International Journal of Science and Research (IJSR)
ISSN: 2319-7064
Index Copernicus Value (2016): 79.57 | Impact Factor (2017): 7.296

The Ability of Root Canal Cleaning and Shaping Procedures to Initiate Dentinal Radicular Microcracks

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Abstract: ***The ability of nickel-titanium rotary instruments to initiate dentinal defects during root canal shaping is contradictory. The type of their alloy, taper, tip design, cross-section and kinematics are analyzed in terms of generating unfavorable stress onto the root canal wall. Along with their positive characteristics, some of the most common irrigant solutions for chemical disinfection and removal of debris - sodium hypochlorite and ethylenediaminetetra acetic acid are reported to contribute to dentinal defect formation and to reduce the microhardness of radicular dentin. The effects of the aforementioned irrigants on dentinal matrix in terms of their concentration and application time are overviewed.***

Keywords: irrigation, microcracks, nickel - titanium rotary instruments, root canal shaping, vertical root fracture

1. Introduction

Endodontic treatment is an attempt to preserve the function and save the integrity of a tooth with irreversibly damaged pulp. Its success depends on acquiring a proper endodontic access, thorough debridement, shaping and three - dimensional obturation of the root canal system along with the adequate postendodontic restoration, allowing pulpless teeth function as an integral part of the dental arch [1], [2].

In the course of the primary endodontic treatment, root canal filling, post and core procedures as well as retreatment cases, craze lines and microcracks into root dentin may appear. The formation of these dentinal defects is a process influenced by various other factors, including repetitive mastication overload, dental premature contacts, parafunctional habits like bruxism, etc. As a result of this, initial damage of root canal walls can progress into vertical root fracture (VRF) which is among the most common reasons for treatment failure and tooth extraction [3]–[5]. It is assumed that the stress generated in the inner root canal wall is distributed to the outer surface, where the binding forces of the dentin are overcome [6], [7]. Dentinal cracks or root fractures occur whenever the tensile stress in the canal wall exceeds the ultimate tensile strength of dentin [8].

There is no unified definition of the different types of dentinal defects. According to the American Association of Endodontists (AAE) the cracks are described as a function of their location, extent and direction and can be classified as: craze line, fractured cusp, cracked tooth, split tooth, and vertical root fracture *(VRF)*. A 'true' VRF is defined as an incomplete or complete fracture, originating only in the root portion of the tooth at any level that can extend coronally to the cervical periodontal ligament. It is usually directed bucco-lingually and might involve either one of the proximal surfaces or both of them. VRFs may extend the length of the root or occur as a shorter crack at any level along the root [9] According to Wilcox et al. root fractures were defined as dentinal defects extending from the root surface and reaching the lumen of the canal [7]. Other defects that do not involve the entire thickness of the root canal dentin are: *craze lines* – a line extending from the outer surface into dentin but without involving the canal lumen [6], [7]; partial or incomplete cracks – lines extending from the canal wall into the dentin without reaching the outer surface [6].

Among the most common factors causing defects of the root canal dentin are: the complexity of the root canal morphology [10]; the types of the instruments used to perform the endodontic treatment along with their kinematics; the use of certain irrigation solutions during the shaping of the root canal – sodium hypochlorite, EDTA, etc. [11]; different obturation techniques; post canal preparation and cementation, retreatment procedures [12], [13], [14].

2. Root Canal Shaping

Nowadays, rotary nickel-titanium (NiTi) instruments are the most widely used and preferred ones for root canal shaping. This is mainly due to their improved cutting efficiency, exclusive superelasticity and flexibility allowing them to follow the original anatomy of the root canal. These favorable qualities of the rotary instruments reduce the preparation time compared to hand instrumentation and prevent procedural errors, such as canal transportation, ledge formation and zipping [15], [16]. After preparation with rotary NiTi instruments canal shape is more likely to be rounder and smoother [17]. Canal irregularities, which are places with high-concentration of stress, are eliminated [18].

Despite their advantages, NiTi rotary instruments can separate unexpectedly, as a result of torsional stress, cyclic flexural fatigue or a combination of them both [15]. These files can generate different level of stress onto the root canal dentin, depending on the type of the alloy they are manufactured from, the taper, the tip design, the cross-section and the kinematics type [19], [20], [21]. Consequently, microcracks and dentinal defects occur [6], [22]–[28]. They can propagate over time, engaging greater portions of the root canal wall thus increasing the risk of fracture [6], [21], [22], [23], [25], [27], [28], [29].

2.1 Type of alloy

Nickel-titanium alloy, usually called NITINOL, is a kind of intermetallic compound with superior ductility, which is a stoichiometric compound of Ti and Ni. It is also an equiatomic alloy due to its one-to-one atomic ratio of nickel to titanium, containing approximately 56wt% nickel and 44wt% titanium. Similar to other metallic systems this alloy can exist in various crystallographic forms. It has three microstructural phases – austenite, martensite and R-phase, whose character and relative proportions determine the mechanical properties of the metal. Behavior and properties of NiTi instruments are highly influenced by their transformational temperatures, which can be altered by small changes in composition, impurities, and heat treatments during the manufacturing process. The crystal structure of NiTi alloy is in austenitic phase at a temperature higher than the transformation temperature range, whilst the structure is in martensitic phase at a lower temperature. The temperature at which the alloy transformation is finished (A_f temperature) for most conventional NiTi files is at or below room temperature, whereas the A_f of the new controlled memory (CM) files is above body temperature. Due to this, the conventional NiTi instruments are in austenitic phase during clinical use, while the CM files are in martensitic one. Transformation from austenitic to martensitic phase can be achieved, as well, by application of external force – stress-induced martensitic transformation. This phase defines one of the special characteristics of the NiTi alloy – superelasticity, i.e. the ability to return to its original shape upon unloading following substantial deformation [15].

From a clinical standpoint, NiTi alloy in martensitic form, is soft and ductile and can be easily deformed. Stress-induced martensitic NiTi is highly elastic, whereas austenitic NiTi is quite strong and hard. The instruments in martensitic form have a remarkable fatigue resistance. They can easily be deformed, yet they will recover their shape on heating above the transformation temperatures [15].

Recent generation endodontic instruments with increased flexibility are developed on the basis of series of proprietary thermomechanical processing procedures. Instruments made of M-Wire and CM-Wire have increased austenite transformation temperatures. Twisted file (TF) instruments are developed by transforming raw NiTi wire in austenite phase into the intermediate R-phase through a thermal process. This phase occurs within a very narrow temperature range [15].

Opinions in literature concerning the relationship between NiTi instruments made of different alloys and the appearance of dentinal defects differ. Some authors claim that the instruments made of conventional NiTi alloy cause much more dentinal defects compared to the thermomechanically-treated ones [30]–[35]. Others, state that there is no significant difference between the instruments with different thermal treatment (e.g. in M-Wire or R-phase) in provoking dentinal damages [31], [36].

2.2 Taper

The diameter of the prepared root canal has a major role in the occurrence and the propagation of dentinal microcracks and the incidence of vertical root fractures [37]. The taper of the shaped canal should ensure proper irrigation and its three-dimensional sealing without unnecessarily decreasing the thickness of the dentinal wall. Large-tapered instruments speedily cut substantial amounts of dentin, especially in curved roots and oval canals. As a result of this, lateral forces develop and induce strain on the canal wall which may be the reason for crack formation [7], [25], [38].

The rotary NiTi instruments have constant or variable taper (especially in the recently-developed systems). In some instruments with variable taper: RECIPROC *(VDW, Munich, Germany)*, WaveOne *(Dentsply Sirona, Ballaigues, Switzerland*), WaveOne Gold *(Dentsply Sirona, Ballaigues, Switzerland*), F-files of ProTaper Universal *(Dentsply Sirona, Ballaigues, Switzerland*) the taper is fixed in the first few millimeters of the file tip and then progressively decreases. This design of the file increases its flexibility and preserves the dentin in the coronal 2/3 of the root canal.

Rotary NiTi instruments exhibiting constant and much higher taper are considered to cause greater strain accumulation in dentin during root canal shaping compared to stainless-steel hand instruments [25], [39]. Bier et al. observed that all groups prepared with rotary NiTi files showed various degrees of damage except for the group shaped with stainless-steel hand instruments [25]. This conclusion is in line with Sathorn et al. who stated that the less the taper of the shaped root canal is, the lower is the risk of fracture[18]. From a clinical standpoint, rotary files remove much more dentin, which may cause dentinal defects from which VRF can develop [6], [25], [40]. Conversely, de Oliveira et al. have presented no instrumentation-driven microcracks regardless of the varying taper of the files used [41].

2.3 Design and cross section

Conclusions on relationship between the design of the NiTi instruments and their ability to cause dentinal defects are contradictory. One of the greatest challenges faced by the manufacturers of NiTi instruments today is to create files with greater cutting abilities, improved flexibility and cyclic fatigue resistance, and at the same time with reduced probability of undesirable stress generation on dentinal walls. The tip design of the rotary instruments, their cross-sectional geometry, constant or variable pitch and taper, and flute form could be related to crack formation [21]. It is assumed that the lower the frictional force between the file and the dentinal walls is, the less dentinal defects appear [42]. The cross section of the endodontic file determines the contact between the instrument and the canal wall. This generates many stress-concentration sites from which a crack may initiate [20], [43]. During the shaping of the root canal system the contact between the NiTi rotary instrument and the root canal wall may induce high pressure onto the dentin, causing an instant microcrack formation [43]. However, according to Karataş et al. and Pedulla et al. there were no significant differences between examined files with different cross-sectional designs in terms of dentinal crack formation [32], [44]. Probably, cracks are initiated by a combination of different factors, experiencing their influence on the root canal wall at one and the same time [32].

2.4 Type of rotation

Two types of motion of the NiTi rotary systems are most commonly used nowadays – continuous rotation: ProTaper Universal, ProTaper NEXT *(Dentsply Sirona, Ballaigues, Switzerland*), Mtwo *(VDW, Munich, Germany)*, HyFlex *(Coltene-Whaledent, Allstätten, Switzerland)* and reciprocating movement: RECIPROC, RECIPROC blue *(VDW, Munich, Germany)*, WaveOne, WaveOne Gold. Reciprocation tends to mimic the manual one and is based on the concept of the „balanced force" described by Roane et al. [45]. The alternation of counterclockwise and clockwise rotation minimizes the stress on the instrument and, therefore, reduces the cyclic fatigue caused by tension and compression, and lowers the risk of file separation [46], [47]. The angles of reciprocating are specific to the design of each particular system [48].

There are certain advantages and disadvantages in both types of rotation. Different research groups come to opposite conclusions when a relationship between the rotation type of files and the development of microcracks is searched for. Some authors state that dentinal defects appear regardless of the motion used or no difference between the experimental groups and the negative control group was found [27], [44], [49]. Others claim that reciprocating files cause less dentinal defects compared to continuously rotating ones [28], [50]–[53]. The continuous rotation generates higher stress concentration on the root canal wall, which might be a reason for a higher number of microcracks [50]. The alternating clockwise and counterclockwise movement reduces the forces acting on the dentinal wall, thus contributing to lesser dentinal cracks formation [54]. A third group of researchers concludes that files using reciprocating motion, cause much more dentinal microcracks and craze lines in the apical third of the root canal [27], [55].

In an attempt to overcome the deficiencies of the two types of rotation a new system with adaptive motion is developed – The Twisted File Adaptive System (TFA) *(Kerr, Orange, CA, USA)* used with the Elements Motor with Adaptive Motion Technology. This technology allows the TFA file to adjust to intracanal torsional forces depending on the amount of pressure placed on it. This means the instrument rotates clockwise and depending on the load on it, adapts and reverses counter-clockwise by coasting in a reciprocating motion [15], [31], [55]. Karataş et al. state that this adaptive movement decreases the stress concentration on the apical part of the root canal wall, resulting in less crack formation [31]. Moreover, in their in vitro investigation, Gergi et al. documented that TFA produced the least dentinal defects not only in the apical third but in the entire root canal compared with the other examination groups [55]. A micro-CT study assessing the effect of TFA on on the root canal wall showed that no new dentinal defects were induced [36].

2.5 Number of files used

The shaping of the complex root canal system might be performed by only one rotary file (single-file, single-length technique) or by various hand and rotary instruments, used in a specific sequence according to the manufacturer's instructions (step-back, crown-down, single-length techniques).

The constant demand for implementation of new rotary NiTi systems reducing the operators' fatigue and the time required for thorough root canal debridement and shaping, led to the appearance of the so called "single-file" techniques. This makes single-file technique (Wave One Gold; RECIPROC) preferred by more clinicians nowadays. Despite their advantages, the use of a single file leads to a higher stress generation in the root canal wall. Consequently, the number and the frequency of dentinal defects incidence is increased [27], [28], [34], [44]. Other researches register opposite outcome– the use of a single file, though with higher taper, causes less dentinal cracks [6], [50], [56].

Understandings concerning the ability of full sequence systems to initiate dentinal defects in the root canal wall are contradictory, as well. Some researchers claim that more manipulations, and more files used, respectively, can result in formation of a higher number of microcracks [28], [52], [57], [58]. Others come to the opposite conclusion and assume that in full-sequence rotary systems each preceding file enables shaping with successive ones thus reducing the contact surface with the dentin wall [27], [59], [60].

3. Root Canal Irrigation

Adequate debridement and disinfection of the complex root canal system can only be achieved by the simultaneous use of shaping instruments and different irrigating solutions [61]. Irrigation enhances eradication of microbiota, facilitates removal of necrotic pulp tissue and dentin debris from the root canal system [62]. Nevertheless, endodontic irrigants are proven to cause alterations in the chemical composition of dentin that are time and concentration-dependent [63], [64]. As a result of this, microhardness, permeability and solubility characteristics of dentin change, thus lowering the fracture resistance of the tooth [65].

Sodium hypochlorite (NaOCl) is the most commonly used and recommended irrigating solution in endodontics [2], [66], [67]. It is an antibacterial agent able to dissolve necrotic and vital pulp tissue, the organic component of smear layer and dentin. NaOCl has a bactericidal, sporicidal and antiviral effect and exhibits greater dissolving effect on necrotic than on vital tissues [2]. The presence of inflammatory exudate, tissue remnants and microbial biomass consumes NaOCl and weakens its effect resulting in a necessity of constant delivery of a fresh irrigant [63].

Dentin is composed of approximately 22% organic material by weight [62], [63]. Most of it consists of a type I collagen, which contributes considerably to the mechanical properties of dentin [64], [68]. Sodium hypochlorite fragments long peptide chains and chlorinates protein terminal groups; the resulting N-chloramines are broken down into other species [69]. Consequently, the degradation of the organic components by NaOCl solutions can alter adversely dentinal biomechanics by significantly deceasing its elastic modulus and flexural strength [63], [64], [70].

Clinicians use this solution in various concentrations, ranging from 0,5% to 6,25%. The most predominant ones seem to be the following: 1% NaOCl, 2% NaOCl, 2,5% NaOCl, 5,25% NaOCl, 6% NaOCl [21], [22], [23], [30], [39], [57], [71]–[79]. However, a consensus does not exist on the ideal concentration and the total amount (ml) used per canal throughout endodontic treatment procedures [62].

Most of the experiments that study the effect of sodium hypochlorite on human root dentin are performed by applying the solution to standardized dentin bars for a prolonged contact time of 1-2 h [11], [80]. These samples are slices obtained by teeth sectioning, using saw microtome. The main drawback of this method is that laboratory conditions do not reflect precisely the clinical situation, where less dentin surface area is exposed for a shorter contact period of time [64]. In the course of the experiments the Young's modulus and flexural bend strength are determined following the requirements of the American Society of testing and materials (1989). The three-point bend test is performed, as well, till failure of the bars appears [11], [62], [80].

Sim et al. reported that exposure to 5,25% NaOCl for 2 h significantly reduces dentinal modulus of elasticity and flexural strength compared to the influence of saline and 0,5% NaOCl [11]. These findings are supported by the results of Marending *et al.* according to which higher concentrations of NaOCl (5% and 9%) reduce by half the mechanical properties of dentin [62]. Grigoratos et al. state similar results but with no significant difference between the higher concentrations of NaOCl - 3% and 5% [80]. However, Machnick et al. reported no significant difference between any of the NaOCl groups (5.25%, 2.6%, 1.3%, 0.6%) [81].

It can be speculated that weakening of dentinal matrix lowers its resistance to strain accumulation and causes defects, such as microcracks or even fractures. Further investigations should focus on finding the optimal combination of NaOCl concentration and method of delivery for obtaining maximum disinfection and clean surface without hampering the mechanical properties of dentin [62], [70].

The complete removal of the smear layer is of essential importance for the outcome of the endodontic treatment because it interferes penetration of gutta-percha and adhesion of root canal sealer to dentinal walls [82]. Despite NaOCl advantages as an irrigant it is not sufficient for achieving thorough cleaning and disinfection of the complex endodontic system [66]. Thus, other irrigants have to be included into the irrigation protocol, along with the sodium hypochlorite [83].

Successive rinses with ethylenediaminetetraacetic acid (EDTA) and NaOCl solutions are recommended for efficient removal of root canal smear layer [84], [85]. EDTA chelates and removes smear layer mineralized ingredients [63], [64]. Chelators are complex ions capable of binding single calcium ions present in the hydroxyapatite crystals of dentin [86], [87]. The demineralization process is self-limited because EDTA loses its activity in cases of complete saturation of chelator complexes with calcium ions [63], [64], [88]. The alteration of the original proportion of organic to inorganic components in dentin may lead to changes in its microhardness, solubility and permeability [89].

Various concentrations of EDTA solutions have been investigated for their ability to enhance instrumentation, effectively remove the smear layer and affect radicular dentin microhardness [90], [91]. EDTA is usually used in its liquid form, in concentration of 17%.

Uzunoglu et al. concluded that fracture resistance of endodontically treated teeth is affected by various concentrations of EDTA at different time exposures [65]. A 10-minute and 5-minute irrigation with 17% EDTA decreases dentin microhardness more than its 1-minute application [65], [92]. The adverse effect of EDTA on the physical and mechanical properties of dentin is due to EDTA's capability to dissolve dentinal mineral content [93], [94]. Long-term exposure to this chelating agent causes deleterious effects on the peritubular and intertubular dentin, which results in a decrease of the modulus of elasticity and flexural strength values [92], [95], [96]. It might be assumed that these changes reduce fracture resistance of the tooth [65].

Combined use of NaOCl and EDTA facilitates reduction of bacterial load [63]. Simultaneously, alternating irrigation with these solutions causes greater strain in dentin, changes its visco-elastic properties, and leads to dentinal erosion [97], [98]. It is known that mineral component in hard connective tissue is responsible for its strength and elastic modulus, while collagen determines the toughness [62], [99]. Therefore, it is assumed that erosion might be a contributing factor in vertical root fracture initiation and depends on the depth of the erosion, the thickness of the root and the amount of the sclerotic dentin [63].

4. Conclusion

In vitro studies reports are inconsistent concerning the incidence of root cracks formation after root canal shaping with hand stainless-steel and rotary NiTi files. There is conflicting data regarding the chemical disinfection of the root canal space comparing time, concentration and irrigation regimens of certain endodontic solutions in terms of their ability to alter and modify the dentin structure. This generates confusion and uncertainty in dental practitioners seeking safer instruments and techniques for cleaning and shaping the root canal anatomy. The risk of VRF development after the initial therapy implies further investigations to examine and find a minimally-invasive endodontic protocol.

5. Acknowledgements

The project is sponsored by the Scientific Council of Medical University – Sofia, Bulgaria

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