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# Biomechanical problems in endodontically treated teeth after separated instruments removal

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***Abstract***
*The incidence of instrument fracture is a common complication during endodontic treatment. The fragment compromises chemo-mechanical cleaning, shaping and 3D obturation of the root canal system. On the other hand, attempts at removing the instrument may result in excessive dentin sacrifice, predisposition to vertical root fracture, perforation, ledge formation, etc. The present review aims to examine the some of the biomechanical problems and risk factors which may be result of separated instrument removal. For this purpose, we analyzed 53 full-text articles and one textbook, published in the time period 1986-2021 year. It emphasizes the importance of preoperative dentin thickness evaluation. Changes in the original design of the canal are taken into account with reference to their impact on the biomechanical integrity of the tooth.*
***Key words:*** *separated instrument, removal, dentin thickness, complication, biomechanics*

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## I. Introduction.

The separation of endodontic file is procedural accident that may occur during root canal preparation procedures[1]. The prognosis of leaving, versus removing the instrument have been broadly discussed in the literature[2,3]. It is preferable to remove the fragment and pursue treatment under ideal conditions, but this is not always possible[4].Wide range of devices, techniques and methods are described in addressing the challenge to remove the fragment. Each individual case requires evaluation of risk factors, analysis and planning, knowledge, patience and creativity. Nowadays, the use of dental operating microscope and ultrasonic instrumentation has driven microsonic technique[1] which opened new horizons for retrieval of separated instruments. Success rates of ultrasonics in clinical trials have ranged from 67% by Nagai et al[5] to 88% and 95% reported by Cujé et al[6] and Fu et al[7], respectively[2]. According to Shahabinejad et al[8], success rate in the roots with file fracture before the curve was 11.5 times more than that of file fracture cases beyond the curve.

Regardless of the technique used, the management of cases with separated instruments must be based on biological and biomechanical considerations[9]. From a biological point of view the broken file is an obstruction and obstacle that compromises the proper cleaning and shaping of the root canal system. It may be the cause of persistent intraradicular infection[9]. The fragment of instrument is seldom the direct cause of treatment failure. It does, however, limit the access to the apical part of the canal[4]. From a biomechanical point of view, once the design of the canal is changed after the first endodontic treatment, but it will change again during the nonsurgical retreatment. The creation of straight access to the head of the fractured instrument is a conditio sine qua non[1]. It provides better visualization and easier handling of instruments used for removal[10], but changes the root canal morphology. The amount of the remaining sound dentin is proportional to the strength of an endodontically treated tooth, the possibility of perforation and the predisposition to vertical root fracture. Therefore, orthograde treatment of a case with a separated endodontic instrument should be considered in the light of minimally invasive approach.

A recent study shows that 61.8% of dentists had complications during or after the removal of fractured instruments[11]. Lambrianidis et al[12] summarize all possible complications as follows:

- root perforation;
- excessive removal of tooth structure;
- fracture of another file;
- inadvertent fracture of the original fragment;
- ledge formation;
- transportation of the root canal;
- thermal injury of dental or periodontal tissues;
- transposition of the instrument fragment deeper into the root canal;

- extrusion of the fragment beyond the apex;
- dislodgement of the fragment into another root canal;
- predisposition of the root to a vertical root fracture.

The main goal in the management of separated endodontic instruments is not only to remove the fragment, but also to preserve the mechanical integrity of the tooth[2]. The resistance to fracture of endodontically treated teeth is a major concern, since the prognosis of the tooth may be compromised. Thus, the clinician must analyze the fine balance between risk factors and benefits during the treatment planning.

## II. Susceptibility to vertical root fracture.

Any attempt to remove a separated instrument requires different degrees of dentin sacrifice. Such a loss of tooth structure could have impact on the biomechanical response of the tooth. Biomechanics is a discipline of science that studies the behavior of biological structures under function or external forces[13]. It is essential to consider the fatigue properties of coronal and apical dentin, in order to better understand how the structure is closely related to the function.

Francis Crick, one of Britain's great scientists, said “If you want to understand function, study structure.” Dentin is a hydrated biological composite comprised of inorganic hydroxyapatite crytallities, organic type-I collagen and water[14]. The mineral components of coronal dentin are higher than those of radicular dentin[15]. Collagen of radicular dentin portions is larger than that of coronal portions[16]. In addition, the collagen biochemistry in the crown and the root dentin differs. The number of specific cross-links in root dentin was significantly higher than that in coronal dentin[17]. Therefore radicular dentin would be expected to have higher capacity for inelastic deformation and crack-tip blunting. Wang et al[18] reported that fracture behavior between coronal and radicular dentin is different. Tensile strength of radicular dentin is greater than that of coronal dentin. However, fatigue strength of radicular dentin is lower than that of coronal dentin[19]. Radicular dentin has increased sensitivity to fatigue and potential for fatigue failure[20]. Fatigue striations in dentin do not develop every fatigue cycle[21]. Typical masticatory stress levels that a human tooth experiences have been estimated to be in the order of 20 MPa[22]. Factors such as high occlusal stress, non-axial loads and sound dentin sacrifice during retreatment could lead to tooth failure due to crack growth and vertical root fracture (VRF).

Vertical root fracture is characterized by an incomplete or complete longitudinal fracture line that extends to different levels of the root[23]. Madarati et al[24] investigated the effect of removal of fractured instruments on resistance to VRF. They conclude that removal of fractured instruments from the coronal one-third of the root canal can be considered as a safe procedure. On the other hand, removal of fractured instruments from deeper locations within the root canal jeopardizes root resistance to vertical fracture. Souter and Messer also stressed those teeth undergone removal of fractured instruments from the apical region were the least resistant to VRF[25]. Suter et al[26] concluded that the removal of separated instrument significantly reduced root strength when file was located in the middle or apical third of the root by 30% and 40%, respectively. Interestingly, instruments left in situ in the apical one-third does not affect root resistance to vertical fracture[10]. Therefore, we would conclude that if the broken instrument is in the apical-third of the canal and beyond the curve, bypassing or even leaving the instrument in situ may be a treatment option. The dental literature indicates that fractured instruments adversely affects treatment outcome only in the presence of existing periapical lesion[10,27,28]. Furthermore, other authors suggest that the reduced dentin thickness did not necessarily increase the fracture susceptibility, while changing the canal configuration from oval to round relives internal stress despite substantial loss of proximal dentin[29,30]. Biomechanical studies demonstrated that extreme degree of iatrogenic root canal dentin removal, particularly away from the canal center, would result in decreased moment of inertia and root flexure. The increased root flexure would shift the radicular stress distribution from the cervical dentin to the apical dentin in the buccolingual plane. It could be suggested that the resistance to VRF after root canal preparation was influenced by the remaining dentin volume and moment of inertia of the root dentin [30]. The ultrasonic application does not significantly affect the required force for root fracture[8].

## III. Perforation.

Instrument fracture may occur in both anterior and posterior teeth, but is more frequently reported in molars[12,31,32,33]. Among molars, it is particularly reported as occurring in the mesial roots of mandibular molars[34,35] and mesiobuccal roots of maxillary molars[36], which correlates with their complicated anatomy. Their canals are often narrow and curved. The dentin thickness between the canal wall and the outer root surface is thin and at high risk of perforation even during standard canal preparation[36]. Consequently, Abou-Rass, Frank and Glick[37] proposed the anticurvature filing method, which consists of working the endodontic instruments against the external wall of the curve. This method is of utmost importance, firstly, because there is always a buccolongual concavity on the distal aspect of mesial roots of lower molars and the mesiobuccal roots of the upper molars. Secondly, these canals are closer to the distal surface of the respective root[38]. In a cross section, the three American authors identify “safety zone” and “danger zone“. The safety zone is bulky, far from the furcation, corresponds to the mesial wall of the mesial roots of the lower molars and of the mesiobuccal roots of the upper molars. The danger zone is with thinner dentin, comprises the distal wall of the mesial roots of lower molars and of the mesiobuccal roots of the upper molars[38]. The biomechanical dilemma arises when an endodontic file breaks right in these canals, and according the literature, this happens in most cases. During retrieval attempts, troughing on the outside of the canal curvature seems logical, but it doesn’t work, because:

- troughing the wall increases the curvature of the canal, while cutting the inside-of-the-curve canal wall straightens the canal;
- activating the ultrasonic tip on the outside-of-the-curve wall hammers the segment and actually moves it further down the root canal[39,40].

The ultrasonic tip must cut inside-of-the-curve canal wall, in the danger zone, in order to be successful. Thus, there is a high chance for perforation known as stripping. The minimum thickness of dentin required to prevent perforation or fracture remains uncertain. Lim and Stock[36,41] speculated that with 200-300 µm of dentin, condensation forces during obturation may exceed the resistance of the dentin and lead to a perforation or fracture. Madarati et al.[24] investigated ex vivo root resistance after ultrasonic removal of fractured instruments. Interestingly, one sample from the apical one-third group was perforated whilst filling adjacent to an area of dentin thickness less than 300 µm. Such a low wall thickness might be a reason for this incident. The hydrostatic pressure whilst injecting the sealer, which is very low, might be an additional factor. Also, a microcrack, which could not be identified, could have contributed to the fracture. Further research is needed about the impact of different obturation techniques on weakened teeth after removed broken instrument.

In a recent study, Gao et al[36] used a virtual model to simulate the attempt to remove fractured instruments in different levels of the canal. They measured the minimum thickness of dentin left in the danger zone, in mesiobuccal canals of maxillary first molars. The dentin thickness was only 300-400 µm when the instrument was broken in the middle third of the canal. The total amount of dentin was reduced by 40% - 50%, increasing the susceptibility to VRF[42]. The same researchers highlighted that the depth of the concavity couldn’t be estimated in radiographs. Radiographs may even give a too optimistic estimation of the dentin thickness on the distal side of the canal. Knowing the true amount of tooth structure could be helpful for risk evaluation. CBCT is the radiographic imaging method of choice in the treatment planning. Nowadays, the results from virtual simulation models can provide valuable insight into the benefit/risk analysis and shouldn’t be underestimated[36].

## IV. Heat generation.

Excessive heat generation is a potential complication of the use of ultrasonic devices, because all ulstrasonic work below the orifice is conducted dry. The clinician has constant visualization of the energized tip against the broken instrument[1]. However, the high frequency vibration and the friction between the ultrasonic tip and both dentin and broken instrument generate heat[43,44]. The heat is transmitted from the intracanal space to the adjacent periodontium and bone. Atrizadeh et al.[45] used electrosurgery tip to generate heat inside root canals of monkeys. Interestingly, the researchers found localized areas of necrosis in periodontal ligament at the third day and resorption or ankylosis at the sixth month. This way, they demonstrate that heat have impact on osteoclastic and osteoblasic activity.

The temperature within the canal might be several times higher than that recorded on the external root surface. It is reported that if the temperature of the outer surface reaches 46° C, that in the canal can be around 200° C[46]. It is widely accepted that raising the temperature of the outer root surface by 10 ° C within 1 minute causes irreversible bone and attachment loss, as well as dentin dehydration, often accompanied by root resorption[47]. Modifications of the dentin surface might disturb the close contact between obturating materials and canal walls[48]. Also, mickrockracks could be initiated. They cannot be observed by the clinician, but their growth could become the reason for delayed treatment failure. It is essential to minimize heat build-up during retrieval procedures.

Factors influencing heat transfer are:

- working time;
- size and surface texture of the ultrasonic tip, power setting;
- thermal diffusion, dentin conductivity and dentin thickness[49].

According to a recent study from Terauchi et al.[50] removal time depends on the root canal curvature and separated instrument length. It has been reported that instrument retrieval attempts should not exceed 45-60 minutes because success rates may drop with increased time[26],[50,]. Fragments longer than 3.1 mm lodged in canals with greater curvature >30° may require longer preparation times, due to a significantly higher contact area along the canal walls. Separated instruments over 6.4 mm appear to be difficult to remove with ultrasonic instruments and should be retrieved using alternative methods such as a loop or XPS instrument. In addition, the material of the fractured instrument also should be considered. Stainless steel files[1] and martensite-phase NiTi files require less preparation time, whereas austenite-phase NiTi files tend to straighten out on the outer wall of the curve, which may require longer loosening time.

Dentin is a poor thermal conductor, thus protecting the periodontal ligament from high temperatures inside s inside the root canal[43]. Therefore, decreased dentin thickness would result in lower thermal tolerance and increased conductivity. Gluskin et al.[51] report that dentin thickness less than 1 mm will transmit heat rapidly when removing metallic or ceramic post. They suggest if post removal attempts are continued beyond 10 minutes, there should be two minutes rest intervals between ultrasound applications for recovery of physiological temperatures. To date, there are no guidelines, recommended protocols or working time intervals to provide heat protection during separated instruments removal. There is still no research information available that quantifies the optimal magnitude of energy for any given ultrasonic device that maximizes clinical efficiency yet mitigates dangerous heat transfer[51]. The use of larger tips and higher power settings increase the temperature[43]. A low-power setting should be used initially, but this may be adjusted upward depending on the obstinacy of the fragment[52].

## V. Ledge formation.

After successful separated file removal, a ledge is inevitably formed in the root canal[25,35]. The latter is created either by the work of GG drills or ultrasonic tips. The ledge may act like a possible zone of stress concentration[53], increasing the risk of VRF[29]. In addition, it may prevent preparing and filling root canal system to the desired length[29,35]. With the aid of dental operating microscope, ledges can be reduced or even removed by inserting a rotary file with greater taper or a precurved hand file and applying an axial filing movement with 1-2 mm amplitude[2]. Nevertheless, if the ledge is located in the apical one-third, an attempt to completely smooth it could lead to thinning of the canal wall and even perforation. Therefore, the decision must be based on the previous evaluation of remaining dentin thickness.

## VI. Conclusion.

The ultimate goal in recovery of the root canal space is to ensure that the remaining dentin is sound and able to support the subsequent restoration structurally, as well as provide a restorative complex that is functionally healthy[54]. Treatment plan depends on the diagnosis of the tooth with separated file and in particular the presence of periapical pathology. Nonsurgical retreatment of a case with a separated endodontic instrument should be always considered in the light of minimally invasive approach. Microsonic technique has high success rates in removing separated instruments, but there is a need to create working protocols protecting from heat generation. Volumetric analysis of the dentin thickness is essential preoperative step, which may prevent further complications, such as overenlargement and perforations.

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