UDC: 616.314.18-71

THE ROLE OF ROTARY SYSTEMS IN ENDODONTIC TREATMENT- REVIEW ARTICLE

УЛОГАТА НА МАШИНСКИТЕ СИСТЕМИ ВО ЕНДОДОНТСКИ ТРЕТМАН-РЕВИЈАЛЕН ТРУД

Mirceska M.[1], Popovska L.[2]

[1]Department of Dental Pathology, Faculty of Dentistry, European University, Skopje, Macedonia, [2]Department of Dental Pathology, Faculty of Dental Medicine, University "Ss. Cyril and Methodius", Skopje, Macedonia

Abstract

The instrumentation of the root canal system involves the enlargement and shaping of the complex endodontic space and its disinfection. Various instruments and techniques have been developed and described for this critical phase of treatment of the root canal system. Although many data on the cleaning and shaping of the root canal system can be found in the literature, the definitive scientific evidence of quality and the clinical proper use of various instruments and techniques remain incomplete. The reasons for this outcome are the existence of methodological problems, due to which it is difficult to make a comparison between the various studies that relate to the different endodontic systems and their implementation in endodontic treatment-retreatment. Therefore, the main purpose of this study is to summarize the data from previous research related to the examination and comparison of various endodontic systems and to consider the role of individual endodontic systems in the final success of the endodontic treatment-retreatment. Key words: efficiency, rotary systems for retreatment, root canals, evaluation, debris extrusion, instrument design.

Апстракт

Подготовката на коренскиот канален систем вклучува проширување и обликување на комплексниот ендодонтски простор и негова дезинфекција. Различни инструменти и техники се развиени и опишани за оваа критична фаза на третман на коренскиот канален систем. Иако многу податоци за подготовка на коренскиот канален систем можат да се најдат во литературата, дефинитивните научни докази за квалитетот и клиничкото соодветно користење на различни инструменти и техники остануваат нецелосни. Причините за ваквиот исход се постоење на методолошките проблеми, поради кои е тешко да се направи споредување меѓу различните истражувања, кои се однесуваат на различните ендодонтски системи и нивната имплементација во ендодонтскиот третман-ретретман. Поради тоа, главна цел на оваа студија е да се сублимираат податоците од претходните истражувања кои се однесуваат на испитување и споредба на различните ендодонтски системи и да се согледа улогата на поедините ендодонтски системи во конечниот успех на ендодонтскиот третман-ретретман. Клучни зборови: ефикасност, ротациони системи за ретретман, коренски канали, евалуација, екструзија на дебрис, дизајн на инструментот.

Introduction

The ultimate goal of endodontic therapy is a fully filled canal system with adequate fillers and preserving a healthy apical periodontium. The success of the endodontic therapy is correlated with the efficiency of the treatment system to be used in this procedure. Technological advances and its implementation in dentistry offer a variety of modern endodontic systems. In the past, endodontic treatment was realized only with the help of manual instruments.

Mechanical instrumentation of the root canal system is a very important stage in endodontic therapy, because it enables the shaping and enlargement of the root canal system and thus allows the irrigation and application of medicaments for more effective results in order to eliminate bacteria and their products. This remains to be one of the most difficult tasks in endodontic therapy. The main objectives of the instrumentation of the root canal system are prevention of periradicular infections and/or realization of endodontic treatment in cases where the infection already exists through:

- Removal of vital and necrotic tissue from the main root canal
- Creation of sufficient space for irrigation and medication
- Preservation of the integrity and location of the apical canal anatomy

- Avoiding iatrogenic damage to the canal system and root structure
- Making the root canal filling easier
- Avoiding further irritation and / or infection of periradicular tissues

The techniques for processing the root canal include: manual instrumentation, root canal instrumentation, ultrasonic instrumentation, use of laser systems and NIT systems (separately or in combination). Ingle[1] formalized a technique for the instrumentation of the root canal system, which was then accepted as a "standardized technique", which compares all other techniques that follow it. In this technique, each subsequent instrument is actively introduced to the working length, after which the canal shape is achieved, which corresponds to the shape and size of the final instrument. Shilder[2] pointed out to the need of removing all organic contents from the entire root canal space using instruments and abundant irrigation and he considers that the final shape of the canal system does not depend solely on the individual and unique anatomy of each root canal, but also on the technique of work and the material for final filling.

Shilder described five design goals for the root channel system:

1. Continuous enlargement of the canal to the funnel form
2. The diameter of the cross section of the canal should be narrower at each point, descending apical
3. The instrumentation of the root canal should follow the shape of the original canal
4. Apical anatomy should remain in its original position
5. The apical opening should be preserved in its original size.

He also described four biological principles:

1. The configuration of the instruments should be appropriate to the root canals
2. To prevent the extrusion of necrotic debris beyond foramen apicale
3. Removal of all tissue from the root canal space
4. Creating a sufficient space for intra-canal medicaments.

Starting from these design goals and biological principles, which are necessary for successful endodontic treatment, the complete endodontic treatment or retreatment is a real challenge. The complexity of the anatomy of the root canal system, including a wide range of variations in number, length, curvature, and root canal diameter; the complexity of the apical anatomy with the accessory canals; the communications between the canal space and the lateral periodontium as well as the furcation area are the factors that affect the final result of the endodontic therapy.

Fauchard, one of the founders of modern dentistry, describes instruments for endodontic instrumentation of root canals and the removal of the pulp in his book "Le chirurgien dentist", giving a systematic description of the instrumentation of the root canal system for the first time at that time. Edvard Maynard is responsible for the development of the first endodontic manual instruments[4, 5]. In 1852, Arthur used thin instruments for processing the root canals[5-9]. In 1885, Gates Glidden instruments were introduced, and in 1915 K-file instruments, and until today, they are part of the standard endodontic instruments. Although standardization of instruments was proposed by Trebitsch in 1929 and again by Ingle in 1958, ISO specifications for endodontic instruments were only accepted in 1974[10].

The first description of the use of machine rotary devices (dental hand pieces) is by Oltramare[11]. He used endodontic rectangular instruments that he introduced passively into the root canal up to the foramen apicale, and then started their rotation. He insists that in curved channels only thin instruments should be used to avoid fractures of the instrument. In 1889, William H. Rollins was the first to use canal instruments with a different design of the working part developed for machine root canal preparation with a 360° rotation. In order to avoid instrument fractures, the rotational speed was limited to 100 r.p.m.[12]. In the following years, several different endodontic rotary systems were introduced, but they all used the same principle of operation (rotation of 360° with rotational speed of 100 r.p.m). In 1928, W & H (Burmoos, Austria) created a system that used a combination of rotational and vertical motion of the instrument. Due to well-managed marketing, Europe's most popular endodontic hand pieces were Hander-handpiece (W & H) in 1958 and Giromatic (MicroMega, Besancon, France) in 1964. The root canal instruments in both systems were made of stainless steel, and their work was limited to only one type of motion; either rotational or vertical motion of the instrument up and down. Racer instruments used vertical motion and Giromatic reciprocal with rotation of 90˚. The dentist could only affect the rotational speed of the hand-piece and the vertical amplitude of the endodontic instrument by moving the dental hand-piece[10, 13].

Then a period of modified endodontic hand-pieces followed, with a main goal to achieve a flexible movement in order to follow the anatomy of the root canal. Excalibur (W & H), which enables the lateral oscillation of the instrument and Endoplaner (Microna, Spreitenbach, Switzerland) are examples of the development of endodontic hand-pieces using flexible motion[10, 13]. The endodontic hand-pieces made of nickel-titanium (NiTi) were first described by Walia et al.[14]. NiTi rotary instruments were introduced later and they used a 360° rotation at low speed. Contemporary endodontics continued to use manual instruments, but NiTi rotary instruments and new techniques for their use (a variety of endodontic motor-rotary systems) offer new perspectives for the instrumentation of the root canal system with the potential to overcome some of the major disadvantages of traditional endodontic instruments.

Discussion

Methodological aspects in the evaluation of the quality of the root canal preparation

During the past decades, a number of studies have been conducted and published on the instrumentation of the root canal system. Unfortunately, the results are partly contradictory and do not result in definitive conclusions that would point to the advantage of certain endodontic systems (manual or motor systems). There is also a significant deficit of studies in terms of the quality of the root canal instrumentation. The fact is that despite the use of endodontic instruments for almost a century, there is no defined mode of operation that would represent a gold standard for their usage[15-17]. In most experimental studies published in the literature, there are a small number of rotary systems or rotational techniques that are examined and compared. Only a few studies included the comparison of four[18, 16, 19-23], five[24] or six and more[11, 25, 26, 27-32] devices and techniques. In most of these published studies, the survey involves a limited number of parameters, which yield results of a limited character. Most of the studies are still focusing primarily on, or only on, the shape of the root canal system and much smaller is the number of studies that analyze the ability of endodontic systems for root canal cleaning. Data on the working time with a certain endodontic system, as well as safety at work (in terms of instrument fractures and periapical debris extrusion as prevention of additional infection) are not usually the target of specific experiments, but are accompanying observations of research designed for other purposes. The wide range of experimental designs of endodontic instruments and different working methods, as well as the various evaluation criteria, do not allow the comparison of results from different studies, even when performed with the same endodontic system and technique.

Many publications do not contain sufficient data on the composition of the examined sample, the experience of the operator, and in particular there has been criticism that many study protocols have been modified by the researchers instead as proposed by the manufacturer of the endodontic system, which may result in inadequate usage of the instruments and lead to false results and conclusions.

Evaluation criteria for endodontic treatment

The first criterion is the cleanliness of the root canal space after endodontic treatment. Several different protocols have been described. Some of these studies are only of descriptive nature[20, 21, 33, 34], whereas others use predefined results. These scoring systems include those with three results[35-36], four results[21, 37], and even seven results according to examined endodontic systems[(38)]. In most of the studies, the cleanliness of the root canal space has been shown to be superior in the coronary section of the root canal compared to the apical third[13]. Because of this, it seems that the evaluation procedure that specifies the results for different parts of the root canal is more adequate.

The second criterion is the evaluation of the postoperative form of the root canal system. The purpose of these type of studies is to evaluate the preservation of the original shape of the canal[39, 40]. It was ascertained that working with samples of extracted human teeth provides better reproduction of the clinical conditions, in contrast to studies using acrylate blockages[41]. On the other hand, the wide spectrum of variations in the three-dimensional morphology of the root canal system makes standardization of the procedure difficult to achieve[42].

There are variations in the length and width of the root canal, the density of the dentin, the irregular calcification of the pulp, the size and location of the apical constriction, and in particular the angle, radius, length and location of the curvatures of the root canal, including the three-dimensional nature of the curvatures[43, 44]. Several techniques have been described to determine the characteristics of the curvature and most commonly used is the Schneider technique[45].

The third criterion is to determine the quantity of debris extrusion through the apical constriction, carried out by collecting and measuring this material during the preparation of the extracted teeth[11, 46-50]. The methods of evaluating the apical debris extrusion are different in various studies, but some can be compared. A significantly higher amount of apical-extruded debris was found in endodontic retreatment with manual instruments compared to motor dental hand-pieces, which is consistent with the results of other studies[51, 52, 53]. Bharathi et al.[52] measured a significantly lower amount of apical extruded debris in endodontic retreatment with ProFile instruments, compared to Hedström's manual instruments. In addition, machine endodontic systems (Mtwo and Reciproc) have proved to be more successful than Hedström's manual instruments in terms of the quantity of apical extrusion (residues in the root canal preparation)[53]. In a study by Topçuoğlu et al.[54], all evaluated techniques for endodontic retreatment caused apical debris extrusion. The researchers concluded that the hand instruments produced significantly more apical extruded material than the ProTaper, D-RaCe and R-Endo rotary systems, while there was no statistical difference between the rotating systems, which is consistent with the results of Pešić et al.[55]. Findings from previous studies have shown that machine endodontic systems tend to direct debris in root canal preparation up to a maximum percent coronary, rather than apically[51, 52, 53, 56]. These studies indicate that the Crown-down technique reduces the possibility of debris extrusion to apical, that is, allows the evacuation of the debris of the root canal treatment in the coronary direction[57].

The fourth criterion is about safety work, and with regard to instrument fractures, apical blockades, loss of working length, perforation. Most of these questions have not been systematically examined in specially designed research for this purpose[58-59]. The instrument fractures may be related to the type, design and quality of the instruments, the material from which they are produced, the rotational speed and torque, the pressure during preparation, the angle and radius of curvature of the root canal, the frequency of use, the technique of sterilization, as well as the level of expertise of the operators.

The fifth criterion is the evaluation of working time in order to obtain conclusions about the efficiency of the system or technique. Data on working time show great differences in identical instruments and techniques, which is due to different methodological approaches, but also due to individual factors (operator)[60, 61].

Conventional rotary systems

Gottingen and coworkers[11] have realized a series of experiments comparing the ability to prepare the root canal system, the ability to completely clean it without residues and the work reliability of various conventional machine endodontic instruments[11]. The study includes a total of 15 groups with 15 teeth. The following endodontic systems were examined: Giromatic, Endolift, Endocursor, Canal-Leader, Canal-Finder, Intra-Endo 3-LDSY, manual preparation, Excalibur, Endoplaner, Ultrasound and Rotofile NiTi Instruments (known as MiTy-Roto-Files).The average curvature of the root canal of the various groups in this study was between 17.81° and 25.11°, and all the root canals were prepared to size # 35 of the instrument. Further studies were performed on Excalibur[62] and Endoplaner. All of these studies have shown that the instrumentation of curved canals using conventional stainless steel instruments in many cases resulted in a serious change in the anatomy of the root canal system, as well as large depositions of debris and smear layers along the canals[20, 29, 63-65]. In addition, in some of the machine endodontic systems there were identified major deficiencies in terms of work safety (apical blockages, loss of working length, perforations and fractures of the instrument[11, 21, 27, 28, 32, 49, 63].

NiTi systems

Metallurgical aspects

The metallurgical aspects of the NiTi instruments refer to the two main characteristics of this alloy composed of approximately 55% nickel and 45% titanium, namely: the memory shape of the metal and the superior elasticity. The elastic limit of bending and torsion is two to three times higher than that of steel instruments. The modulus of elasticity is considerably lower for NiTi alloy than for steel and therefore forces applied to the radicular dentine in the instrumentation of the canal are much smaller than when working with steel instruments.

These unique properties are related to the fact that NiTi is the so-called "alloy with memory of shape", which exists in two different crystalline forms: austenite and martensite. The austenitic phase is transformed into a martensitic phase during stress at a constant temperature and in this form a small force for working with the instrument is required. After the release of the metal from the stress moment, it returns to the austenitic phase and the instrument returns to its original form. Because of these properties of the NiTi alloy, it became a reality to produce endodontic instruments with a larger cone of 2%, which is a standard for steel instruments[66].

Design of NiTi systems

Over the years, several different NiTi systems have been designed and introduced to dentists. The characteristics of the design of the endodontic instrument such as: cutting angle, number of blades, top design, cone and intersection will affect its flexibility, cutting efficiency and torsion resistance.

NiTi Rotary Systems

Initially, NiTi instruments were used to work with conventional motor dental hand-pieces resulting in clinically unacceptable number of instrument fractures. For this reason, manufacturers have created controlled torque motors with individual adjustment of the torque limits for each individual instrument, which aims to allow the instrument to operate under the limit of its elasticity, which reduces the risk of fracture[67].

Root instrumentation studies using various NiTi systems in recent years have focused on analyzing the ability to maintain the curvature of the root canal and maintaining its original form as well as the safety of operations with these new motor systems, while relatively little information is available for their cleaning ability in terms of the quantity of the extrusion material and the absence of debris and smear layer of the walls of the root canal. The results for the Quantec instruments were clearly superior to the hand instruments for the middle and apical third of the roots canals and with best results for the coronary third of the root canal[37]. In a further study, the differences between Quantec SC and Lightspeed[68] were analyzed, with both systems showing almost complete removal of debris. In most samples in both groups, the cleanliness was better in the coronary than in the apical part of the root canals. Studies that analyzed the endodontic systems: FlexMaster, ProTaper and Hyflex showed almost complete removal of the residues of the canal instrumentation[69, 70].

All studies together point to the fact that the various endodontic rotary NiTi systems vary in their efficiency, which is probably due to the different design and technological processing of the NiTi alloy. Regarding the safety aspects, there is a significant incidence of instrument fractures during the instrumentation of the root canal[71]. There may be two types of fractures: torsion and flexural fractures[72]. Flexural fractures may arise from defects in the surface of the instrument and occur after cyclical fatigue[73]. Anatomical conditions such as radius and curvature of the root canal, frequency of use, different torque as well as operator experience are among the main factors for fractures[74-78].

Additional aspects of occupational safety, such as the frequency of apical blockades, perforations, loss of working length or apical residue extrusion, have not been systematically evaluated so far. From the studies presented so far it can be concluded that loss of working length and apical blockages actually occur in some cases, while the perforation is considered to be insignificant. The quantity of apical extruded material was analyzed in a minimal number of studies, and it was found that the difference between manual, conventional machine and rotary NiTi endodontic systems was not significant[13, 49].

Most of the comparative studies present some evidence of shorter working hours with rotary NiTi systems compared to manual instrumentation. The reason for this is considered to be the smaller number of instruments in NiTi systems (ProTaper), which are required for complete endodontic instrumentation.

Conclusion

All the results obtained so far have shown that the use of NiTi endodontic systems results in less tension and better preservation of the form in the instrumentation of the root canals, especially those with curvature; the use of NiTi instruments alone does not provide completely clean walls of the root canal (the purity decreases from the coronal to the apical part of the root canal); the use of EDTA during instrumentation does not completely remove the smear layer; the use of NiTi instruments with the active blade is superior to the instruments with radial surfaces in terms of the purity of the channel walls; the use of NiTi instruments in accordance with the manufacturer's recommendations shows that they are safe to use; it is necessary to use a special engine (endodmotor) at a constant speed that is low and with torque control. All of these conclusions indicate that the application of NiTi instruments facilitates the preparation, especially of curved root canals.

Modern technological developments allow those benefits to be implemented by the manufacturers of endodontic systems in their product range. Therefore, it is necessary to carry out new research that will examine the benefits and characteristics of the new endodontic systems and whose results will give new practical knowledge of the efficiency of these systems in the realization of their goal: endodontic instrumentation of the root canal system with preserved anatomy, maximum possible cleanliness of radicular walls, minimal debris extrusion, shorter working time and greater safety.

Reference

1. Ingle JI. A standardized endodontic technique using newly designed instruments and filling materials. Oral Surg Oral Med Oral Pathol 1961: 14: 83–91.
2. Schilder H. Cleaning and shaping the root canal. DentClin North Am 1974: 18: 269–296
3. Fauchard P. Tractat von den Zahnen. Heidelberg: Reprint Huthig-Verlag, 1984.
4. Ruddle C. Cleaning and shaping the root canal system. In: Cohen S, Burns R, eds. Pathways of the Pulp, 8th edn. St Louis, MO: Mosby, 2002: 231–292.
5. Grossman LI. Endodontics 1776–1976: a bicenten- nial history against the background of general dentistry. J Am Dent Assoc 1976: 93: 78–87.
6. Bellizzi R, Cruse WP. A historic review of endodontics, 1689–1963, Part III. J Endod 1980: 6: 576–580.
7. Anthony LP, Grossman LI. A brief history of root- canal therapy in the United States. J Am Dent Assoc 1945: 32: 43–50.
8. Curson I. History and endodontics. Dent Pract 1965: 15: 435–439.
9. Grossman LI. Pioneers in endodontics. J Endod 1987: 13: 409–415.
10. Hulsmann M. Zur Geschichte der Wurzelkanalauf- bereitung. Endodontie 1996: 5: 97–112.
11. Oltramare Plotzliche Exstirpation der Zahnpulpa mittels einer durch die Bohrmaschine in Rotation versetzten Nadel. Dtsch Monatsschr

Zahnheilk 1892: 32: 407–409.
12. Milas VB. History. In: Cohen R, Burns R, eds. Pathways of the Pulp, 4th edn. St Louis, MO: C.V. Mosby, 1987: 619–634.
13. Hulsmann M. Entwicklung einer Methodik zur standardisierten Uberprufung verschiedener Auf bereitungsparameter und vergleichende In-vitrUntersuchung unterschiedlicher Systeme zur maschinellen Wurzelkanalaufbereitung. Berlin: Quintessence, 2000.
14. Walia H, Brantley WA, Gerstein H. An initial investigation of bending and torsional properties of nitinol root canal files. J Endod 1988: 14: 346–351.
15. Baumgartner JC, Martin H, Sabala CL, Strittmatter EJ, Wildey WL, Quigley NC. Histomorphometric comparison of canals prepared by four techniques. J Endod 1992: 18: 530–534
16. Peters OA, Schonenberger K, Laib A. Effects of four NiTi preparation techniques on root canal geometry assessed by micro computed tomography. Int Endod J 2001: 34: 221–230.
17. PettietteM, Delano E, TropeM. Evaluation of success rate of endodontic treatment performed by dental students with stainless steel K-files and Nickel– Titanium hand files. J Endod 2001: 27: 124–127.
18. Glickman GN, Dumsha TC. Problems in canal cleaning and shaping. In: Gutmann JL, Dumsha TC, Lovdahl PE, Hovland EJ, eds. Problem Solving in Endodontics, 3rd edn. St Louis, MO: Mosby, 1997: 91–122.
19. Lehmann JW, Gerstein H. An evaluation of a new mechanized endodontic device: the endolift.Oral Surg Oral Med Oral Pathol 1982: 53: 417–424.
20. Schaller H, Gotze W, Schommer G. Vergleichende Untersuchungen uber den Dentinabrieb und die Dentinoberfla ¨che nach Bearbeitung mit maschinell angetriebenen Systemen zur Wurzelkanalaufberei- tung. Dtsch Zahnarztl Z 1987: 42: 784–788.
21. Hulsmann M, Bertzbach F. Die Aufbereitung ge krummter Wurzelkanale mit Handinstrumenten und maschinellen Aufbereitungshilfen. Dtsch Zahnarztl Z 1989: 44: 448–451.
22. Briseno BM, Kremers L. Der Einfluss verschiedener Wurzelkanal-Aufbereitungsmethoden und-systeme auf die sogenannte Schmierschicht. Zahnarztl Welt/ Reform 1992: 101: 78–84.
23. Morgenstern G, Nell A, Sperr W. Verschiedene Endodontiewinkelstucke im Vergleich. Eine Studie u ¨ber Giromatic, Endo-Cursor und Megasonic 1400. Z Stomatol 1992: 89: 523–532.
24. Kielt LW, Montgomery S. The effect of endosonic instrumentation in simulated curved root canals. J Endod 1987: 13: 215–219.
25. Nagy CD, Bartha K, Bernath M, Verdes E, Szabo J. A comparative study of seven instruments in shaping the root canal in vitro. Int Endod J 1997: 30: 124–132.
26. Nagy CD, Bartha K, Bernath M, Verdes E, Szabo J. The effect of root canal morphology on canal shape following instrumentation using different techniques. Int Endod J 1997: 30: 133–140.
27. Caporale P, Ciucchi B, Holz J. Vergleichende REM- Studien uber drei Techniken der Aufbereitung von Wurzelkanalen mit acht Instrumenten-Typen. Schweiz Monatsschr Zahnmed 1986: 96: 261–276.
28. Tronstad L,Niemczyk SP. Efficay and safety tests of six automated devices for root canal instrumentation. Endod Dent Traumatol 1986: 2: 270–276.
29. Caselitz R, Kockapan C. Untersuchungen uber die Effektivitat von sechs verschiedenen Methoden zur maschinellen Wurzelkanalaufbereitung. Quintessenz 1990: 41: 597–610.
30. Schadle CW, Velvart P, Lutz F. Die Reinigungswir- kung verschiedener Wurzelkanalinstrumente. Schweiz Monatsschr Zahnmed 1990: 100: 274–285.
31. Hennequin M, Andre JF, Botta G. Dentin removal effijency of six endodontic systems: a quantitative comparison. J Endod 1992:18: 601–604.
32 Hulsmann M, Stryga F. Comparison of root canal preparation using different automated devices and hand instrumentation. J Endod 1993: 19: 141–145.
33. Hulsmann M, Meyer G, Bertzbach F, Grossbernd E. Untersuchungen zur Wurzelkanalaufbereitung mit dem maschinellen Canal-Finder-System. Dtsch Zah- narztl Z 1988: 784–788.
34. Beer R, Gangler P. Rasterelektronenmikroskopische Untersuchung der Wurzelkanalaufbereitung mit Ul - traschall. Dtsch Zahna ¨rztl Z 1989: 44: 334–339.
35. Turek T, Langeland K. A lightmicroscopic study of the efficacy of the telescopic and the Giromatic preparation of root canals. J Endod 1982: 8: 437–443.
36. Velvart P. Effizienz der Wurzelkanalaufbereitung mit Ultraschall und unter Verwendung verschiedener Spul- mittel. SchweizMonatsschr Zahnmed 1987: 97: 756–765.
37. Goldberg F, Soares I, Massone J, Soares IM. Comparative debridement study between hand and sonic instrumentation of the root canal. Endod Dent Traumatol 1988: 4: 229–234.
38. Bertrand MF, Pizzardini P, Muller M, Medioni E, Rocca JP. The removal of the smear layer using the Quantec system. A study using the scanning electron microscope. Int Endod J 1999: 32: 217–224.
39. Kim HC, Kwak SW, Cheung GS, Ko DH, Chung SM, Lee W. Cyclic fatigue and torsional resistance of two new nickel-titanium instruments used in Reciprocation motion: Reciproc versus WaveOne. J Endod. 2012 Apr; 38(4):541–4.
40. Yoo YS, Cho YB. A comparison of the shaping ability of reciprocating NiTi instruments in simulated curved canals. Restor Dent Endod. 2012 Nov; 37(4):220–7.
41. Bürklein S, Hinschitza K, Dammaschke T, Schäfer E. Shaping ability and cleaning effectiveness of two single-file systems in severely curved root canals of extracted teeth: Reciproc and WaveOne versus Mtwo and ProTaper. Int Endod J. 2012 May; 45(5):449–61.
42. Al-Manel KK, Al-Hadlag SM. Evaluation of the root canal shaping ability of two rotary nickel-titanium systems. Int Endod J. 2014 Oct; 47(10):974–9.
43. Cheung GS, Stock CJ. In vitro cleaning ability of root canal irrigants with and without endosonics. Int Endod J 1993: 26: 334–343.
44. Yang G, Yuan G, Yun X, Zhou X, Liu B, Wu H. Effects of two nickel-titanium instrument systems, Mtwo versus ProTaper Universal, on root canal geometry assessed by micro-computed tomography. J Endod. 2011 Oct; 37(10):1412–6.
45. Schneider SS. A comparison of canal preparations in straight and curved root canals. Oral Surg 1971: 32: 271–275.
46. Ferraz CC, Gomes NV, Gomes BP, Zaia AA, Teixeira FB, Souza-Filho FJ. Apical extrusion of debris and irrigants using two hand and three engine-driven instrumentation techniques. Int Endod J 2001: 34: 354–358.
47. Myers GL, Montgomery S. A comparison of weights of debris extruded apically by conventional filing and CanalMaster techniques. J Endod 1991: 17: 275–279.
48. Kramer N, Flessa HP, Petschelt A. Menge des apical uberstopften Materials bei schrittweiser Wurzelkana- laufbereitung. Dtsch Zahnarztl Z 1993: 48: 716–719.
49. Al-Omari MA, Dummer PM. Canal blockage and debris extrusion with eight preparation techniques. J Endod 1995: 21: 154–158.
50. Beeson TJ,Hartwell GR, Thornton JD, Gunsolley JC. Comparison of debris extruded apically in straight canals: conventional filing versus ProFile .04 Taper Series 29. J Endod 1998: 24: 18–22.
51. Huang X, Ling J, Wei X, Gu L. Quantitative evaluation of debris extruded apically by using ProTaper Universal Tulsa rotary system in endodontic retreatment. J Endod 2007; 33(9): 1102−5.
52. Bharathi G, Chacko Y, Lakshminarayanan L. An in-vitro analysis of gutta-percha removal using three different techniques. Endodontology 2002; 14: 41−5.

53. Lu Y, Wang R, Zhang L, Li HL, Zheng QH, Zhou XD, et al. Apically extruded debris and irrigant with two Ni-Ti systems and hand files when removing root fillings: A laboratory study. Int Endod J 2013; 46: 1125−30.
54. Topçuoğlu HS, Aktı A, Tuncay Ö, Dinçer AN, Düzgün S, Topçuoğlu G. Evaluation of debris extruded apically during the removal of root canal filling material using ProTaper, D-RaCe, and R-Endo rotary nickel-titanium retreatment instruments and hand files. J Endod 2014; 40(12): 2066−9.
55. Pešić D, Melih I, Kolak V, Nikitović A, Jakovljević A .Evaluation of apically extruded debris during removal of gutta-percha and Resilon™ using different instrumentation techniques. Vojnosanit Pregl 2018; 75(1): 56–61.
56. Saad AY, Al-Hadlaq SM, Al-Katheeri NH. Efficacy of two rotary NiTi instruments in the removal of Gutta-Percha during root canal retreatment. J Endod 2007; 33(1): 38−41.
57. Al-Omari MA, Dummer PM. Canal blockage and debris extrusion with eight preparation techniques. J Endod 1995; 21(3): 154−8.
58. Castagnola L, Alban J. Uber das Abbrechen von Instrumenten bei der Wurzelkanalbehandlung. Schweiz Monatsschr Zahnheilk 1955: 65: 855–893.
59. Crump MC, Natkin E. Relationship of broken root canal instruments to endodontic case prognosis:a clinical investigation. J Am Dent Assoc 1970: 80: 1341–1347.
60. Kerekes K, Tronstad L. Long-term results of endo-dontic treatment performed with a standardized technique. J Endod 1979: 5: 83–90.
61. Tepel J, Schafer E, Hoppe W. Properties of endodontic hand instruments used in rotarymotion Part 1: cutting efficency. J Endod 1995: 21: 418–421.
62. Schafer E, Tepel J, Hoppe W. Properties of endodontic hand instruments used in rotary motion. Part 2: instrumentation of curved canals. J Endod 1995: 21: 493–497.
63. Hulsmann M, Gambal A, Bahr R. An evaluation of root canal preparation with the automated Excalibur en-dodontic handpiece. Clin Oral Invest 1999: 3: 70–78.
64. Rollinger J, Fritz U, Eiffinger F. Vergleichende REM-Untersuchung nach Wurzelkanalaufbereitung mit den Intraendokopfen 3-LDSY und 3-LD. Dtsch Zahnarztl Z 1990: 45: 748–750.
65. Haikel Y, Allemann C. Effectiveness of four methods for preparing root canals: a scanning electron micro-scope study. J Endod 1988: 14: 340–345.
66. Mandel E, Machtou P, Friedman S. Scanning electron microscope observation of canal cleanliness. J Endod 1990: 16: 279–283.
67. Bergmans L, Van Cleynenbreugel J, Wevers M, Lambrechts P. Mechanical root canal preparation with NiTi rotary instruments: rationale, performance and safety. Status report for the American Journal of Dentistry. Am J Dent 2001: 14: 324–333.
68. Gambarini G. Rationale for the use of low-torque endodontic motors in root canal instrumentation. Endod Dent Traumatol 2000: 16: 95–100.
69. Hulsmann M, Herbst U, Schafers F. A comparative study of root canal preparation using Lightspeed and Quantec SC rotary Ni–Ti instruments. Int Endod J 2003: 36: 748–756.
70. Surakanti JR, Venkata RC, Vemisetty HK, Dandolu RK, Jaya NK, Thota S. Comparative evaluation of apically extruded debris during root canal preparation using ProTaper™, Hyflex™ and Waveone™ rotary systems. J Conserv Dent. 2014 Mar;17(2):129–32.
71. Paque F, Musch U, Hu ¨lsmannM. Comparison of root canal preparation using RaCe and ProTaper rotary Ni–Ti instruments. Int Endod J 2005: 38: 8–16.
72. Schafer E, Fritzenschaft B. Vergleichende Untersu- chung zweier permanent rotierender Wurzelkanalauf- bereitungssysteme auf Nickel–Titan-Basis. Endodontie 1999: 8: 213–226.
73. Peters OA, Barbakow F. Dynamic torque and apical forces of ProFile .04 rotary instruments during preparation of curved canals. Int Endod J 2002: 35: 379–389.
74. Marending M, Lutz F, Barbakow F. Scanning electron microscope appearances of Lightspeed instruments used clinically: a pilot study. Int Endod J 1998: 31: 57–62.
75. Dougherty DW, Gound TG, Comer TL. Comparison of fracture rate, deformation rate, and efficiency between rotary endodontic instruments driven at 150 rpm and 350 rpm. J Endod 2001: 27: 93–95.
76. Peters OA. Current challenges and concepts in the preparation of root canal systems: a review. J Endodon 2004: 30: 559–567.
77. Berutti E, Negro AR, Lendini DP. Influence of manual preflaring and torque on the failure rate of ProTaper rotary instruments. J Endod 2004: 30: 228–230.
78. Fife D, Gambarini G, Britto L. Cyclic fatigue testing of ProTaper NiTi rotary instruments after clinical use. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2004: 97: 251–256.