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Separated Instrument in Endodontics: Frequency, Treatment and Prognosis

SUMMARY

Instrument separation during endodontic therapy is a frequent accident with rotary instruments being more likely to separate than manual ones. The treatment of cases with a separated instrument can be either conservative or surgical. A conservative approach involves the following treatment choices: a) bypass of the fragment, b) removal of the fragment, c) instrumentation and obturation coronally to the fragment. Concerning the removal of a separated instrument, a variety of techniques and systems have been developed. Ultrasonics, in combination with the operative microscope constitute the most effective and reliable tools for removing a separated endodontic instrument from a root canal. The likelihood of successful removal depends on: the level of separation (coronal, middle or apical third); location in relation to the root canal curvature; the type of separated instrument; its length; the degree of canal curvature and the tooth type. Several complications may occur during the management of a separated instrument: separation of the ultrasonic tip or file used for bypassing or removing the instrument; further separation of the fragment; perforation; ledge; extrusion of the file into periapical tissues; tooth weakening due to dentin removal, as well as excessive temperature rise in periodontal tissues. Prognosis for a tooth retaining a separated instrument depends on the presence of a periapical lesion, the microbial load of the root canal during the time of separation and the quality of the obturation.

Key words: Broken Endodontic Instrument, Fractured Endodontic Instrument, Separated Endodontic Instrument, Treatment of Instrument Separation, Prognosis of Tooth with Retained Instrument

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Introduction

Instrument separation may occur during the use of several endodontic instruments (hand or rotary files, Gates Glidden burs, lentulo, pluggers, spreaders) made of different materials (NiTi, stainless steel). The mishap of instrument separation, is a frustrating situation for the clinician as it may prevent access to the apex and most of the time, impedes full length instrumentation and obturation of the root canal. As a consequence, the level of difficulty of the certain case augments, while the tooth healing is challenged. The aim of this review is to discuss approaches to, and techniques and methods of, treating endodontic cases with separated instruments, the possible complications and the prognosis for teeth containing file fragments.

Frequency of endodontic instrument separation

According to clinical studies, the overall endodontic instrument separation frequency (either rotary or hand files) is between 1.83% and 8.2%[1-3]. The frequency of rotary instrument separation ranges between 0,13% and 10%[2,4-15] and includes several kinds and types of instruments. The manual instrument separation frequency is 0.25% to 6%[2,10,16-18].

The highest frequency of instrument separation is presented during the treatment of molars (77% - 89% of all cases)[3,14,18-20]. A greater risk of separation

occurs during treatment of lower molars (50% - 55%), compared to upper molars (25% - 33.3%)[1,2]. Regarding upper molars, the separation of endodontic instruments is three times more liable to occur in the mesio-buccal root canals than the disto-buccal ones, due to the distal curvature of the mesial root[1-3]. As far as the lower molars are concerned, the mesial root canals present a distal and a buccolingual curvature[21]. In fact, the lingual curvature of the mesio-buccal root canal is more severe than the buccal curvature of the mesio-lingual root canal. As a result, the frequency of instrument separation in the mesio-buccal root canals is three times more common than in the mesio-lingual ones[2].

With respect to the root canal curvature, separation frequency rises proportionally to increased curvature: 7% in straight root canals, 35% in averagedly curved ones, and 58% in intensely curved ones[1,19]. Regarding the location of the separated fragment, a higher rate of separation is observed in the apical third (41% - 82.7%)[1-3,14,18,19], a lower one in the mesial third (14.8% - 32%)[1-3,19], and an even lower one in the coronal third (2.5% - 20%)[1-3,19]. The most common separation site is 2mm from the tip of the instrument. The most common sizes of instruments undergoing separation are No 20-40 (ISO). As to taper, separation most commonly happens in files with a taper between 4% and 9%[14,19].

Madarati et al.[22] conducted a study during which the frequency of separation of instruments was examined in both general and endodontic dental practices. Overall, 88.8% of dentists and endodontists have reported instrument separation. Instrument separation was more common among endodontists. This finding is explained by the fact that endodontists carry out more root canal treatments, they treat more difficult cases, and they use rotary instruments to a greater extent than general dentists do[22].

Techniques and methods of endodontic treatment in cases with a separated instrument

No officially approved instructions regarding the treatment of instrument separation have been promulgated to date. An immediate periapical radiograph is recommended so as to confirm the separation of the instrument, locate the instrument in the root canal, evaluate the anatomy of the root canal and measure the length of the fragment[23,24]. When all the above factors have been taken into account, a decision has to be made about the type of treatment to rectify the situation[23,24]. The management of a separated instrument can be conservative and/or surgical. There are three approaches to conservative treatment: a) bypass of the separated instrument, b) removal of the separated instrument, c) instrumentation and obturation of the root canal coronally to the fragment[25]. It is also suggested that the patient should be informed about the instrument separation, the treatment to be followed, and the prognosis for the tooth[23,24].

Bypass of the separated instrument

Bypassing the separated endodontic instrument is considered to be the safest treatment path, given that it does not involve removing an excessive quantity of dentin from the root of the tooth[25,26]. It allows the instrumentation and obturation of the root canal up to the apex and is believed to contribute to a successful treatment outcome[6,17,27,28]. It is also considered to be the first step towards the removal of the separated instrument fragment from the root canal[1], as it reduces the contact between the instrument and the root dentin, and creates space for inserting other instruments, such as ultrasonic tips, able to fully detach the fragment from the root dentin[25]. However, it is a very demanding technique where success depends on the clinician's sense of touch and perseverance[28]. In addition, the success of this procedure depends on the ISO size and taper of the separated instrument.

Bypassing the separated instrument requires the use of hand files[25]. The use of a rotary NiTi instrument is not recommended as an increased risk of a new separation exists[21]. A No 10 K file, precurved to the edge, is used. The file is used with slight pressure and rotated a quarter of a turn to attempt to insert it between the instrument and the root canal wall. Provided that this can be achieved, the file is then carefully advanced until the separated instrument has been completely bypassed and the file reaches the apical foramen. During the bypass attempt, radiographs are necessary to detect any possible erroneous route of the file in time and risk of a perforation avoided[26].

Removal of the separated instrument

The actual removal of a separated instrument is a rather challenging procedure. The difficulty is mainly related to the type of separated instrument and its position in the root canal. As far as manual instruments are concerned, Hedstroem files are more problematic than K files due to their morphology which causes a stronger engagement with the dentin[17,20]. With respect to NiTi instruments, their removal is more difficult than removing instruments made of stainless steel. This is due to NiTi instruments usually separating at a shorter fragment length, more apically, in the curvature of narrow root canals, with the rotation movement locking them into the dentin[29]. NiTi instruments can further separate or shorten due to damage from ultrasonics vibration during the attempt to remove the fragment. Additionally, the shape memory of NiTi alloy increases the level of difficulty because as they are released from the dentin, they tend to straighten and re-engage with the root canal wall[21]. So far, a number of techniques and means of instrument removal have been reported. However, none has been proved to be fully effective[30].

Techniques and systems used for the removal of separated instruments

A separated instrument can be removed with the aid of an endodontic file: after bypassing the fragment with K files No 10-20, instrumentation of the root canal can take place in an effort to loosen the fragment from dentin, engage it with the cutting edges of the inserted file and eventually remove it[26]. Tweezers, endodontic forceps, mosquito and dental pliers can be used when the instrument projects from the root canal orifice. It is recommended to use them with a counterclockwise rotation to assist in disengaging the fragment from the dentin[31-33]. Other techniques that can be applied when the coronal part of the fragment is free and visible include a micro-tube or an injection needle that are applied over the free part of the instrument combined with a Hedstroem file or an orthodontic wire which engage, pull and remove the fragment[34,35].

Endo-Extractor system (Roydent Dental Products, USA)/ Masserann kit (Micro Mega, France)/ Instrument Removal System (San Diego Swiss, USA)/ Separated Instrument Removal System (Vista Dental Products, USA)/ Cancelier instrument and Mounce extractor (SybronEndo, CA)

The above devices are tube-like systems which entrap and pull out the fragment. Removal of dentin around the separated instrument to reveal its coronal section to a length of at least 2mm is required before their appliance. Dentin removal is carried out either with a special trepan kit which is included in each system or with the use of ultrasonics. Especially, the Cancelier instrument removal system and Mounce extractor are systems properly designed for working under the Dental Operating Microscope, in a way which does not obstruct visibility of the separated instrument. Most of these systems are considered to be aggressive, since they entail the risk of root weakening and perforation[33,36-40].

Ultrasonics- Dental Operating Microscope

The systems described above cannot be applied to narrow and curved root canals, especially if the instrument is located deep in the root canal[17]. In contrast, ultrasonics can be inserted in depth into the root canal and can be used in several cases[41,42]. When using ultrasonics, both immediate access and visual contact with the separated instrument are important. The use of an operative microscope allows working under bright illumination and magnification[30], so as to limit the risk of the excessive removal of dentin and possible perforation[2,10,43]. The general opinion is that use of an operative microscope increases the chances of success in removing a separated instrument[20].

Endodontic tips for ultrasonics of various sizes and lengths, are used in different parts of the root canal. Most tips are made of stainless steel, some of which are coated with diamond or zirconia. The coated tips burnish the dentin throughout their length, whereas the uncoated ones only remove dentin at their cutting edge. There are also tips made of titanium alloy which is considered to make them more flexible[30,44].

Especially thin tips are used to remove dentin around the fragment to loosen it and make it more easily removable from the root canal wall[30]. During this process, the ultrasonic tips should move in the reverse direction of rotation to that of the instrument. It has been suggested that the use of citric acid or EDTA combined with ultrasonics, can help the removal of debris and smear layer from the grooves of the instrument and thus facilitate the fragment removal from the root canal[45,46].

It is important to note the Ruddle technique, during which Gates Glidden modified burs are used to create a flat platform in the dentin that surrounds the coronal edge of the separated instrument, before the use of ultrasonics[47]. Gates Glidden burs (No 2-4) are modified by cutting them vertically along their linear axis at their maximum diameter[25]. The platform has to be formed with great care in order for the Gates Glidden bur to remain centered above the instrument and remove equal quantity of dentin from around it, so that any mishap is avoided[25]. After the formation of the platform, ultrasonics remove dentin circumferentially to the fragment. An important aspect of this technique is the use of ultrasonics without water to increase visibility[40].

In order to reduce the possibility of secondary instrument separation, a modified removal technique with ultrasonics has been suggested[46]: The ultrasonic tip works in the inner surface of the curvature of the root canal, avoiding the outer surface of the curvature, so as to maintain the dentin wall that supports the fragment. The detachment of the fragment is assisted by the use of EDTA. The removal of dentin from the inner surface of the curvature ceases when there is a danger of perforation or excessive weakening of the tooth[46]. Although this technique is deemed interesting, it is relatively dangerous. When the dentin is removed from the inner surface of the curvature, where the thickness of the root canal wall can be particularly limited, there is increased risk of a clinical mishap.

Laser

Laser ND:YAG can be used for the removal of a separated instrument in three ways: a) by melting the dentin, bypassing the instrument and removing it with an H file, b) by melting the fragment, c) by welding a connection between a tube and the coronal end of the fragment in order to retrieve it. The following advantages of using the laser technique have been reported: a) minimum dentin removal, b) quick removal of the instrument from the root canal. However, its safety regarding the adjacent periodontal tissues has

not been established in relation to the possibility of an excessive increase in temperature in the outer root surface. Moreover, there is a possibility of carbonizing the dentin, due to high temperature, which may negatively affect the adhesion of the obturation materials to the root canal wall[48,49].

Electrolysis

Dissolving the NiTi fragment through electrolysis has been suggested. The method involves filling of the root canal with a solvent which acts as an electrolyte and dipping two electrodes (anode-cathode) in the electrolyte. The electrode, functioning as the anode is placed in contact with the fragment. The voltage between the two electrodes causes a flow of electrons from the anode to the cathode, release of metallic ions from the fragment to the solvent, and a progressive dissolution of the fragment. The efficiency of the method depends on the type of solvent, its concentration, its pH, as well as the extent of its contact with the fragment[50-53].

So far this method has only been tested in ex vivo[53] or in vitro studies where the fragment was dissolved only sufficiently to allow it to be bypassed with a No 10 K file after 60 minutes[52,54]. What has been suggested is that the advantage of electrolysis is the avoidance of dentin removal from the root canal wall[50,51]. However, the disadvantage is that the solvent used as an electrolyte may cause cytotoxicity especially in combination with insoluble components of the NiTi fragment[55].

Instrumentation and obturation coronally to the fragment

When the conservative removal or bypass of the fragment is impossible, or there is a high risk of a mishap, instrumentation and obturation of the root canal coronally to the fragment with subsequent follow up of the tooth are recommended. In cases of clinical symptoms, periapical lesion, or enlargement of a pre-existing periapical lesion, a surgical endodontic treatment is suggested[25,26].

Surgical endodontic treatment

With respect to the surgical treatment of a separated instrument, the following options are available: surgical removal of the fragment from periapical tissues, apicectomy, root resection, bisection, and intentional replantation. When intense clinical symptoms are observed and conservative removal or bypass of the fragment is not possible, an immediate surgical endodontic treatment is advised[26]. Instrumentation and obturation of the root canal up to the fragment should take place before surgery so that the microbial load of the root canal is significantly reduced[25].

Success rates of treatment techniques

The rates of successful removal of a fragment vary, and depend on such factors as the location of the fragment in relation to the root canal curvature, the depth of the fragment location in the root canal, the type of the instrument, its length, the radius of the curvature, as well as the location of the tooth[17,20,29,56]. A number of studies have assessed the success rate of various techniques of removing instruments in relation to these factors.

According to both in vitro and ex vivo studies, the success rate for treatment of a separated instrument ranges between 70% and 91.8%[56-62] Clinical studies (of in vivo treatment) indicate an even higher range, since they start at 53% and reach 95%[1,3,18,20,27-29,57]. Both bypass and removal of the fragment are included in the above success rates. The lower success rates in some clinical studies may be due to the increased difficulty of treatment under clinical conditions. Different ranges among clinical studies may be attributed to the fact that they were conducted under different and non-comparable conditions with respect to sample choice, technique used, as well as the capability of the clinician. The rate of successful fragment removal (44%-95%) is higher than that of successful instrument bypass (9%-47.7%)[28,61]; something that could be ascribed to the challenging nature of bypass procedure[28].

Removing the instrument is easier with the use of ultrasonics and an operating microscope compared to other techniques[60]. Visibility plays an important part in removing the fragment[28,57]. Removal is easier when the fragment is found in the coronal or mesial third, rather than when it is located in the apical third of the root canal[1,3,20]. With respect to the location of the tooth, the possibility of a successful instrument removal is higher for the anterior and upper teeth compared to the posterior and lower ones[20,27]. When the fragment lies coronally to the curvature, or at the level of the curvature, it is more easily removed than when being beyond the curvature [20,27,29,56,61]. The more severe the curvature, the more the difficulty of its removal[20,27,59]. Finally, longer fragments are more easily removed than shorter ones[20].

Complications

Weakening of dentin mass – danger of perforation or tooth fracture

Tooth fracture

In vitro removal of separated instruments from extracted teeth using ultrasonics or the Masseran system, increased the percentage of fracture in relation to the control group. The reduced resistance to fracture was attributed to dentin removal during the formation of a staging platform[63]. A platform made with a Gates Glidden bur coronally to the fragment significantly reduces resistance to fracture, even if the fragment is not removed, compared to teeth where no attempt at instrument removal has been made[64].

The resistance of a tooth to fracture following the removal of a separated instrument is affected by the location of separation. Studies have shown that the process of removing an instrument from the coronal third has no effect on resistance to fracture. Conversely, instrument removal from the mesial third, and to a greater extent, from the apical third requires significant dentin removal and increases the possibility of a vertical root fracture[57,65,66]. Similar findings relate to the position of the separated instrument and the canal curvature. The removal of an instrument separated before the curvature causes less dentin loss compared to an instrument that is separated inside the curvature or apically to the curvature[56]. However, Shahabinejad et al.[61] found that the location of the fragment does not statistically affect the strength that is required to fracture the tooth.

Fu et al.[67] conducted a retrospective study, in the course of which they recalled 66 teeth over a period of 1-5 years following attempts to remove fragments with the Ruddle technique: no case of fracture was detected. This may be due to the conservative effort of removing the instrument, without excessive dentin removal, the prosthetic restoration, and the occlusal adjustment. Moreover, the presence of periodontal ligament may relieve the pressure of the occlusal forces and reduce the possibility of tooth fracture[67]. This in vivo finding contradicts in vitro research findings.

Perforation

The rates for perforation from in vitro studies of instrument removal range from 5.5% to 13.3%[57-59,61]. Whereas clinical research findings range from 0.5% to 11.6%[1,20,28,57]. In the above studies, perforations occurred in teeth where the instrument was in the apical third[1,57], beyond the root canal curvature[68], and the removal attempt lasted more than 90min[1]. The latter was attributed to the dentist's fatigue, the increased difficulty of the case, or the excessive access cavity preparation of the root canal[1].

Special interest presents the retrieval of a separated instrument from the middle third of the mesial root of maxillary molars. The shaping of a staging platform in combination with ultrasonics, removes considerable amounts of dentin. The remaining dentin thickness in the distal wall of the mesial root, the so called "danger zone", is notably reduced when a distal concavity is present. Usually, the depth, or even existence, of the concavity is impossible to measure or depict radiografically. As a result, such cases run high risks of perforation[69].

Temperature increase in periodontal tissues

The use of ultrasonics without air or water may increase the temperature at the outer surface of the root. An increase in temperature of more than 10˚C above body temperature may inflict damage on the bone of the alveolar process[70-73]. Experiments conducted on animals have shown that an increase in the temperature of periodontal tissues causes bone necrosis, bone resorption, tooth resorption, and ankyloses[70,73,74]. Various clinical cases of temperature increase in periodontal tissues caused by ultrasonics have been reported[75-79].

Temperature increase in the outer surface of roots during the removal of separated instruments from extracted teeth has been examined in the studies of Hashem et al.[79] and Madarati et al.[80] where different ultrasonic tips, without air or water, were used at different powers and durations. The use of ultrasonics at power 5 without water for ≥ 60sec and at power 1 for ≥ 90sec increased the temperature in the outer surface of the root ≥ 10˚C. Consequently, the use of power 5 is not recommended without water, whereas power 1 may be used without water for a time period of < 90 sec[79,80]. Madarati et al.[81] examined the extent to which the use of ultrasonics without water, but with an air spray, can restrict the increase of temperature in the outer surface of the root. The use of air significantly reduced the rise of temperature in the outer surface of the tooth; whereas, the use of ultrasound at volume 1.5 without water or air for ≥ 90 sec increased the temperature by > 10˚C. Adding an air spray at power 1.5 for 120sec prevented a temperature augmentation. When considering the use of air cooling for ultrasonics the risk of causing an air embolism must always be taken into consideration[81]. Generally speaking, the extent of temperature rise depends on the width of the root canal wall, the type of the tip used, the power, and the duration of usage[79,80].

Secondary separation of the fragment

There is a risk of secondary separation of the instrument during attempts at its removal, especially when using ultrasonics. In vitro studies have shown the rate of secondary instrument separation to be low: 1.1%[58] and 3.3%[59]. Terauchi et al.[46] found that fragments located in dentin blocks separated in a shorter period of time when they were very curved and not supported by a dentin wall. The researchers suggest that the most likely causes of a secondary separation of a separated fragment are the following: a) the instrument that broke inside a curvature is subject to internal pressure and the use of ultrasonics adds further fatigue leading to further separation, b) the use of ultrasonics increases the temperature of the internal root canal surface considerably; much more than it does at the external root canal surface. As a result, the flexibility of the instrument is reduced and its separation becomes more likely[46].

On a clinical level, only one study exists where the secondary separation of a fragment during an attempt at its removal is mentioned. Suter et al.[1] used various instrument removal techniques and recorded secondary separation only during the use of ultrasonics. The overall rate of secondary separation was 29%. Specifically, 28% of NiTi instruments, 22% of stainless steel files, and 57% of lentulo secondarily separated during the removal

procedure. The further separation of the instruments increased the difficulty in removing the fragment, but did not affect the chances of its removal. Researchers correlated the high rate of separation with the fact that they used ultrasonics for a long period of time and at high power[1].

Alteration of root canal morphology

During the process of removing a fragment, the morphology of the root canal may suffer alterations. Ward et al.[56] implemented a modified Ruddle technique on acrylic blocks and teeth with separated instruments. A large alteration in the morphology of the root canal was observed following instrument removal. The frequency and degree of alteration of the morphology varied with the location of the fragment in relation to the curvature (10% before the block curvature, 55% inside the curvature, and 100% following the curvature)[56]. Shahabinejad et al.[61] conducted research on extracted teeth using a modified Ruddle technique and reported a transformation of the root canal by 5.7%.

Further complications

The removal of a separated instrument entails the risk of causing further complications such as: a) extrusion of the fragment in periapical tissues (1,1% - 7,5%)[58,59,61,66] and b) separation of the ultrasonic tip or file used during removal or bypass process (1,4%)[61].

Prevention of complications

The systems using trephine burs (e.g. Masseran) are not fully effective and may cause complications[42,82,83]. In contrast, the use of an operative microscope and ultrasonics increases the possibility of a successful removal and reduces that of complications[29,47,56]. In order to avoid a perforation, attention is necessary when using Gates Glidden No 3-4 to shape a platform, especially in the mesial roots of upper or lower molars[84-86], and lower incisors[87]. During the shaping of a platform, radiographic checks on the remaining dentin thickness may not prevent the possibility of perforation[88]. It has been found that, in the case of mesial roots of maxillary molars, radiographs taken with the parallel technique overestimate the remaining dentin thickness, while an angulated technique (21˚) provides the clinician with more accurate information for assessing the risk of perforation[89]. When the fragment lies in the apical third, especially in curved root canals, excessive dentin removal is unavoidable to achieve straight access to the fragment[57]. This is due to the difficulty of focusing a Gates Glidden bur on the coronal edge of the fragment[90]. If the fragment remains invisible to in the microscope, after an attempt to create immediate access, it is recommended that the removal attempt is abandoned[36]. In general, after 45-60 min of attempting to remove the fragment, the risk of perforation increases[1].

The use of a thin ultrasonic tip requires great attention, because it entails the risk of the tip separating in the root canal. This indicates it should be used in low power mode[91]. When the ultrasonic tip approaches a NiTi instrument, it should be prevented from coming in contact with the fragment, as the separated instrument could be broken or consumed. Regarding temperature rise; ultrasonics should be set at low power when used without water[92] and not exceed 60sec of constant use[46]. Up until now, no definitive instructions for the proper use of ultrasonics in order to avoid a temperature increase in periapical tissues have been suggested. Overall, during the removal of a separated instrument all the necessary precautions should be taken so that the least possible damage is caused to the tooth and periapical tissues.

Prognosis

Several views have been voiced as to whether instrument separation affects the prognosis of endodontic therapy. Generally, it has been reported that it reduces the prognosis for tooth maintenance[93] because it inhibits access to the apex and full disinfection of the root canal[83]. In particular, when the instrument separates at the beginning of instrumentation of an infected root canal, its presence affects therapy prognosis negatively, while if the separation occurs during the last stages of instrumentation of an infected root canal, or in an aseptic root canal, the prognosis is better[24,94,95].

The healing rate of 66 clinical cases after an attempt at separated instrument removal with the Ruddle technique was retrospectively examined[67]. Follow-up periods of time ranged between 12 and 68 months and the follow-up rate was 64.7%. Healing criteria included the absence of clinical symptoms, the periapical index PAI $\leq$ 2, and the maintenance of the tooth in function. An overall healing rate of 81.8% was observed. During the early stages of the statistical processing, three factors were found to affect healing: Whether the instrument was removed or not, the presence of perforation, and the quality of the root canal obturation. In cases where the instrument was removed, the healing rate was 86%, whereas in those where it was retained, the healing rate was 50%. In case of perforation, the healing rate was 57%, compared to teeth without perforation where it reached 88%. When the obturation of the root canal was adequate, the healing rate was 93% compared to 64% in cases where the obturation was inadequate. However, the sole factor presenting a statistically significant difference was the quality of the obturation of the root canal[67].

In another study[18], 30 clinical cases of separated instruments that were either: removed, bypassed or retained in the root canal were followed up. The follow-up period of time was at least 12 months, and the absence of clinical symptoms and radiographic findings were set as an index of success. Overall, a success rate of 60% was observed, regardless of the removal or retention of the

instrument, and irrespective of the initial diagnosis. In cases of instrument removal, the success rate was 71.4%; in those of instrument bypass it was 40%, and 64,7% in those cases that were obturated coronally to the fragment. As to the initial diagnosis, the cases with vital pulp had 72.7% success, those with primary pulp infection 58.3%, and those of retreatment 42.9%. These findings indicate that the instrument removal and the root canal infection affect tooth prognosis. However, this correlation was not supported by the statistical analysis[18].

A systematic review and meta-analysis that included two case control studies has been performed[96]. The two studies comprised this systematic review, Spili et al.[10], Crump & Natkin[16], included a total of 199 teeth with a separated instrument with their follow-up examination set at a time of at least 12 months. The following healing criteria were set: full healing, partial healing, and uncertain outcome. Regardless of lesions, teeth with a separated instrument healed in 91% of cases, compared with teeth without a separated instrument where 92% healed. Irrespective of the presence of a fragment, 80.7% of teeth with a lesion healed, while teeth without a lesion showed 92.4% healing. When a lesion did not preexist, teeth with a separated instrument had the same healing rate as those without an instrument (95%). When a lesion did preexist, teeth with a separated instrument had the same healing rate (88%) as those without a fragment (89%). The results of these studies may not be applicable to the conditions met in general dental offices, since they derive from specialist practices and university clinics where conditions are better controlled[96].

Therefore, the separation of an instrument *per se* does not reduce tooth prognosis but makes the full disinfection and hermetic sealing of the root canal problematic. The prognosis of a tooth with a separated instrument depends on a number of factors like: the presence of a lesion, the microbial presence within the root canal at the time of instrument separation and the quality of the obturation. Particularly, in cases where the instrument separation is combined with the presence of a lesion, the tooth prognosis is compromised only when the proper disinfection of the root canal is obstructed.

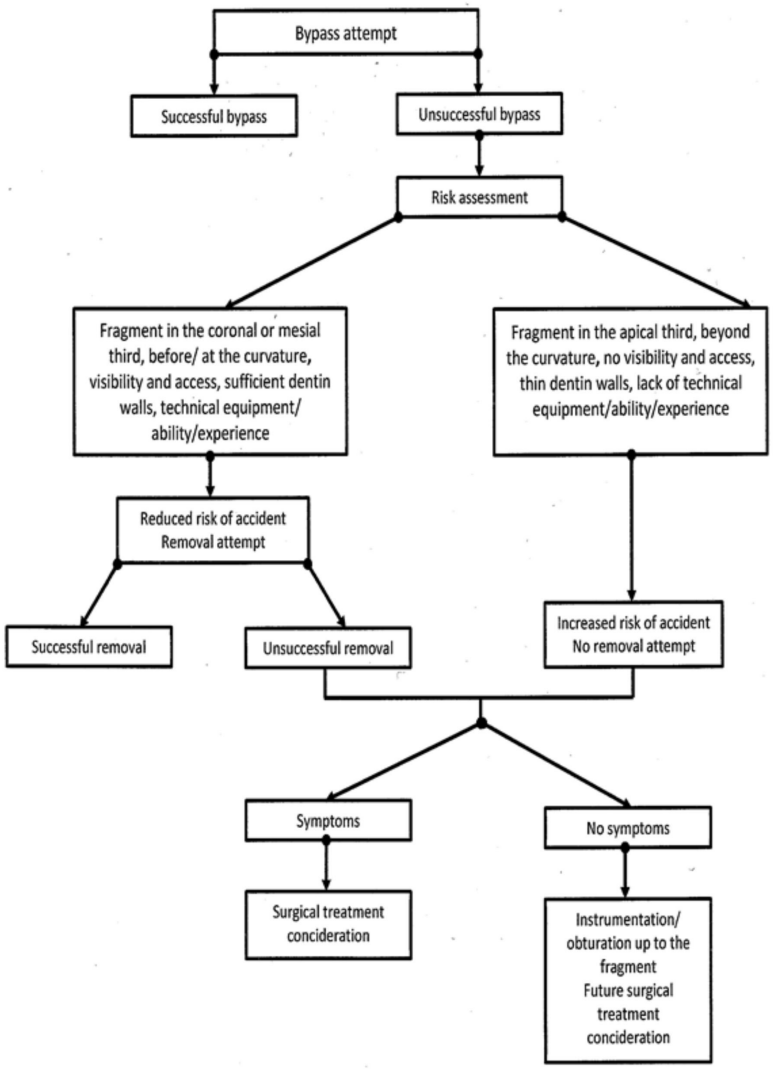

Figure 1. Suggested treatment protocol in cases with separated instruments

Conclusions

In cases of instrument separation, the recommended treatment option is first to endeavor to bypass the fragment because this is considered to be a conservative technique, with low risk of clinical mishap, with the additional advantage of possibly contributing to the final removal of the instrument. Where bypassing the instrument proves impossible, the next treatment option is to try to remove the fragment. At this stage, a careful assessment of the case is necessary so as to be fully aware of the risks involved of causing further complications in each particular case. If removing the instrument is deemed a safe choice, the use of a microscope and ultrasonics is the suggested removal technique.

Removing the instrument is more likely to succeed when the fragment is found in the coronal third, before the root canal curvature, when the root canal curvature is not severe, and when it concerns upper or anterior teeth. However, in cases where the fragment is found either in the apical third or beyond the root canal curvature, or visibility and access are impossible, removing the instrument is not recommended, since there is a high risk of perforation. Further complications that may occur are the weakening of the mass of the tooth, secondary separation of the instrument, extrusion of the fragment into periapical tissues, transformation of the root canal, and raised surface temperature sufficient to cause tissue damage.

Where the removal of the instrument is impossible or dangerous, the possibility of retaining the fragment in the root canal should be evaluated. If clinical symptoms exist, immediate surgical treatment is recommended. If no symptoms are present, instrumentation and obturation of the root canal coronally to the fragment can be performed, and the tooth entered into a follow-up schedule. The possibility of a future surgical treatment, in case of failure, should be taken into account. Retaining the fragment in the root canal does not seem to affect tooth prognosis, which depends mainly on the presence of a lesion, the infection of the root canal at the time of separation, and the quality of the root canal obturation afterwards.

The conclusions of this review, regarding the indicated treatment of cases with separated instruments are briefly outlined in a flow chart (Figure 1).

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