont la préparation et l'obturation canalaire.

Tableau 6- Facteurs de risque

N°	Risk factor for crack/fracture	Number of articles in which cited
1	Preparation	12
2	Obturation	13
3	Post placement	9
4	Lack of cuspal coverage	6
5	Tooth type	3
6	Loss of tooth integrity	5
7	Endodontic irrigation	1
8	Age factors	1

Analyse quantitative

Figure 1-Taux de défauts dentinaires pour la préparation et l'obturation



Hétérogénéité

Tableau 13- ***Preparation vs. obturation***

Heterogeneity				Tau-squared			
Q-value	df (Q)	P-value	I-squared	Tau Squared	Standard Error	Variance	Tau
7.116	5	0.212	29.739	0.158	0.338	0.114	0.398

Les résultats montrent une variabilité considérable entre les études. Ceci nous rassure dans notre choix d'analyse à effets aléatoires.

Le logiciel SPSS/PC version 13 (SPSS Inc. Chicago, IL) à été utlisé pour les analyses statistiques. Toutes les analyses ont été éffectuée à l'intervalle de confiance de 95%.

Note: **pour plus de détails sur les résultats et les tableaux, ainsi que la discussion et la conclusion, veuillez vous référer à la version originale en anglais.**

ABSTRACT

Aims: The aim of this study were (1) to perform a review on the factors influencing crack formation, propagation and fracture susceptibility of endodontically treated teeth, (2) identify and quantify the most cited factors.

Methodology: A literature systematic review using MEDLINE via PubMed, Cochrane Library and Google scholar was performed. Articles suggested by colleagues were also integrated in the review. The search terms were determined using the MeSH browser and combined using Boolean operators. A number of 612 citations were retrieved. Based on the abstract and the pre-established selection criteria, 44 articles were selected for the qualitative analysis (number and type of factors). The study also included a quantitative review with 10 articles in order to determine which of the most cited factors (i.e preparation and obturation) influenced crack initiation the most. Two reviewers independently selected the articles for the quantitative review based on pre-established eligibity criteria. The data was extracted using a customized extraction sheet and submitted to an event rate analysis and an odds ratio analysis. The null hypothesis was that there was no significant difference between crack initiation due to obturation and crack intiation due to obturation. The statistics software used for the analysis was SPSS/PC version 13.

Results: Eight risk factors were isolated from the systematic review and classified as either controllable or non-controlable. The most cited factors were canal preparation and obturation. The quantitative analysis showed that 24.9% of the teeth presented cracks after preparation and that 43.7% of the teeth presented cracks after obturation. However, the difference was not significant (p=0.055). The null hypothesis was not rejected.

Conclusions: The qualitative analysis showed that the etiology was multifactorial. The qualitative analysis also showed that endodontic procedures (preparation and obturation) significantly contributed to crack initiation. This study highlighted the importance of differenciating the crack initiation phenomenon from that of global weakening of the tooth, which is oftentimes measured by fracture strength. Crack initiation is clinically and biologically more relevant than fracture strength because preventive action is an upstream effort and the prognosis of fractured teeth is extremely unfavorable. This study also showed the importance for the clinician to

take non-controllable factors in consideration and act on the controllable factors for a coherent therapeutic approach.

Key words: Cracks, root canal therapy, endodontic treatment, fracture, dentinal defect

LIST OF TABLES AND FIGURES

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Luca De Rose

INTRODUCTION

Tooth fracture is a major problem in dentistry, and is the third most common cause of tooth loss after dental caries and periodontal disease [1,2]. The American Association of Endodontics has defined fives types of tooth cracks depending on their location, extent and direction[3]. This terminology, which is commonly accepted by clinicians and scientists, does not clearly distinguish crack from fracture in that it considers fracture as the “ultimate consequence” of crack propagation.

Cracked or fractured teeth can be asymptomatic or symptomatic. When symptomatic, patients often present with protracted history of pain of varying intensity; the origin of which may be difficult to locate for the patient as well as for the clinician[4]. Moreover, radiographic imagery does allow for visualization of small cracks[5]. Therefore, misdiagnosis and/or late diagnosis of cracks is a common problem, which might lead to fracture and ultimately tooth extraction. Studies show that root canal treated teeth are more prone to fracture than vital teeth[6,7], particularly to VRF. These fractures are usually complete and extend a variable length originating from the root generally in a bucco-lingual direction and may extend into the crown[8-11]. A large majority of the time, a tooth presenting VRF is sentenced to extraction. While it is obvious that endodontic teeth are structurally compromised, there is currently no scientific consensus explaining the prevalence of fracture in this group. The mechanical properties can only partially account for the increased fracture rate[12,13].

Management of fracture is usually difficult, aggressive and invasive. Therefore, it is more important to prevent than to treat. However, before taking preventive measure, a better understanding of the risk factors for cracks and fracture of endodontic teeth

is necessary in order to help clinicians make a coherent therapeutic choice. To this end, this study aimed to validate some factors and identify others.

The goals of this study were (1) to perform a systematic review of previous studies relating to this issue in order to identify its etiology, (2) to perform a quantitative analysis comparing and constrasting the most cited factors in the systematic review. To do so, event rate analysis and odds ratio analysis were performed.

The null hypothesis of the quantitative analysis was that there was no significant difference between crack initiation regardless of the cited factors.

CHAPTER 1 – LITERATURE REVIEW

1.1 ENDODONTIC TREATMENT PRINCIPLES

"Endodontology is concerned with the study of the form, furcation, health, injuries, diseases of the dental pulp and peri-radicular region as well as their prevention and treatment"[13].

Root canal treatment is a "non-surgical" approach used to treat two distinct endodontic disease entities (1) vital but irreversibly inflamed pulp, where the goal is to maintain existing periapical health and thus prevent periapical disease (2) non-vital or dying, infected pulp, associated with apical periodontitis[15]. Root canal treatment is the procedure done to preserve the infected tooth. This procedure involves removal of the damaged or the infected pulp, treatment of the infection and filling the canals[16].

1.2 INDICATION FOR ENDODONTIC TREATMENT

Endodontic treatment is indicated in cases of necrosis or gangrene, for prosthetic reasons or to treat irreversibly damaged pulp tissue (extirpation). Acute irreversible pulpitis is probably the most common reason for which endodontic treatment is performed. Acute irreversible pulpitis may be due by iatrogenic damage caused by wrong clinical procedures, trauma induced fractures/cracks or dental caries[17,18]. Table 1, lists the most common causes for which root canal treatment is indicated[19].

Table 1- ***Indications for endodontic treatment***

Dental trauma without fracture
Dental trauma with fracture
Dental caries
Conservative and/or prosthetic dental treatment
Conservative treatment of the pulp (capping)
Periodontal disease
Periodontal surgery
Orthodontic treatment

1.3 ENDODONTIC TREATMENT SEQUENCE

Modern endodontic therapy involves a number of sequences carried out over an average of 2 or 3 appointments. These include a) creation of the access cavity b) measurement of the tooth length c) irrigation d) preparation e) obturation[15].

1.3.1 ENDODONTIC CAVITY ACCESS AND CANAL PREPARATION[1,2,8,15,16]

A well-designed cavity access is essential for optimal endodontic result. The main objectives of access cavity preparation consist of 1) remove the roof of the pulp chamber, 2) identifying the root canal entrances for subsequent procedures 3) preserving sound tooth structure and 4) achieving straight-line access to the apical foramen or to the initial curvature of the canal.

When prepared correctly, the access cavity allows complete irrigation, shaping, cleaning, and quality obturation. Studies suggest that the loss of structural tooth integrity associated with cavity access preparation might lead to a higher occurrence of fractures in teeth.

The principles of endodontic canal preparation are to remove all organic debris and microorganisms from the root canal system, and to shape the walls of the root canal to facilitate that cleaning and the subsequent filling of the root canal space.

Manual preparation techniques[15,16,20]

(a)Standardized system- manual technique requires each instrument, file or reamer, to be placed to the full working length. This method is satisfactory in straight canals, but unsuitable for curved canals (b)Stepback technique- this technique was devised to overcome the problem of the curved root canal (c)Stepdown technique- the principle of these techniques is that the coronal aspect of the root canal is widened and cleaned before the apical part.

Endodontic instrument manipulation[15,16,20,21]

(a)Watchwinding and circumferential filing- continuous back and forth rotation with slight apical pressure. This method is generally used in canals with a moderate-to-severe curve (b)The balanced force technique- it is now the most widely taught technique for manipulating handfiles. It is particularly good when negotiating the curved root canal. (c)Ultrasonic technique- used to activate specially designed endodontic files. Ultrasonic machines are now largely used for their efficient irrigation properties rather than for canal shaping.

Automated devices[20,22,23,24]

There have been many automated handpieces on the market over the years, which suffered from major inconveniences surch as zipping, performation or broken instruments. However, the introduction of Nickel-titanium (NiTi) instrument has changed the way root canal preparations was peformed and allowed for fewer procedural errors. NiTi instruments can withstand the distortions caused by repeated rotation in curved canals without causing preparation errors. Most of these

instruments have design features such as radial lands to keep the instrument centred in the canal, and a non-cutting tip to guide the instrument down the canal. Some of the more 30 current NiTi instrument systems on the market are classified according to their design, shaping characteristics, breakage potential and clinical performance (Table 2). A controlled high-torque, low-speed motor is required for efficient use of NiTi instruments.

Table 2– *Nickel titanium rotary file classification according to their mode of cutting*[24]

Group	Rotary file	Enlargement potential	Preparation Errors	Fracture resistance	Clinical performance
I- Radial-landed 	Profile, ProSystem GT, K3, Qnatec, Guidance	+, Depending on size, often time consuming	++, Low incidence usually <150 canal transportation	+/- Fatigue, + Torsional load, depending on system	++ Good, depending on treatment conditions.
II- Nonlanded 	ProTaper, Pow-R, Race, Sequance	+/- Good with use of hybrid technique	+/-, Overall more demanding of clinician's ability	+ Fatigue +/- Torsional load, depending on taper, handling	No difference between rotaries shown so far, except for inexperienced clinicians
III- Others	Light speed & LSX, Endo EZE AET, Liberator	Varies, + with Light Speed	++ Light Speed, - Other systems	Varies	Varies
++ Good	+ Adequate		- Problematic		+/- Undecided

1.3.2 ENDODONTIC IRRIGATION[25-31]

The purpose of endodontic irrigation is to remove debris created during preparation, and to dissolve and/or flush out inorganic and organic remnants of the pulp system (smear layer), bacteria and bacterial byproducts that are not removed by mechanical instrumentation. Modern root canal treatment requires the use of both mechanical and chemical preparation and disinfection of the canal system. NaOCl is the most

frequently and dominantly used agent for root canal irrigation because of its bactericidal effect and its capacity to dissolve necrotic tissues. However, NaOCl has been reported to have toxic effect on dentine and periapical tissues.

1.3.3 ENDODONTIC FILLING MATERIALS AND TECHNIQUES

Once shaped and cleaned, the root canal system is obturated to prevent further ingress of microorganisms, both apically and coronally[15].

Materials[14-16,26,32]

A number of materials have been employed to obturate the root canal. They fall in 3 broad categories: sealers, semisolids and solids.

Sealers

Sealers are essential components because they are used to fill the space between the canal wall and core obturation material. Sealers are grouped by type (a) Zinc oxide-eugenol formulations and resins (b) calcium hydroxide (c) Glass-ionomers.

Solids

Solid materials are not widely used because they suffer form several deficiencies. The rigidity that made them easy to introduce into the canal also made them impossible to adapt to the irregular canal preparation.

Semisolids

Gutta-percha is semisolid and is the most universally accepted filling material. It can be compressed and packed to fill the irregular shapes of a root canal using lateral or vertical compaction techniques. However, gutta percha is distorted by pressure and can be forced through the apical foramen if too much pressure is used. Gutta percha does not adhere to the canal walls, regardless of the filling technique used. For this reason, it is generally used together with a sealer.

Techniques[14-16,26,32]

Lateral compaction of gutta-percha (cold and warm)

This is a commonly taught method of obturation and is the gold standard by which others are judgedThe objective is to fill the canal with gutta-percha points by compacting them laterally against the sides of the canals walls using a spreader.

A simple modification to the cold lateral compaction technique is to apply heat to the gutta-percha.

Single gutta percha point and sealer

This technique consists of matching a point to the prepared canal. For this technique, a type of canals preparation is advocated so that size of the point and the shape of the preparation are closely matched. These fit the prepared canal so well that some operators are using a single gutta-percha point and sealer. This simple technique presents several disadvantages and cannot be considered as one that seals canals completely.

Thermatic compaction of gutta-percha

This technique involves a reverse turning instrument. A modified version of this technique consists in the lateral condensation of a master point and two or three accessory points to prevent any apical extrusion (Tagger's technique). The thermatic technique is particurarly useful for the rapid and effective obturation of the coronal part of a root canal after placement of an accurate apical seal.

Heated gutta-percha carriers (e.g. Thermafil)

It consists in a technique in which gutta-percha is attached to a rigid carrier. Most carriers are plastic. The excess material is removed, and the carrier remains in the canal as a central core. Most systems apply a method of ensuring the fit of the device before obturation begins.

Vertical compaction of warm gutta-percha

In this technique, the gutta perch is warmed using a heated instrument and then packed vertically. Heated gutta-percha has been shown to flow extremely well into all canal irregularities. A continuous wave of heat is applied to soften and downpack a cone, resulting in well-compacted obturation of the apical portion of the canal. The remainder of the canal may be obtured by further increments or by injectable gutta-percha.

Injectable gutta-percha (e.g. Obtura, Ultrafil)

These machines extrude heated gutta-percha into the canals. Devices for injecting softened gutta-percha have been available for some time, but in the past have suffered from technical difficulties in accurate apical placement. Apical control can be difficult and this technique is often used as coronal back-filling of gutta-percha.

1.4 MECHANICAL PROPERTIES OF ENDODONTICALLY TREATED TEETH[12,33-37]

Some studies suggest that the moisture content of dentine of endodontically treated teeth is lower than teeth with vital pulp (about 9 %) and that endodontically treated teeth were more brittle because of water loss[34] and loss of collagen cross-linking. However, more recent studies dispute this finding. Authors compared the physical and mechanical properties of dentine specimens from teeth with and without endodontic treatment at different levels of hydration. They concluded that neither dehydration nor endodontic treatment caused changes of the physical or mechanical properties of dentin. Another study tested the biomechanical properties of dentin of endodontically treated teeth and vital teeth and concluded that contrary to common belief endodontically treated teeth were not more brittle. Additionaly, a study showed

that the loss of vitality and a proper RCT affected tooth biomechanical behaviour only to a limited extent. These studies support the interpretation that it is the loss of structural integrity associated with the endodontic procedures, rather than biomechanical changes that contribute to a weakening of the tooth after endodontic treatment.

1.5 DENTINAL DEFECTS AND FRACTURES

1.5.1 TERMINOLOGY AND CLASSIFICATION

Authors suggested several terms to define cracks/fractures. The terminologies are generally based on either the type or the location of the crack, the direction and extent of the crack, and/or the risk of symptoms and / or pathological processes. Below is non-exhaustive table of the difference terms used by authors since the 1960's.

Table 3-*Terminology of cracks and fractures*[38]

Year	Author(s)	Terminology	Definition
1964	Cameron	**Cracked tooth syndrome**	-
1972	Wiebush	Hairline fracture	-
1973	Hiatt	Incomplete crown-root fracture	-
1974	Talim & Gohi	Incomplete coronal fracture	-
1976	Silvestri	Split-root syndrome	-
1977	Maxwell & Braly	Incomplete tooth fracture	*A fracture of tooth structure which extends into dentin but in which the tooth remains grossly intact*
1981	Andreasen	Enamel infraction	*An incomplete fracture of the enamel without loss of tooth substance*
1981	Caufield	Hairline too fracture	
1981	Johnson	Crown craze/crack	*Injury of enamel without loss of enamel*

1983	Abou-Ras	Tooth structure cracks	*A line that breaks or splits the continuity of tooth dentin surface*

CHAPTER 1 : Literature review

			the surface
1983	Abou-Ras	Crack/craze lines	*Located in coronal enamel*
1984	Luebke	Incomplete tooth fracture	-
1984	**Kruger**	**Cracked cusp syndrome**	-
1986	**Brannstrom**	**Dentin crack syndrome**	-
1988	Williams	Incomplete vertical tooth fracture	-
1989	Lost *et al*	Tooth infraction	
1989	Schweitzer	Odontiatrogenic tooth fracture	-
1990	**Ehrmann & Tyas**	**Cracked tooth syndrome**	***Incomplete fracture of a vital posterior tooth involving the dentin and possibly the dental pulp***
1998	Zuckerman	Cracked tooth	*Fractures segments are still joined to one another by a portion of that tooth through which the fracture has not extended*
2001	Ellis	Incomplete tooth fracture	*A fracture plane of unknown depth and direction passing through tooth structure that, if not already involving, many progress to communicate with the pulp and/or periodontal ligament.*

The highlighted terminologies in Table 3 show that a number of authors consider cracked tooth a syndrome. As a matter of fact, the term “Cracked Tooth Syndrom” (CTS) suggested in the late 60s by is often referred to by clinicians and scientists. However, the term “syndrome” is misleading because it is defined as a “set of symptoms occurring together and characterizing a specific disease” which suggests

that cracked tooth is a disease. However, cracked tooth is not a disease but rather the “cause of a disease”. Therefore, some argue that a “cracked tooth” is a clinical observation rather than a “syndrome”.

Table 3 shows that there is a wide variation in terms. However, a relatively recent classification of cracks given by the American association of endodontists, in a document titled “cracking the cracked tooth code” which identified 5 types of cracks in teeth is widely referenced[3].

Table 4- *Classification of cracks by the American association of endodontists and their prognosis*[3]

Classification	Symptoms	Prognosis
Craze line	No	Excellent
Fractured cusp	Mild and generally only to biting and cold	Good
Cracked tooth	Acute pain on biting occasionally sharp pain to cold	Questionable: dependent on depth and extent of crack
Split tooth	Marked pain on chewing	Poor unless crack terminates just subgingivally
Vertical root fracture	Vague pain Mimics periodontal disease	Poor: root resection in mutli-rooted teeth.

For this study and simplification purposes, we will define 3 types of “cracks”

1-Craze: common and inconsequential

2-Crack: with a dentine component, incomplete tooth fractures

3-Fracture: division of the tooth

Together, crazes and cracks will be referred to as dentinal defects.

1.6 SIGNS AND SYMPTOMS ASSOCIATED WITH CRACKS AND FRACTURES[38-40]

Patients may or may not present with symptoms produced by the crack before the tooth fractures. Cracks are often diagnosed by a very detailed history of the

complaint[38]. The patient will give a history of pain on biting on a particular tooth, often occurring on grainy or tough foods with the pain being short and sharp. Patients may also complain of sensitivity to cold, sweet or hot, or stimulation, depending on how far the crack has propagated into the dentin. These symptoms can be explained by the hydrodynamic theory which supposes that the pain is produced with movement of dentinal fluid when the crack is opened by pressure, and it also explains the short shaper pain as the fluid moves back on releasing pressure.

1.7 DIAGNOSIS VISUALIZATION TOOLS AND MANAGEMENT

Management:[38,41,42,48] : a suggested treatment instituted to alleviate symptoms and secure the safety and longevity of the tooth consists in tying the tooth together on either side of the crack to prevent its propagation, microleakage and hydrodynamic pressure in the dentinal tubules. Use of reinforced glass ionomer cement or bonded resin composite to hold the cusps together are other options. A study suggested that the ideal treatment consists of applying a stainless steel band to the tooth followed full coverage restoration.

Visualization[38,42] : A study suggested the use of dye ,for example, methylene blue, which can be sealed into the cavity with zinc-oxide eugenol dressing. The use of rubber dam enhances the probability of visualizing cracks by isolating the tooth with a contrasting color, keeping the area free of saliva and removing peripheral distraction was suggested. Use of magnification loupes or dental microscope was mentioned as facitiliating crack detection.

Radiograhic Examination[5,39,41] : radiography should be taken when there issuspicion of crack. However, it is well known that cracks are rarely identified during routine

radiographs. As a matter of fact, mesio-distal cracks defy radiographic detection as the crack si perpendicular to the path of the x-ray beam.

1.8 PREVALENCE OF CRACKS AND FRACTURES[5,6,18,39,43,44-48]

VRF seems to be associated with endodontic treatment and is a more common reason for extraction of endodontically treated teeth currently than in the past. This may be an effect of increased awareness among dental practioners that endodontically treated teeth are vulnerable to fracture, combined with reports and text highlighting the difficulty of making a correct diagnosis of this condition. Studies show that there is a higher prevalence of VRF among endodontically treated teeth. However, the prevalence of VRF leading to tooth extraction is not well established. Reports from case series and follow-ups of patients treated with prosthetic reconstructions and retrospective radiological studies suggest a prevalence of 2% and 5%. However, postulating percentages of VRF from studies on presumed causes for extraction of endodontically treated teeth are probably inaccurate. The low percentage are probably related to the difficulties in the clinical diagnosis of VRF. Some VRF cases included in these studies were probably diagnosed incorrectly as either root canal treatment failure or as progressive periodontal disease; the defintive diagnosis is made years after extensive treatment. It is therefore, not suprising to see a higher prevalence of VRF in more recent studies. In two studies on root filled teeth referred for extraction, 11% and 20% of VRF were found, respectively. Table 5 shows results of a survey conducted about the reasons for extraction of endodontically treated teeth.

Table 5- ***Reasons for extraction of 147 endodontically treated teeth***[95]

Cause	Number of teeth	Percentage
Restorative	64	43.5
Endodontic	31	21.1
Endo-restorative	28	19.1
VRF	16	10.9
Periodontal	6	4.1
Perio-endo	2	1.4
Total	147	100

In that specific survey, the prevalence roof vertical root fracture was 10.9 %, which was close to the 12.9% found by other authors which evaluated 635 endodontically treated teeth in a success and failure study for a period of 8-10 years.

As for cracks studies showed that they occur most frequently in the mandibular molars with large or poor restoration in those over 45 years of age.

1.9 QUESTION OF THE STUDY

Why are endodontically treated more susceptible to cracks and fractures?

METHODOLOGY

CHAPTER 2 – METHODOLOGY

2.1 CLINICAL QUESTION FORMULATION

Our study relates to the etiology of cracks and fractures in endodontically treated teeth. Here we tried to determine the risk factors as well as the greatest risk factor. The outcome of the study is therefore an undesirable (crack/fracture). We used the PICO (participants, intervention, comparator, and outcome) template suggested by the Cochrane library to formulate the clinical question[49]. In our case, participants were teeth, intervention was the endodontic treatment, the comparator was the absence of endodontic treatment and the outcome was crack/fracture.

Question of the study

What makes endodontic teeth more prone to fracture than non-endodontic teeth?

2.2 SEARCH COMBINATION

		AND
	Concept 1	Concept 2
	root canal therapy	dental fissure
Subject Heading (MeSH Terms)		tooth fracture
	OR	OR
Text Words	endodontic*.tw. (canceled)	dent* defect*.tw.
		OR
		dent* crack*.tw.

2.3 LITTERATURE SEARCH

The literature search was performed using MEDLINE via PubMed, Cochrane Library as well as Google scholar. Articles were also suggested by colleagues. The search themes were determined and combined using Boolean operators as followed:

1- Search for MeSH headings for exploded search: Root canal therapy, Dental fissure and Tooth fracture

Search text words (truncated): endodontic*, dent* defect*, dent* crack*

2- Combination with “OR” using search history lead to Concept 1 (# 1) and Concept 2 (# 2)

3- Combination with “AND” of the two concepts: # 1 AND # 2

4- Addition of filters: Human + Dental journals

5- Resulted in 1302 citations

The sensitivity/precision ratio is too high. In order to increase precision, the “text word” endodontic*” was removed from search.

6- Increase of precision using following combination:

Root canal therapy [mh:exp]= concept 1

Dental fissure [mh:exp] OR Tooth fracture [mh:exp] "dent* defect*".tw. OR "dent* crack*".tw. = concept 2

Concept 1 AND Concept 2 = 987 citations

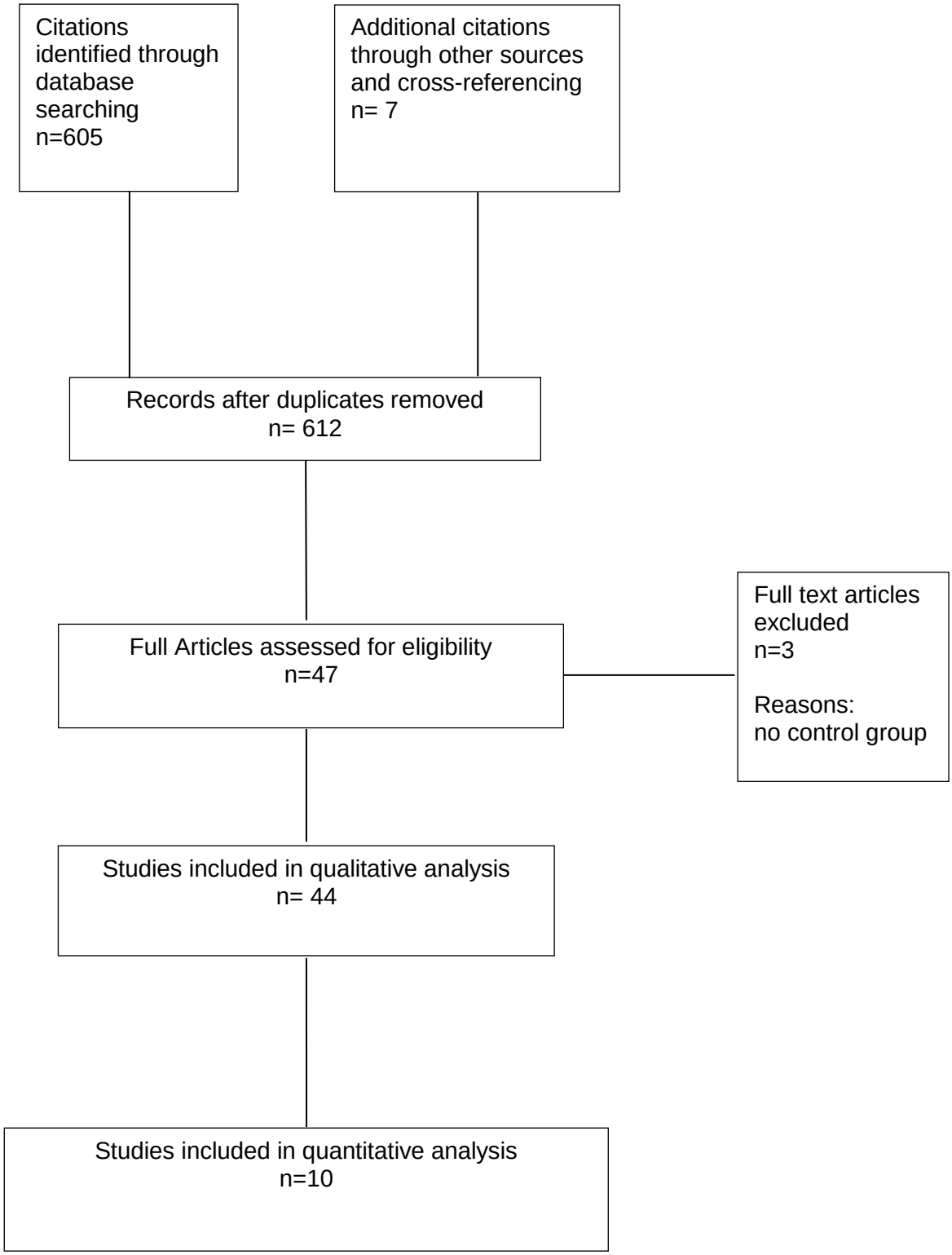
7- Additional filter: Time frame from 1993-2013 increases precision and yields 605 citations

605 citations was an acceptable compromise between sensitivity and precision

2.4 SELECTION CRITERIA

Criteria	Inclusions	Exclusions
Language	NO RESTRICTIONS	
Publication type		
Geographic considerations		
Time period	20 years (1993-2013)	
Participants	Aged older than 16 years	Restored teeth
	Upper and lower teeth	
Intervention	Endodontic treatment	
Outcome	Cracks/fractures	
Types of studies	Randomized controlled studies comparing endodontically treated teeth with untreated teeth (control group) In vitro In vivo Ex vivo	Crossover studies,quasi randomized studies or non-randomized studies Abstracts or unpublished work

2.5 STUDY SELECTION FLOWCHART



All statistical analyses were performed using SPSS/PC version 13 (SPSS Inc. Chicago, IL). The interval of confidence was 95%.

RESULTS

CHAPTER 3 – RESULTS

3.1 QUALITATIVE DATA ANALYSIS

The procedures that were most cited as risk factors for cracks and fractures were tooth preparation, obturation and post placement.

Table 6- *Risk factors*

N°	Risk factor for crack/fracture	Number of articles in which cited
1	Preparation	12
2	Obturation	13
3	Post placement	9
4	Lack of cuspal coverage	6
5	Tooth type	3
6	Loss of tooth integrity	5
7	Endodontic irrigation	1
8	Age factors	1

3.2 QUANTITATIVE DATA ANALYSIS

Table 7- *Dentinal defect rate for preparation*

Model	Study name	Statistics for each study					Event rate and 95% CI
		Event rate	Lower limit	Upper limit	Z-Value	p-Value	-1.00 -0.50 0.00 0.50 1.00
	Shemesh & al. 2009 IEJ	0.300	0.141	0.527	-1.736	0.082	
	Adorno & al. 2010 IEJ (work.)	0.233	0.143	0.356	-3.897	0.000	
	Souza Bier & al. 2009 JOE	0.064	0.038	0.105	-9.735	0.000	
	Shemesh & al. 2010 IEJ	0.120	0.055	0.242	-4.578	0.000	
	Adorno & al. 2010 IEJ (end.)	0.400	0.158	0.703	-0.628	0.530	
	Barreto & al. 2012 JOE	0.533	0.293	0.759	0.258	0.796	
	Onnink & al. 1994 JOE	0.350	0.177	0.574	-1.320	0.187	
	Adorno & al. 2013 IEJ	0.400	0.158	0.703	-0.628	0.530	
	Liu & al. 2013 JOE	0.225	0.147	0.329	-4.619	0.000	
Random		0.249	0.152	0.379	-3.548	0.000	

24.9 % of teeth show dentinal defect after preparation.

Table 8- ***Dentinal defect rate for obturation***

Model	Study name	Statistics for each study					Event rate and 95% CI
		Event rate	Lower limit	Upper limit	Z-Value	p-Value	-1.00 -0.50 0.00 0.50 1.00
	Shemesh & al. 2009 IEJ	0.675	0.517	0.801	2.165	0.030	
	Shemesh & al. 2010 IEJ	0.276	0.196	0.372	-4.276	0.000	
	Adorno & al. 2010 IEJ (end.)	0.450	0.253	0.664	-0.446	0.655	
	Barreto & al. 2012 JOE	0.511	0.368	0.652	0.149	0.882	
	Onnink & al. 1994 JOE	0.317	0.212	0.444	-2.771	0.006	
	Adorno & al. 2013 IEJ	0.450	0.253	0.664	-0.446	0.655	
Random		0.437	0.311	0.571	-0.921	0.357	

43.7 % of teeth show dentinal defect after obturation

Table 9- ***Obturation vs preparation (odds ration analysis)***

Model	Study name	Statistics for each study					Odds ratio and 95% CI
		Odds ratio	Lower limit	Upper limit	Z-Value	p-Value	0.01 0.10 1.00 10.00 100.00
	Shemesh & al. 2009 IEJ	4.846	1.515	15.504	2.660	0.008	
	Shemesh & al. 2010 IEJ	2.789	1.066	7.292	2.091	0.037	
	Adorno & al. 2010 IEJ (end.)	1.227	0.263	5.734	0.260	0.795	
	Barreto & al. 2012 JOE	0.915	0.284	2.950	-0.149	0.881	
	Onnink & al. 1994 JOE	0.861	0.296	2.503	-0.276	0.783	
	Adorno & al. 2013 IEJ	1.227	0.263	5.734	0.260	0.795	
Fixed		1.695	1.045	2.750	2.137	0.033	
Random		1.663	0.926	2.989	1.701	0.089	

For Table 9, we combined studies that contained both preparation and obturation procedures. The odds ration was superior to 1 (however, the superiority is not big), which means obturation leads to more dentinal defect than preparation. However, this difference is not significant (p=0.089).

Figure 1- ***Dentinal defect rate for obturation and preparation***

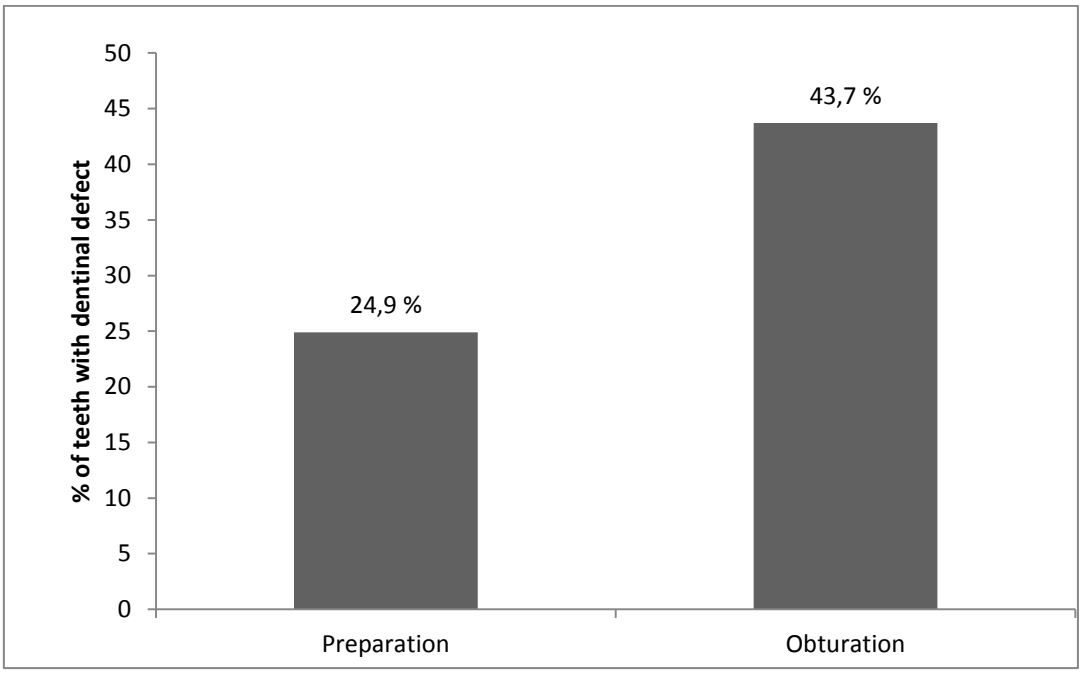


Table10- ***Risk difference (corrected obturation)***

Model	Study name	Statistics for each study							Risk difference and 95% CI
		Risk difference	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value	-1.00 -0.50 0.00 0.50 1.00
	Shemesh & al. 2009 IEJ	0.375	0.126	0.016	0.127	0.623	2.966	0.003	
	Shemesh & al. 2010 IEJ	0.156	0.064	0.004	0.029	0.282	2.414	0.016	
	Adorno & al. 2010 IEJ (end.)	0.050	0.191	0.036	-0.324	0.424	0.262	0.793	
	Barreto & al. 2012 JOE	-0.022	0.149	0.022	-0.314	0.269	-0.149	0.881	
	Onnink & al. 1994 JOE	-0.033	0.122	0.015	-0.273	0.207	-0.272	0.785	
	Adorno & al. 2013 IEJ	0.050	0.191	0.036	-0.324	0.424	0.262	0.793	
Fixed		0.129	0.046	0.002	0.038	0.219	2.788	0.005	
Random		0.117	0.061	0.004	-0.003	0.237	1.917	0.055	

Obturation implies preparation. We therefore attempted to estimate dentinal defect rate due to obturation without preparation. Results show that obturation leads to 11,7% of teeth with more dentinal defects than preparation. However, this difference is not significant (p= 0.055).

3.3 HETEROGENEICITY ASSESSMENT

Table 11- ***Dentinal defect rate for preparation***

Heterogeneity				Tau-squared			
Q-value	df (Q)	P-value	I-squared	Tau Squared	Standard Error	Variance	Tau
42.047	8	0.000	80.974	0.669	0.462	0.213	0.818

Table 12- ***Dentinal defect rate for obturation***

Heterogeneity				Tau-squared			
Q-value	df (Q)	P-value	I-squared	Tau Squared	Standard Error	Variance	Tau
21.875	5	0.001	77.143	0.340	0.294	0.087	0.583

Table 13- ***Preparation vs. obturation***

Heterogeneity				Tau-squared			
Q-value	df (Q)	P-value	I-squared	Tau Squared	Standard Error	Variance	Tau
7.116	5	0.212	29.739	0.158	0.338	0.114	0.398

Table 14- ***Risk difference (corrected obturation)***

Heterogeneity				Tau-squared			
Q-value	df (Q)	P-value	I-squared	Tau Squared	Standard Error	Variance	Tau
7.090	5	0.214	29.478	0.006	0.014	0.000	0.081

Results show variability in studies, thus comforting our choice of random effect analysis.

DISCUSSION

CHAPTER 4 : DISCUSSION

4.1 SYSTEMATIC REVIEW ANALYSIS

The systematic review was the **first part** of this study and showed that a number of factors could contribute to crack formation and to increased fracture susceptilibity of endodontically treated teeth.

Risk factors for cracks and fractures that were extracted from the systematic review were classified in two categories: controlable factors and non-controlable factors[6,33]. Non-controlable factors consisted of those that stemmed from a natural process (disease, age, etc.) and controlable factors were those caused by an external intervention. The risk factors cited in the systematic review are listed below, in Table 15[6,33].

Table 15- *Risk factors for cracks and fractures*

I-CONTROLLABLE FACTORS	
ENDO PROCEDURES	- Preparation - Obturation - Irrigation
RESTORATIVE PROCEDURES	- Post/Dowel use - Cuspal coverage - Cavity preparation
II-NON CONTROLLABLE FACTORS	
PATHOLOGICAL CAUSE	- Previous cracks/restorations - Caries
PHYSIOLOGICAL CAUSE	- Age - Type/position of tooth

A- PREPARATION

Preparation was cited 12 times in the systematic review. Articles either assessed dentinal defects [50-58] or tooth fracture strength [59-61] after preparation. In all cases, canal preparation showed to have a significant effect on the incidence of microcracks (including enamel crazes) and on the decrease of fracture strength. All studies examining microcracks used control groups in which teeth were intact, in order to determine if sectioning for observation induced cracks. In general, no cracks were observed in control groups, which lead authors to reject the hypothesis that sectioning was responsible for crack formation. During canal preparation the canal is shaped via contact between the instrument and the dentinal walls, thus, creating a momentary stress concentration in the dentin. This stress concentration may lead to dentinal defects in which fractures can begin from[54,57,61]. Higher incidence of dentinal defects was reported with nickel-titanium rotary files compared with hand instruments. Authors attribute this disadvantage to the greater taper of rotary instruments[62] and the high number of rotations associated with mechanical rotary systems[54,59]. This observation was particularly true in the case of the ProTaper Universal rotary files (Dentsply Maillefer, Ballaigues, Switzerland), probably because this system is reported to generate the highest tensile and compressive stress in the dentin[50,61].

Studies assessing fracture strength saw a significant decrease of fracture strength after preparation. It is generally accepted that the fracture strength of a tooth is directly related to the amount of remaining sound tooth structure[12,33,34]. Canal preparation involves removal of dentine, which may compromise fracture strength of the tooth. Moreover, tooth deformation increases progressively after tooth canal preparation, which could also make the tooth more susceptible to fracture. Studies

showed that the ProTaper system (Dentsply Maillefer) lead to lower fracture strength which concords with the studies showing more dentinal defects with the ProTaper.

The in vitro studies attempted to reproduce the periodontal ligament (PDL) by creating artificial sockets with acrylic resin. In normal conditions, the periodontal ligament acts as a "shock absorber" and is responsible for force distributions around the tooth when external forces are applied by providing better stress distribution during fatigue loading[63]. However, it is difficult to reproduce these functions experimentaly, which might be a possible cause of bias. Moreover, the in vitro studies also cited the absence of alveolar housing and the dehydration of the tooth during the setting of the acrylic resin as possible causes of bias[64].

In conclusion, it may be hypothesized that some rotary Ni-Ti systems lead to a higher number of dentinal defects, which under compressive load may propagate into fracture.

B- OBTURATION

Obturation was cited 13 times in the systematic review. In all cases, obturation process lead to a significant increase in dentinal defects and a decrease of fracture resistance. The outcome measures were identical to those assessing impact of preparation procedure, i.e., dentinal defects[51-53,56,57,65] and fracture resistance[66-72]. The studies examined the influence of canal filling materials and techniques with or without mechanical loading.

A number of techniques were cited for canal obturation, they included lateral compaction, vertical compaction, Thermafil (Tulsa dental products, Tulsa, OH), Ultrafil (Hygienic Corp., Akron, OH), Tagger's hybrid technique and passive insertion. Studies showed the lowest occurrence of defects with passive insertion and the higher occurrence of dentinal defects with lateral compaction technique. Authors

attributed this tendency to the pressure of the instruments on the dentin in compaction techniques. Moreover, lower fracture strength was found with lateral condensation and systems using heat (Thermafil, Ultrafil) compared with passive insertion.

The studies also examined the effect of different filling materials on the fracture resistance of teeth. Authors found the lowest resistance to fracture with gutta-percha. Recently authors developed the “monoblock” concept to explain the performance of filling materials on fracture strength[73]. In endodontics, the term monoblock refers to a mechanically homogenous unit with the root dentin and the obturation materials. Monoblocks are classified as primary, secondary or tertiary depending on the number of interfaces they make with the dentin. An ideal endodontic monoblock is that in which (1) the modulis of elasticity of the root filling material and the accompanying resin cements/sealers are close to that of dentin a (2) high bonding between materials occur, in order for loading stresses to be evenly distributed and borne by all the components.

The filling materials cited in the systematic review were either silicon-based, resin-based or glass ionomers. Gutta-percha is a long established root canal filling material, but it does not adhere to the dentin, and its modulus of elasticity is much lower than that of dentin[75]. Therefore, gutta-percha does not act as a homogenous monoblock unit with the dentin. Moreover, conventional sealers such as AH-plus do not adhere to gutta percha and tend to pull away from gutta percha on setting[74].

Systems using resin-based materials performed high resistance to fracture regardless of the obturation technique used. This might be due to the stronger bond of resin materials with the dentin, which creates an endodontic monoblock able to distribute the loads homogeonously and reduce stress during loading.

In conclusion, stable adhesion to root canal dentin walls and an elastic modulus similar to dentin are two key factors for root filling materials to improve the fracture resistance of endodontically treated teeth and minimize crack initiation and propagation. These criteria might be partly satisfied by highly filled resin composite.

C- ENDODONTIC IRRIGATION WITH NAOCL

Endodontic irrigation with NaOCl was only cited once in the systematic review[75]. It is generally accepted that NaOCl applied at a high concentration for a long period has undersired effects on the root canal dentine, changing the physical properties of the dentine and reducing its hardness[28]. The authors hypothesized that the chemically affected radicular dentine contributed to the formation of potential sites for cracking and subsequent fatigue failures.

In conclusion, we may hypothesize that irrigation alone does not create cracks but facilitates crack formation.

D- POST USAGE

Post placement was cited 9 times in the systematic review[76-84]. The outcome measure was fracture strength in almost every study. Post usage did not necessarly translate into increased fractured strength. As a matter of fact, when referring to the endodontic “monoblock” concept, the usage of post introduces interface and thus an additional difficulty because the new component should be similar in terms of modulus of elasticity to the dentine and the obturation materials. Additionally, post preparation requires removal of dentin, which could further weaken the tooth. The studies determined the resistance to fracture of post restored teeth under loading and showed lower, identical or higher fracture strength than their counterparts restores without post. The materials, length and shape of posts were investigated as well.

However, the conclusions were very contradictory. This could be due to (1) high methodological variabilites (2) high variability of parameters taken in consideration in the different in vitro studies (type of tooth, type of materials used, length and shape of the post, operative technique, preservation of tooth structure, age, etc).

In conclusion, it was not possible to extract a general tendency regarding the influence of posts on endodontically treated teeth.

E- CUSPAL COVERAGE

Influence of cuspal coverage was cited 6 times in the systematic review[84-88,97]. The studies investigated the stability of endodontically treated teeth and considered the influence of different restorations techniques and materials. A study showed that cuspal protection with indirect restorations increased fracture strength. Another study showed that maxillary first premolar had greater resistance to fracture when the cuspid was fully and directly covered with composite resin. Two studies discussed the influence of cusp coverage on the fracture resistance of premolars and suggested that cusp reduction and coverage with composite resin significanly increased the fracture resistance of premolar. As for the influence of material, a study suggested that fracture resistance with ceramic or composite inlays were similar. One study on premolars showed that the residual cavity wall thickness played a major role in deciding whether to cover the cusp or not. Authors suggested that a thin cavity wall (less than 2mm) should be covered.

In conclusion, regardless of the technique used, full cuspal coverage of molars and premolars seem to increase fracture strength, especially when cavity wall is thin.

F- LOSS OF TOOTH INTEGRITY: CAVITY PREPARATION, CARIES, PREVIOUS, CRACKS/RESTORATIONS

Loss of tooth integrity was cited 5 times in the systematic review[79,85,89,90,98]. The studies suggested that the strength of a tooth was directly related to the amount of remaining tooth structure and that cavity preparation, previous restorations or caries may compromise the mechanical integrity of the tooth by contributing to the loss of dentin. Teeth with previous cracks might also be responsible for lower fracture strength as the crack might propagate after final restoration is placed or even during treatment. Some authors suggested that the loss of the dental pulp eliminates the protective feedback mechanism of the tooth, which may also contribute to tooth fracture. The studies all concluded that the preservation of tooth structure was crucial to mitigate fracture risk.

G- AGE

Age factor was only cited once in the systematic review[91]. The study conducted showed that crack propagation occurred 100x time more rapidly in old dentine than in young hydrated dentine. Age related modifications of collagen such as crosss-linking were also suggested to cause deterioration of the mechanical properties of the tooth and thus contribute to decreased fracture strength. This is not a factor the clinican can act upon but it should be taken into account when planning treatment.

Most vitro studies include “adult teeth” i.e., teeth extracted from patients from age 16 and above. Therefore, the variability in dentine quality can be very high which might be a cause of bias.

H- TYPE AND POSITION OF TOOTH

Type of tooth was cited 3 times in the systematic review[90,92,96]. The studies showed that the anatomical location influenced the fracture predilection of endodontically treated teeth. The studies show that intact pulpless anterior teeth that have not lost further tooth structure are at minimal risk for fracture. On the other hand, posterior teeth bear greater occlusal loads during masticatory functions and are therefore more susceptible to fracture. The type of tooth also influences predilection to fracture. This is due to the anatomical differences between teeth.

In conclusion, the studies also indicate that endodontically treated premolars and mesial roots of mandibular molars are generally more susceptible to fracture.

4.2 DENTINAL DEFECTS VS. FRACTURE

The aim of the **second part** of the study was to perform a quantitative review on the most cited factors contributing to the fracture susceptibility of the tooth, i.e, preparation and obturation. To do so we performed a small metanalysis with the studies referring to obturation and preparation. Resistance to fracture was the most frequent outcome measure used in the studies of the systematic review. This method is different from the one used to assess fracture in that it applies an external force until the tooth fractures[72], whereas in studies assessing cracks, the influence of various procedures on the tooth is directly observed with application of any external force. Furthermore fracture strength gives no information on the formation process of the fracture, it only provides information about VRF. It is currently not possible to make clear conclusions about the clinical consequences of dentinal defects developed in vitro, however, it may be strongly hypothesized that dentinal defects may propagate and lead to fracture after completion of endodontic procedures[74], or simply by forces due to masticatory functions and/or occlusal loading[87]. Based on this

reasoning, fracture should not be considered to be an instant phenomemen, but rather the result of a gradual phenomenon, i.e, the result of an ongoing crack. This hypothesis is supported by a number of authors[9,94-96]. It is also suggested that dentinal defects as benine as craze lines could be indicators of fracture susceptilibity; a study assessing root canal enlargement to finger-spreader induced root fracture showed that no VRF occurred after testing unless craze lines were previously present on the tooth[94]. Studies have further highlighted the influence of endodontic procedures on crack initiation by showing that many defects did not connect with the pulp space, and were located in places away from direct contact with intra-canal instruments which suggests that preparation can lead to other clinical complications than VRF (periodontal conditions, recurrent infection, etc)[94,65]. Authors suggested that the stresses generated from inside the root canal were transmitted to the surface [94,37].

In conclusion, fracture strength relates to the moment of the tooth's final failure but ignores crack initiation, which is of paramount biologic importance. Therefore, the clinical importance of fracture strength is limited. For these reasons, we decided to only include studies that assessed cracks and dentinal defects for the metaanalysis comparing and contrasting obturation and preparation procedures.

4.3 DISCUSSION OF METHODOLOGY FOR QUANTITATIVE ANALYSIS.

Almost every study used for this analysis used a control group which consisted of intact teeth, and in which the number of cracks or dentinal defect was equal to "0". In these cases, it is impossible to calculate an odds ratio because the program replaces "0" by an arbitrary "0.5" which creates a very high interval of confidence. For this reason, we chose not to use the control group and to estimate the rate of dentinal defect in the preparation and obturation group. This allows for a more precise, less

arbitrary and more intuitive method of assessment. Moreover, we chose a random effect analysis. Studies relating to crack initiation in endodontically treated teeth are not numerous and the number of samples included in the studies was relatively low. Therefore, we suspected and predicted a considerable degree of variability. For this reason, we agreed that a more stable and robust technique for the quantitative analysis was to use a random effect analysis rather than a fixed effect analysis.

4.3.1 MAJOR FINDINGS OF THE QUANTITATIVE ANALYSIS

The results of the studies showed that both preparation and obturation lead to dentinal defects (Table 7-8). The difference in dentinal defect occurrence between the two processes was not significant. The null hypothesis was therefore not rejected. For the purpose of this study we regrouped all mechanical techniques together in order to have a global reading of the crack formation and propagation phenomenon.

Figure 1, showed that the event rate for preparation was 24.9%. In other words, ¼ of the teeth that underwent preparation exhibited 1 or more dentinal defect(s). Results showed that the event rate for obturation was 43.7. Both preparation and obturation showed that results were significant.

The analysis showed that the dentinal defect rate for obturation was higher than that for preparation but that this difference was not significant (Table 9, p=0.089).

Obturation implies preparation. Therefore, we attempted to determine the cracks due to obturation only. Results showed that obturation causes 11.7 % more cracks than preparation (Table 10). However this result was not significant (p=0.055). Moreover, this result cannot be regarded as a general tendency, because of the big variations of risk difference among studies. For example, two studies included in the analysis[52,54] showed that preparation intiated more cracks then obturation which contradicts the

results of the present analysis. For these reasons, it is not possible to conclude that obturation leads to more defects than preparation. However, we can hypothesize that some dentinal defects seen in obturated teeth were initiated by preparation.

4.4 HETEROGENEICITY

In this study, p values for the chi square test were all inferior to 0.05. Therefore, the hypothesis that the observed dispersion is not superior to the one we would find due to sampling hazard is rejected and consequently the hypothesis of identitical effects for all studies is rejected. This justifies the choice of random effect metanalysis. Tables 11-14 showed a considerable degree of variability for all three tests, which lead us to conclude that there is a high degree of heterogenicity. A simple examination of the odds ratio confirms this. For these reasons, it is not possible to conclude that there is a difference in crack occurrence between preparation and obturation.

4.5 PUBLICATION BIAS

The usual hypothesis for publication bias is to assume that studies containing many subjects are usually published (whether result is significant or not) and that studies with less subjects are less likely to be published if the results are not significant. In this present study, this would mean that studies showing a significant difference between preparation and obturation would be published. However, upon examination of the studies, this hypothesis is not verified; both of Adorno et al.'s studies and Barreto et al.'s study are smaller than others in terms of number of subjects and are significant.

4.6 SUGGE STIONS

It would be interesting to conduct another metaanalysis when more data is available. Further in vitro studies should include identification of the cracks in order to identify and monitor their propagation during preparation and obturation procedures. More in vitro and clinical studies are necessary to explore the true extent and impact of cracks.

CONCLUSION

CONCLUSION

In this study we attempted to determine the risk factors for cracks and fractures in endodontically treated teeth. The most cited factors were preparation and obturation which are controlable factors, i.e., factors the clinician could act upon. However, these procedures are of utmost importance for successful endodontic treatment and can not be compromised. For this reason, the role of the clinician is to integrate the knowledge that endodontic procedures do create cracks and to weigh the potential benefits of the approach used vs its potential risks. This customized approach should also take in consideration the patient's age and medical history and the type and location of the tooth which are uncontrollable factors. However, it was also clear from the study that a high number of fractured endodontic teeth will be extracted. For this reason, it is important to focuse on prevention.

The review showed that a high number of studies ignored crack initiation and favored fracture strength as an outcome measure. However, crack initiation is of paramount importance; most of the time, a fracture is a result of an ongoing crack.

Within the limitations of this study we can conclude that the etiology of fractures is multifactorial and that the factors are probably interconnected. While it was clear that propagation and obturation lead to increased crack formation, it was not possible to determine which contributed the most to crack formation because the heterogenicity of the study was high.

It would be interesting to conduct further in vitro investigations of crack initiation and propagation and fracture susceptibility due to controllable factors to get a better understanding of this complex phenomen.

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ANNEXE I - STUDY ELIGIBILITY FORM

FACTORS	ASSESSMENT		
Type of study	Yes	Unclear	No
Is the study described as randomized?	Yes	Unclear	No
Is there a control group?			
Teeth (Participants)	Yes	Unclear	No
Were teeth treated endodontically?	Yes	Unclear	No
Types of teeth (human)?	Yes	Unclear	No
Were the teeth restored ?			
Outcomes	Yes	Unclear	No
Did the study report specific outcomes?			
Final decision *	**INCLUDED**	**UNCLEAR**	**REJECTED**

***Final decision (1x "No"=EXCLUDE, 1x "Unclear"=UNCLEAR, 2x "Unclear"=EXCLUDE**

ANNEXE II - DATA EXTRACTION SHEET

CHARACTERISTICS FOR ANALYSIS

Hypothetical cause for condition	
Sample size	
Control group	
Number of arms (groups)	
Statistical analysis	
Group of intereste	

ORGANISATIONAL ASPECTS

Reviewer, date	
Author, year	
Journal/source	
Impact/country of origin	
Publication type	

STUDY CHARACTERISTICS

Condition	
Intervention	
Cause for condition	
Type of control	