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Comparing techniques for removal of separated endodontic instruments: Systematic review and meta-analysis

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***Abstract*---**Purpose: The goal of this study is to look into several approaches to approaching damaged instruments in the root canal, as well as to show possible outcomes in terms of dentin thickness, fracture resistance, technique success, and clinical time. Methodology: PubMed, Cochrane, Lilacs, Web of Science, Scopus, grey literature, and manual searches were used to conduct the bibliographic research. The titles and abstracts of 506 papers were examined using the inclusion and exclusion criteria. Sixty items were chosen and read in their entirety. This systematic review includes fourteen papers. Results: The ultrasonic approach was the most extensively researched and yielded positive results in general. The more apically positioned the tool is, the more difficult it is to remove it, the more dentin is removed, and the poorer the tooth's fracture

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resistance. When removal is not possible, the bypass technique (bypassing) can be employed, and the GentleWave System approach can be used on weakened teeth or with little dental fragments. Conclusion: The data from laboratory investigations showing the curvature and root third in which instrument fractures originate is related to fracture resistance and success is presented in this comprehensive review. The best results were obtained using the ultrasonic approach. Clinical practice should be based on well-conducted clinical trials.

***Keywords*---**Endodontics, endodontic accident, and fracture resistance.

Introduction

In terms of scientific evolution, new technology, materials, and techniques, endodontics has progressed steadily in recent years. As a result, root canal therapy is quite safe and has high success rates, even in difficult clinical settings. However, endodontic root treatment can be complex, with variable degrees of difficulty and hazards associated during the cleaning, modeling, and filling of the root canals [1].

Several unintended endodontic mishaps might occur at any point during therapy [2]. Separation of endodontic instruments within the root canal is an undesirable event. Because it impairs the chemo-mechanical preparation and obturation process, instrument fracture may delay the completion of the therapy and affect the prognosis [3, 4]. Cyclic flexural fatigue, torsional failure, or a combination of both can lead to instrument fracture [4]. The design of the instrument, the caliber of the files, the fabrication process, the dynamics of the instrument's use, the number of previous uses, the cleaning/sterilization of the instrument, and canals that did not receive irrigation prior to the insertion of the instrument are all factors that contribute to instrument separation. Furthermore, fractures are more common after endodontic retreatment [5-10]. Attempts to remove the material can result in gaps, excessive widening, residue transfer, or holes. As a result, removal procedures must be carried out with caution and be as least intrusive as possible [5]. Given the complexities of clinical care and determining prognosis when an instrument separation occurs, reviewing data from research on this topic is critical for providing evidence and directing clinical practice. As a result, the purpose of this systematic review is to look into techniques for dealing with broken tools in root canals and to offer possible results related to tooth fracture strength, dentin thickness, operating time, and the success rate of various techniques.

Material and Methods
Materials and procedures

The Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols (PRISMA-P) were used to report the current study [9].

Criteria for eligibility
In vitro studies that used strategies to address fractured instruments in the middle or apical third of the root canal in human permanent teeth met the inclusion criteria. PICO was observed. Studies that did not report techniques for dealing with fractured instruments in the root canal, studies that evaluated surgical techniques for removing fractured instruments, studies that evaluated apicectomy and root retreatment, as well as literature reviews, clinical studies, case reports, case series, conference annals, editorial letters, and pilot studies, were all excluded.

Information sources
PubMed, Cochrane, Scopus, and other databases were combed through. Endodontics OR root canal treatment OR root canal OR roots canals OR root canal therapy OR endodontic treatment OR endodontic therapy AND fractured instruments OR broken instrument OR separated instrument OR fractured file OR instrument fragments OR broken file OR separated file OR fractured instrument removal OR broken file OR separated file OR fractured instrument removal (and other synonyms). TABLE 1

Extraction of data
Authors, years of publication, study design, country, sample size, intervention, technique for treating broken instruments in root canal, and outcome of technique used were all collected from the publications included in this review.

Data collection and analysis
The information was categorized based on how a fractured instrument was addressed. The results were compared, and the findings were reported in terms of tooth group and root thirds.

Bias potential
Two reviewers separately assessed the research' potential for bias. The assessment tool for laboratory studies described by Faggion (2012) [10] was used, which consists of a checklist modified from the CONSORT declaration. The abstract, introduction, methodology, results, and discussion of the article, as well as other information were examined. Each criteria that was met properly was marked "yes," whereas those that were not met adequately were marked "no."

TABLE 1: STARTEGY OF SEARCH

PubMed (http://www.pubmed.gov) ((((((((Endodontics [MeSH Terms]) OR Endodontics [Title/Abstract]) OR “root canal treatment” [Title/Abstract]) OR “root canals” [Title/Abstract]) OR “root canal” [Title/Abstract]) OR “Root canal therapy” [MeSH Terms]) OR “Root canal therapy” [Title/Abstract]) OR “endodontic treatment” [Title/Abstract]) OR “endodontic therapy” [Title/Abstract]) AND (((((((“fractured instruments” [Title/Abstract]) OR “broken instrument” [Title/Abstract]) OR “separated instrument”	**208**

[Title/Abstract]) OR "fractured file" [Title/Abstract]) OR "instrument fragments" [Title/Abstract]) OR "broken file" [Title/Abstract]) OR "separated file" [Title/Abstract]) OR "fractured instrument removal" [Title/Abstract])	
Scopus (https://www.scopus.com) TITLE-ABS-KEY (endodontic* OR "root canal treatment" OR "root canal therapy" OR "endodon- tic treatment" OR "endodontic therapy" OR "root canal" OR "root canals") AND TITLE-ABS-KEY ("fractured instrument" OR "broken instrument" OR "separated instrument" OR "fractured instrument removal")	**282**
Web of Science (http:// www.webofknowledge.com) TS = (endodontic* OR "root canal treatment" OR "root canal therapy" OR "endodontic treatment" OR "endodontic therapy" OR "root canal" OR "root canals") AND TS = ("fractured instrument" OR "broken instrument" OR "separated instrument" OR "fractured file" OR "instrument fragments" OR "broken file" OR "separated file" OR "fractured instrument removal")	**101**
LILACS (http://lilacs.bvsalud.org/) (tw:(mh: Endodontics OR "root canal treatment" OR mh: "root canal therapy" OR "root canals" OR "root canal" OR "endodontic treatment" OR "endodontic therapy")) AND (tw:("fractured instrument" OR "broken instrument" OR "separated instrument" OR "fractured file" OR "instrument fragments" OR "broken file" OR "separated file" OR "fractured instrument removal"))	**6**
Cochrane Library (https://www.cochranelibrary.com/) "endodontics" OR "root canal treatment" OR "root canal therapy" OR "endo- dontic treatment" OR " endodontic therapy" OR "root canal" OR "root canals" AND "fractured instrument" OR "broken instrument" OR "separated instrument" OR "fractured file" OR "instrument fragments" OR "broken file" OR "separated file" OR "fractured instrument removal"	**13**
ProQuest (https://about.proquest.com/) (endodontics OR "root canal treatment" OR "root canal therapy" OR "endodontic treatment" OR "endodontic therapy" OR "root canal" OR "root canals") AND ("fractured instrument" OR "broken instrument" OR "separated instrument" OR "fractured file" OR "instrument fragments" OR "broken file" OR "separated file" OR "fractured instrument removal")	**95**
OpenGrey (http://www.opengrey.eu/) (endodontics	**0**

OR “root canal treatment” OR “root canal therapy” OR “root canal” OR “root canals” OR “endodontic treatment” OR “endodontic therapy”) AND (“fractured instrument” OR “broken instrument” OR “sepa- rated instrument” OR “fractured file” OR “instrument fragments” OR “broken file” OR “separated file” OR “fractured instrument removal”)	
Google Scholar (https://scholar.google.com.br/) (“root canal treatment” OR “root canal therapy” OR “endodontic treatment” OR “endo- dontic therapy”) AND (“fractured instrument” OR “broken instrument” OR “separated instrument” OR “fractured file” OR “instru- ment fragments” OR “broken file”) filetype:pdf – (removing patents and quotations)	**123**

Results

There were 22 duplicates among the potentially relevant 528 articles obtained from the PubMed, Lilacs/BBO, Scopus, Web of Science, and Cochrane Library databases and grey literature. So, using the qualifying criteria, 506 papers were assessed based on their titles and abstracts, resulting in the preselection of 60 articles. 14 publications (11–24) were included in the systematic review after full-text analyses, whereas 46 were excluded. Australia [11], Austria [12], China [13–15], the United States [16], India [17], England [18], Iran [19, 20], Japan [21], Sweden [22], and Turkey [23, 24] were among the countries studied. All of the articles were written in English. The removed human teeth samples varied from 21 [15] to 70 [20]. Ultrasound [11, 13, 15, 17, 18, 20, 22–24], bypass [19], microtubes (iRS) [14, 15, 22], GentleWave System [16], Laser (Nd:YAG) [12, 21], Masserann Kit [23, 24], and micro-retrieve & repair system [14,15] were all employed to treat fractured instruments.

Ultrasound

Garg and Grewal (2016) [17] split mesial roots from 40 mandibular first and second molars into two groups of 20 teeth in their study. In one group, Endochuck tips (ESM) were employed, while in the other, ProUltra Endo tips were used. The removal of detached instruments was successful 87.5 percent of the time. In canals with low curvature, removal was 100% successful, 90.9 percent in canals with moderate curvature, and 81 percent in canals with a significant curvature angle. Utilizing the ProUltra system, the average removal time was 63.9 minutes, whereas using the EMS system, it was 50.2 minutes.

In the EMS group, the average increase in root canal volume was 112.5 percent, while in the ProUltra group, it was 55.3 percent. ET25L, ET25S, ET25, and ET20 ultrasonic tips were employed in the study by Shahabinejad et al. (2013) [20]. An experimental group of 70 maxillary premolars and a control group of 35 teeth were divided into two groups of 35 teeth each. In eight teeth (22.8 percent), the file broke in the middle third of the root, and in 27 teeth, it broke in the apical third (77.1 percent). The overall success rate of the removal was 80%. (28 of 35 teeth). The removal success rate for file fragments in the middle third was 100%, whereas the removal success rate for file fragments in the apical third was 74%. Roots with a broken file before the curvature had an 11.5-fold higher success rate than roots with a fractured file after the curvature. The average removal time was 36.3 7.1 minutes. Mechanical tests were performed on 23 successfully removed cracked instruments, and vertical fracture was discovered in 22 of them.

CPR ultrasonic tips were utilized by Souter and Messer (2005) [11]. Sixty mandibular molars were separated into two groups: a control group of 15 teeth with no instrument fracture attempts and an experimental group of 45 teeth. The experimental group's teeth were radiographed and separated into subgroups based on where the fragments were located. 14 teeth with shattered tools were found in the coronal third, 16 in the middle third, and 15 in the apical third of the mouth. Removal was accomplished in all situations in which the file fragment was found in either the coronal or middle third. Only 73.3 percent of files in the apical third were successfully removed (11 out of 15). Overall, 91.1 percent of the participants were successful. In comparison to the control group, removing the fragmented tools from the middle and apical third drastically weakened the root. 18 pairs of mandibular incisors were separated into a control and an experimental group in a study by Mei et al. (2019) [13]. The fractured instruments were removed using the ET25 ultrasonic tip. The force required to fracture the root vertically was lower in the ultrasonic group than in the control group.

Madarati, Qualtrough, and Watts (2009) [18] split 53 dogs into four groups in their study. The control group consisted of eight teeth that were processed with ProTaper F5. The experimental groups were split according to the site of the ProTaper F5 fracture. CPR 5, 6, and 7 ultrasonography tips were used to remove the shattered devices. When compared to the middle and coronal groups (0.9 0.3 and 1.2 0.3 mm, respectively), the apical group's minimum root canal wall thickness (0.6 0.4 mm) was significantly less. When fractured files were removed from the apical third, the canal capacity increased the most, followed by the middle third and coronal third.

Microtube device (iRS) ultrasound

Alomairy (2009) [22] categorized 30 molars with broken NiTi rotary instruments into mild, moderate, and exacerbated subgroups based on curvature angle. The fractured file was removed with ultrasound or the microtube in groups of ten teeth that were randomly distributed (iRS). The overall removal success rate (n = 21) was 70%. Ultrasound was used to remove 12 fragments (80%), while a microtube was used to remove nine (60%). (iRS). The average ultrasound removal time was 40 minutes, while the iRS removal time was 55 minutes.

Hand files, ultrasound, and the Masserann kit

63 anterior teeth with straight canals and 30 first molars with curved canals carrying a pre-fractured instrument were categorized into three subgroups by Gencoglu and Helvacioglu (2009) [23] based on the location of the fragment (apical, middle, or coronal third). There were 21 teeth with straight canals and 10 teeth with curved canals in each group. Ultrasound, a Masserann kit, or the

traditional approach were used to remove the equipment (K files to loosen or drill around the fragments under viewing with an operating microscope). The overall removal success rate (n = 74) was 82.2 percent. When ultrasound tips were utilized in curved canals, the overall success rate was 93.3 percent, compared to 66.6 percent when the conventional approach was used. The Masserann kit had a success rate of 47.6% in straight canals, 95.2 percent with ultrasonography, and 80.9 percent with the conventional approach.

Gerek et al. (2011) [24] used ultrasound and the Masserann kit to assess the fracture strength of teeth after the removal of fractured instruments. Thirty-nine mandibular incisors were separated into three groups, each consisting of 13 teeth: ultrasonic, Masserann kit, and control (no attempt of instrument fracture). K files (size 30) were cracked at a depth equal to half the instrument's length and radiographed to check that the fracture occurred in the canal's middle third. The force required to fracture the roots in the control group (278.6 92.5) was significantly higher than that required in the ultrasonography (116.4 49.5) and Masserann kit (85.8 51.2) groups.

Microtube device (iRS), ultrasound, and microretrieve and repair system

Using micro-computed tomography, Yang et al. (2016) [15] investigated the effects of two procedures on the root dentine of mesial canals in mandibular molars (micro-CT). The micro-tube device was only utilized if the ultrasound or trephine efforts failed to remove the instrument. Ultrasound/microtube and micro-retrieve & repair system/microtube were used to split 43 teeth into two groups. Instruments were shattered 5 millimeters apically from the canal's opening. The micro-retrieve & repair system/microtube group had a considerably reduced root canal volume and mean canal diameter after removal (5.3 1.1 mm3 and 0.9 0.1 mm, respectively) than the ultrasound/microtube group (7.6 0.7 mm3 and 1.0 0.1 mm, respectively). The average file removal time in the ultra-sound/microtube group was 25 minutes, while in the micro-retrieve & repair system/microtube group it was 9 minutes.

Microtubes and the Microretrieve & Repair System V 2.0 (iRS)

Meng et al. (2020) [14] used the micro-retrieve & repair system V 2.0 and the microtube device to evaluate the removal of fractured tools in mandibular incisors (iRS). After an instrument fracture in the apical third of the root, micro-CT was used to examine 34 mandibular incisors. The success rate of the removal was 76.5 percent (26 out of 34). Six of the 26 successful cases were removed with a trephine bur, while the other 20 were recovered with the microtube device (iRS). Removal took an average of 8.5 minutes and 5.8 minutes.

Bypass

The success rate and time required to bypass shattered instruments from four rotational systems were compared by Adl et al. (2017) [19]. Based on the manufacturer, sixty mandibular first molars were classified into four groups (15 teeth in each group). The overall success rate (n = 55) was 83.3 percent, with a mean bypass time of 2.6 minutes.

System GentleWave

The GentleWave System was assessed by Wohlgemuth et al. (2015) [16] for the removal of broken instruments from the apical and middle thirds of root canals. Thirty-six first and second molars had K files shattered as far as possible in the apical direction in the canal. 3 percent NaOCl for 5 minutes, distilled water for 30 seconds, 8 percent EDTA for 2 minutes, distilled water for 15 seconds, for a total treatment period of 7 minutes and 45 seconds with the GentleWave System. Three treatment cycles were used to the utmost extent possible. The entire removal of the instrument was deemed a success. File fractures occurred 18 times in the apical third and 18 times in the middle third of the 36 teeth. The apical third had a 61.1 percent success rate, whereas the middle third had an 83.3 percent success rate. The removal of the fractured devices took an average of 10 minutes.

The use of a laser (Nd:YAG)

Laser (Nd:YAG) was utilized to remove stainless steel broken tools from the root canals of 33 mandibular central incisors, lateral incisors, and premolars in a study by Cvikl et al. (2014) [12]. The internal diameter of the root canal was used to split the teeth into two groups. In 16 teeth, stainless steel ISO 15 files (Mani-K-Files, Japan) were utilized, and in 17 teeth, ISO 20 files were used. The energy from the laser was utilized to melt the solder, connecting the broken instrument to the brass tube, and a brass tube loaded with solder was attached to the coronal extremity of the fractured instrument. When more than 1.5 mm of the broken instruments was visible, the removal rate was 77.3 percent, and when less than 1.5 mm was visible, the removal rate was 27.3 percent.

Yu et al. (2000) [21] looked into the ability of the Nd:YAG laser to remove filler material and cracked files from root canals. Thirty-six incisors were split into two groups, each with 18 teeth. The first group underwent traditional endodontic therapy in its entirety (with no attempt of instrument fracture). The 18 teeth in the second group were separated into three groups of six depending on the three irradiation powers employed, and stainless steel Hedströem files were shattered in the apical third during root canal preparation. The dentin around the fragment was removed with a laser, allowing the file to be removed later. The overall time was 478 67.4 s with a power of 1 W, and two of the six fragmented files were successfully removed. The entire duration was 284.7 46.7 s with a power of 2 W, and four of the six fragmented files were successfully removed. The overall duration was 134 20.0 s with a power of 3 W, and four of the six fracture files were effectively removed. The average removal time was 298.9 seconds. Overall, 55.6 percent of the removals were successful.

Bias potential

All of the articles did a good job of explaining the context and aims, the intervention, and the statistical analyses. None of the studies specified the technique utilized to apply the randomization procedure, the person who performed the randomization, or the place where the entire study protocol could be examined. A structured abstract (14.3%), sample size (64.3%), blinding

(14.3%), statistical methods (7.1%), restrictions (35.7%), and funding sources (57.1%) were not always presented clearly. FIGURE 1

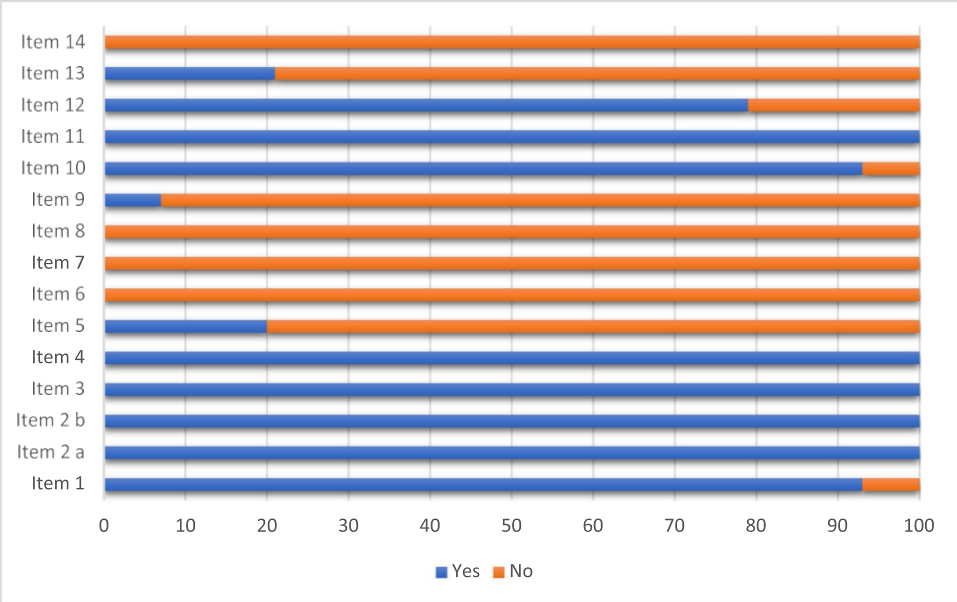

Fig. 1 Risk of bias of the in vitro studies.

Item 1. Structured sum- mary with study design, methods, results and conclusions. Item 2a. Scientific basis and explanation of the reason. Item 2b. Specific objectives and/or hypotheses. Item 3. The intervention for each group, including how and when it was administered, with sufficient details to allow replication. Item 4. Fully defined and pre-specified primary and secondary outcome measures, including how and when they were assessed. Item 5. How the sample size was determined. Item 6. Method used to generate the random allocation sequence. Item 7.

Mechanism used to implement the random allocation sequence, describing all the steps taken to hide the sequence until the intervention was assigned. Item 8. Who generated the random allocation sequence, who entered the teeth and who assigned the teeth for intervention? Item 9. If done, who was blinded after the assignment to the intervention and how. Item 10. Statistical methods used to compare groups for primary and secondary outcomes. Item 11. For each primary and secondary result, results for each group and the estimated size of the effect and yours. Item 12. Limitations of the essay, addressing sources of potential bias, inaccuracy and, if relevant, multiplicity of analyzes. Item 13. Sources of financing and other support, role of funders. Item 14. Where the complete trial protocol can be accessed, if available

Discussion

Instrument fractures are one of the most irritating aspects of endodontic therapy because they prevent access to the apex and, as a result, prevent thorough cleaning, modeling, and sealing of root canal systems, aggravating both the dentist and the patient [4, 25–27]. The most researched technique in this systematic review was ultrasound, which had a high success rate. Due to its widespread usage in daily clinical practice for a variety of operations and specializations, this modality also has a favorable benefit-to-cost ratio. Ultrasound has consistently been recognized as safe and effective among the various file removal methods [23, 28, 29]. However, because this procedure necessitates the removal of a certain amount of dentin, it raises the risk of root fracture.

The total success rate was the same in studies that simply looked at the ultrasonic procedure. The apical third had the lowest success rate when considering the third in which the instrument was shattered [11, 20]. Furthermore, successful removal differed depending on where the shattered instrument was in reference to the canal's curvature [17]. The CRP tip [11] outperformed the Endochuck (ESM) [17], ProUltra Endo tips [17], ET25, ET25L, ET25S, and ET20 [20], and ET25, ET25L, ET25S, and ET20 [20]. The ET25, ET25L, ET25S, and ET20 tips [20] were the quickest (36.3 min). The ET25 ultrasonic tip increased the root canal volume by 135.3 percent while requiring little force to fracture the tooth [13]. The thickness of the canal dentin was less when the instrument fragment was situated in the apical third compared to the middle and coronal thirds when using the CPR 5, 6, and 7 ultrasonic tips [18]. When the fragment was situated in the apical third of the root canal, the increase in root canal volume was larger than when it was located in the middle and coronal thirds.

The ultrasonic approach outperformed the microtube device (iRS) [22]. In compared to the Masserann kit and hand files for removal or bypass, the ultrasound approach had a greater success rate in removing fractured instruments from straight and curved canals [23]. Furthermore, when comparing teeth treated with the ultrasound approach to those treated with the Masserann kit, more power was required to fracture the roots [24]. The dentin in the apical third was lowered to the required thickness in one research using the Masserann kit [29]. Furthermore, in curved canals, the utilization of the Masserann kit and ultrasonic tips is limited [11, 30, 31]. When compared to the micro-retrieve & repair technology, the root canal volume and mean canal diameter were larger following ultrasound removal. Furthermore, the file removal time with ultrasound was 25 minutes and with the micro-retrieve & repair method was 9 minutes [15].
The overall success rate of the bypass approach [19] was the same as the ultrasonic technique, with a shorter mean operating time. In the current investigation, bypassing the fragments was quite successful, whereas in one clinical experiment, only 37.5 percent of broken files were successfully bypassed [32]. Another clinical research found that recovering or bypassing the fragment was successful in 53% of cases. The success rate is affected by the kind of tooth, the placement of the fragment in the canal, the degree of curvature, the length of the fragment, and the type of shattered instruments [33]. Factors relating to the study design may have contributed to the high bypass success rate in this study.
The GentleWave System [16] has a lesser success rate than the ultrasonic approach for removing hair. The GentleWave approach, on the other hand, does not jeopardize dentinal integrity because it does not include modeling or instrumentation, and no extra dentin is removed [30]. As a result, while

attempting to remove shattered instruments from the root canal of teeth with little remaining dentin or fragile teeth, this procedure is recommended.

The success rate was lower than that achieved with ultrasound, the bypass method [19], and hand files (for removal or bypass), but greater than that achieved with the Masserann kit [24] when using the micro-retrieve & repair system V 2.0 and microtube device (iRS). Due to the necessity for specialized, expensive equipment and low success rates when employing laser Nd:YAG [12, 21], this method is deemed the least effective when compared to the other methods studied.

Few papers addressed the randomization of the samples in the examination of the risk of bias among the research included in the current systematic review. The ideal study method is to use all strategies to verify that the results are genuine, that the researcher has no influence over sample selection, and that data is collected from a sufficient number of samples to avoid biased results. The CONSORT declaration is the foundation of the Faggion assessment tool (2012) [10]. Because all of the investigations were conducted in a laboratory setting, uniformity occurred in the selection of which teeth to utilize and which root curvatures to include in the test and control groups in many of the research included in this review. Furthermore, the sample sizes of the investigations did not differ considerably. As a result, we feel that the research' results were not harmed by the lack of or limits in randomization and sample size calculation in these circumstances. It's worth noting that the PRISMA-P [9] guidelines were followed in the study selection procedure, ensuring methodological reliability. In computerized databanks, grey literature, and hand searches, appropriate search criteria were utilized. During the article selection process, the reviewers were blinded. The methodological quality of the studies included in the review was determined using a risk of bias analysis. The inclusion of laboratory research was made since there are more studies with similar outcomes in this methodological design, allowing for better compacting of the results and analysis of a larger number of broken instrument removal approaches. More clinical trials on this topic are needed, as the decision to employ a technology should always be based on the results of randomized clinical trials. Future research should focus on methods and tactics for reducing dentin loss from the root canal and lowering the risk of vertical fracture. Guidelines for the care of fractured instruments are needed, as well as research into solutions for circumstances where separated instruments cannot be retrieved. Furthermore, dentists should be aware of strategies to avoid instrument fracture in the inside of root canals by discarding instruments within the manufacturer's specified timeframe and understanding the instrument's and technique's limitations. Should a fracture occur, it is also vital to have awareness of the techniques utilized to resolve the problem.

Conclusion

The most well-studied method for removing shattered tools from root canals is ultrasound, which has a high success rate. The placement of the shattered instrument in the root canal and the manner employed to remove it determine the risk of root fracture. Because access to these places is more difficult, a fracture of an instrument in or near the curve of the root and in the apical region is unfavorable. A fragment in the apical third causes more dentin to be removed, reducing fracture strength and making removal more difficult. When removing a fragment is not possible, a bypass can be performed, which has a high success rate and a quick operating time. When a tooth is frail or there is little left of the crown, the GentleWave System should be used to remove a broken instrument since it preserves the dentin's integrity.

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