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ORIGINAL

Micro-CT-Based Comparison of the Effects of Three NiTi Rotary Systems on Root Canal Morphology

Comparación basada en micro-TC de los efectos de tres sistemas rotatorios de NiTi en la morfología del conducto radicular

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Abstract

Introduction and aim: Micro-CT imaging is becoming an increasingly popular method for evaluating root canal preparation techniques. The purpose of this study was a micro-CT imaging-based comparison of the effects of three different NiTi systems (ProTaper Gold (PTG), ProTaper Next (PTN), and WaveOne (WO)) on root canal morphology after instrumentation.

Methods: The study employed a search strategy using four databases (Google Scholar, PubMed, Web of Science, and Cochrane), with identical keyword patterns including micro-CT, rotary, NiTi, instrumentation, and root canal preparation.

Results: The results of the study showed that each system had its own advantages and disadvantages. PTG is similar to ProTaper Universal (PTU) but has a gold proprietary processing that provides better cyclic fatigue resistance and greater flexibility. In comparison to PTN, which is designed for rotary users to minimize the number of files and has an advanced swaggering motion that can reduce the risk of instrument fracture, PTG showed comparable volume and surface area enlargement in the coronal third and middle third of the canal. PTN, on the other hand, resulted in less resin removal and better centering ability. WO, a single-file system designed for inexperienced dentists or those seeking simplicity, enabled more centralized biomechanical preparation, particularly in the apical third of the root canal system compared to the shaping ability of PTG.

Conclusion: The research emphasizes the significance of data-driven decision-making for selecting the most appropriate NiTi system for specific clinical cases. It highlights the value of micro-CT imaging for objective assessment of root canal preparation techniques and suggests that system choice should consider individual needs and practitioner experience. Ultimately, as endodontics continue to advance, further research and development are vital for more efficient root canal enlargement systems that match the intricacies of the root canal system's original anatomy.

Key words: Micro-CT, Root canal preparation, Rotary, ProTaper Gold, ProTaper Next, WaveOne.

Resumen

Introducción y objetivo: La microtomografía computarizada se está convirtiendo en un método cada vez más popular para evaluar las técnicas de preparación del conducto radicular. El objetivo de este estudio fue comparar mediante micro-TC los efectos de tres sistemas NiTi diferentes (ProTaper Gold (PTG), ProTaper Next (PTN) y WaveOne (WO)) sobre la morfología del conducto radicular tras la instrumentación.

Métodos: El estudio empleó una estrategia de búsqueda utilizando cuatro bases de datos (Google Scholar, PubMed, Web of Science y Cochrane), con idénticos patrones de palabras clave que incluían micro-CT, rotatorio, NiTi, instrumentación y preparación del conducto radicular.

Resultados: Los resultados del estudio mostraron que cada sistema tenía sus propias ventajas y desventajas. PTG es similar a ProTaper Universal (PTU), pero tiene un procesamiento patentado de oro que proporciona una mejor resistencia a la fatiga cíclica y una mayor flexibilidad. En comparación con PTN, que está diseñado para usuarios rotatorios con el fin de minimizar el número de limas y tiene un movimiento de balanceo avanzado que puede reducir el riesgo de fractura del instrumento, PTG mostró un aumento comparable del volumen y la superficie en el tercio coronal y el tercio medio del conducto. PTN, por otro lado, dio como resultado una menor eliminación de resina y una mejor capacidad de centrado. WO, un sistema de lima única diseñado para odontólogos inexpertos o que buscan simplicidad, permitió una preparación biomecánica más centrada, especialmente en el tercio apical del sistema de conductos radiculares, en comparación con la capacidad de modelado de PTG.

Conclusiones: La investigación subraya la importancia de la toma de decisiones basada en datos para seleccionar el sistema NiTi más adecuado para casos clínicos específicos. Destaca el valor de la microtomografía computarizada para la evaluación objetiva de las técnicas de preparación del conducto radicular y sugiere que la elección del sistema debe tener en cuenta las necesidades individuales y la experiencia del profesional. En última instancia, a medida que avanza la endodoncia, es vital seguir investigando y desarrollando sistemas de ampliación de conductos radiculares más eficaces que se adapten a las complejidades de la anatomía original del sistema de conductos radiculares.

Palabras clave: Micro-TC, Preparación del conducto radicular, Rotatorio, ProTaper Gold, ProTaper Next, WaveOne.

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Introduction

The biomechanical preparation of a root canal is a crucial step in endodontic therapy. The target is adequate cleaning and shaping of root canal space for residual pulp tissue, infected dentin, and bacteria removal; besides the correct shaping of the canal for the preservation of the original and initial profile of root canal anatomy and the apical foramen position. Complete cleaning and shaping lead to a successful root canal obturation. However, cleaning and shaping are more challenging especially in the case of heavily curved root canals where the prepared canal is always in danger of being diverted away from the original shape[1]. Canal configuration-based root canal instrumentation requires comprehensive and profound morphology knowledge to achieve successful obturation and sealing efficacy and prevention of iatrogenic procedural errors such as perforations, zip, elbow, and asymmetrically poor preparation.

A profound impact on the effective result of endodontic therapy is achieved by the shaping ability of the files. Considering numerous available rotary systems in the market with different shaping abilities, clinicians need to evaluate the features of these techniques impartially to select the superior one according to their clinical demands. Consequently, in order to assess factors such as the shaping capacity of endodontic instruments, several studies focus on the morphometric examination of teeth[2]. Furthermore, several methods have been proposed to identify the canal anatomy, such as radiography, diaphonization, computed tomography (CT), and more recently, micro-CT[3].

In order to choose the most appropriate endodontics rotary systems available on the market to be used in clinical settings, dentists need an unbiased evaluation of capabilities of different systems. The purpose of the present literature review study was to compare different mechanized root canal enlargement methods introduced by Dentsply, Maillefer company with nickel-titanium (NiTi) files and quantifying changes of root canal geometry after instrumentation via the assistance of the micro-CT.

Methodology

The search strategy was proceeded using four databases (Google Scholar, PubMed, Web of Science, and Cochrane), with identical keyword patterns including micro-CT, rotary, NiTi, instrumentation, root canal preparation. The search was executed between February to April 2023, and there was no publication year or journal restriction. The search fields were "Title, Abstract, and Keywords". Initially, 260 full papers were chosen, which later were read and screened. Finally, 33 articles were selected and reviewed for this literature review study.

The article selection strategy and criteria were the micro-CT analysis of the mechanized (rotary and reciprocating) root canal biomechanical instrumentation. In addition, only experiments in English language that examined mechanized root canal systems by using human natural or artificial teeth (any form of tooth group and root canal) or articles that investigated three-dimensional (3D) and two-dimensional (2D) root canal system factors before and after preparation were included in order to minimize the possibility of bias.

Micro-computed tomography applications in endodontics

In the 1980s, Jim Elliott developed x-ray micro-computed tomography (micro-CT or μCT)[4]. Micro-computed tomography is a low scale (micrometer voxel size) but high-resolution 3D imaging modality that nondestructively provides volumetric information from microstructure. Therefore, it has been extensively employed as a reliable approach for quantitatively assessing root canal preparation procedures[5,6].

In other words, in endodontics, by scanning the teeth and comparison of images before and after the instrumentation, microtomography enables us to analyze the root canal systems qualitatively and quantitatively at the micrometer level while maintaining root integrity[2].

In 1989, Tachibana and Matsumoto examined the suitability of the computed tomography (CT) in root canal therapy[7]. Micro-CT results has better resolution quality to conventional CT[2] by providing 3D high resolution pictures of hard tissues that allows evaluation of external morphology and complex internal root canal system[1]. Consequently, this imaging modality has been regarded as the gold standard for laboratory research in the field of endodontics to investigate the effects of different mechanized instrumentation methods[2,8].

To characterize the efficiency of various root canal preparation procedures, micro-CT imaging studies have been employed to analyze three-dimensional parameters, including volume alteration (ΔV), alteration in surface area (ΔSA), surface area to volume alteration ratio (ΔSA/ΔV), center of mass change (CM shift), structure model index alteration (ΔSMI), and two-dimensional factors such as area, perimeter, roundness and form factor of the canal, major and minor diameter[1,5,6,9,10].

Although ex vivo micro-CT (refers to the systems that scan items that used to be alive or samples excised from something that had been alive) is very common in root canal investigations, research conducted on upper molars demonstrated no distinction in canal detection between micro-CT and CBCT images[11]. Moreover, CBCT images obtained with a voxel size below 300 μm have proven to be compatible with micro-CT images for the morphological analysis of hard tissues[12]. Micro-CT has the disadvantage to be slower for scanning compared to

CBCT, and consequently, the levels of radiation exposure are higher. Therefore, micro-CT is recommended for laboratory and ex vivo researches, whereas CBCT is indicated to in vivo analysis[4].

Nickel-titanium rotary preparation

Over the past two decades, endodontic technology has evolved dramatically by many revolutionary changes from the first generation (passive cutting design) to the fifth generation (Offset Design)[13]. In 1988, nickel-titanium (NiTi) alloy called Nitinol composed of 55% nickel and 45% titanium was used in construction of endodontic files which were identical with stainless steel files in size but 2-3 times more flexible. Engine-driven nickel-titanium (NiTi) rotary files need air or electric motors for their motions that can be full rotation like in ProTaper which is a serial files system or reciprocating (incomplete rotation) like in WaveOne which is single file system.

In addition to simplifying and expediting root canal preparation, the utilization of automated NiTi instruments has provided consistent, predictable, and reproducible canal shaping while significantly reducing iatrogenic effects[14]. Gandhi and Gandhi (2011)[7] by using micro-CT showed less transportation as well as better canal centering ability of rotary files in human curved canals compared to hand files.

To evaluate the efficacy of instrumentation of canals, both extracted natural and simulated resin teeth have been widely utilized[2,7,10,15-18]. However, using resin canals with rotary instruments can create possible side effects because the generated heat during instrumentation makes the resin softer. Additionally, due to the micro-hardness difference between dentine (35 to 40 kg/mm^2) and resin material (20 to 22 kg/mm^2), the resin is not cut and instrumented like dentine[7]. Furthermore, the necessity for human operator interference is a significant limitation of the majority of the canal enlargement studies. Therefore, new errorless automatic enlargement studies measuring the canal without the intervention of any operator have been recently proposed[16].

ProTaper Gold

ProTaper family developed by Dentsply is among the most convenient rotary systems in the market for endodontic treatment and retreatment that has NiTi files with progressive but variable conicities and triangular convex cross-sectional architecture with an innovative flute design that integrates several tapers within the shaft[7]. The instrumentation speed and force, kinematics and torque values, and the number of instruments utilized in instrumentation are several factors that may affect the final quality of root canal preparation[19].

ProTaper Gold (PTG) instruments have a progressively tapered design and advanced metallurgy that enhances cutting efficiency and safety using heat treatment technology[20]. ProTaper Gold is identical to ProTaper Universal (PTU) files regarding the morphology of the files involving taper, sizes and cross-section. However, PTG has 24% more flexibility and more than twice the resistant to cyclic fatigue due to its modern metallurgy (gold thermal treatment), ensuring a more centered preparation of curved canals. Greater flexibility of ProTaper Gold is extremely crucial in finishing files, during negotiation of difficult curved apical parts[21].

According to Silva et al. (2016)[16], PTG system compared to PTU produces less transportation of curved canals due to their different manufacturing processes that makes PTG files more flexible and decreases their affinity to become straight and unbend in curved canals. In fact, more flexible instruments produce more centrally positioned canal preparations which is the case in PTG compared to PTU[16].

Similarly, another micro-CT imaging study showed the superior potential to preserve the thickness of dentin and less transportation of PTG and PTN in contrast to PTU[22].

In comparison, in spite of their dissimilar size and dimensions, PTG and PTN methods exhibited comparable volume and surface area enlargement in the coronal third and middle third of the canal. It may be suggested that thermal treatment of the PTG instruments alloy can induce plastic deformation of files and cutting edges damage during usage that result in reduced cutting ability[22].

CBCT imaging analysis of shaping ability of PTG continuous rotary files based on M-wire technology compared with WaveOne Gold (WOG) reciprocating files based on G-wire technology on moderately curved (25-30 degree) canals of mandibular molars showed PTG has significantly larger removal dentine volume and canal transportation and the less centering ratio at 3mm, 5mm and 7mm from apex Indeed, in this study, WOG respected the initial morphology of the canal more than the PTG file[23]. This result is consistent with Berutti et al. (2012)[31] findings that in comparison to continuous rotary motion, reciprocating movement enables more centralized biomechanical preparation, particularly in the apical third of the root canal system.

ProTaper Next

The ProTaper Next (PTN) system by Dentsply Maillefer represents a relatively modern approach that utilizes specific heat-treated M-wire nickel-titanium instruments, which evidently improves cyclic fatigue resistance and flexibility. PTN produces a special swaggering rotation outside and external to the center of mass of the file as a result of variable regressive or reduced taper pattern and symmetrical bilateral rectangular cross-sectional offset from the rotation axis[13].

According to manufacturer company, PTN instruments are designed to reduce taper lock and screw effect,

reduce file contact with dentinal wall that generates greater space debris, improved flexibility and less fatigue in the instrument[22]. Apart from less PTN file stress, coronally directed debris removal due to the off-centered cross-sectional design, leads to better cutting performance[24].

In a study conducted using micro-CT, which involved twenty-four mandibular first molars, PTG and PTN demonstrated improved preservation of furcation dentin thickness and less transportation compared to ProTaper Universal[22]. Nevares et al. (2016)[25] documented the efficacy of PTN in gutta-percha obturation removal from highly curved canals and its potential application in endodontic re-treatment. Nevertheless, PTN may not achieve complete obturation material removal, necessitating additional supplementary procedures to optimize root canal cleaning. ProTaper Next instruments result in less amount of debris extrusion compared to PTU instruments which can be attributed to their difference in cross-sectional design[25]. In other words, PTN with rectangular geometry allows more coronal elimination of the dentinal debris compared to convex triangular cross-sectional geometry of PTU. Comparison of the peak torque and force of the PTU and PTN instruments during root canal preparation confirmed that the PTN had a higher peak torque consistency that may be attributable to the asymmetric interaction between the dentine and ProTaper Next instrument[19]. Moreover, compared with ProTaper Universal instruments, ProTaper Next instruments offer less dentinal cracks.

Gagliardi et al. (2015)[22] studied shaping abilities of ProTaper Universal, ProTaper Gold, and ProTaper NEXT in aggressive root canals. Surprisingly, although PTN and PTG share neither metallurgy nor geometric design, their centering ability was not influenced drastically by their differences. The results showed PTG and PTN had significantly less transportation and percentage decrease in dentin thickness compared with PTU. Moreover, PTN showed less canal wall contact, therefore, showed more dentine preservation. Also, PTN had less increase in perimeter, the minor diameter of the canals, and surface area compared to PTG and PTU. This finding is supported by the fact that unlike similar geometry of the PTU and PTG, ProTaper NEXT file with the smaller size, the off-centered rotational mass, and the regressive taper minimizes the area of contact with the canal and hence the cutting ability is reduced as well[22].

The centering ability of the file is very critical since it enables the canal walls to be homogeneously shaped and the untouched dentinal wall areas at the end of the instrumentation to be minimized. Another study on the comparative evaluation of centering and shaping abilities of PTN (multifile asymmetrical rotational system) and WaveOne (single-file reciprocating system) in simulated canals revealed that although both systems are made of M-wire, PTN resulted in less resin removal with better centering ability[17]. In disagreement with the theory that files with an off-centered mass have a bigger motion envelope relative to files with the same size and symmetrical mass design, this article reported PTN with superior centering ability. In addition, it was highlighted that the creation of glide paths obviously increased the shaping ability of both systems, and also the number of pecking motions of the WaveOne file to reach the full working length (WL) was reduced by the establishment of reproducible glide paths[17].

In the preparation of curved mesial roots of mandibular molars, micro-CT evaluation ProTaper Next, WaveOne Gold, Reciproc, and ProDesign Logic systems verified that they were significantly identical in terms of increased root canal volume (VI), dentine removed (DR), accumulated hard tissue debris volume (AD) and untouched surface area of the root (UA) parameters, except the structure model index (SMI). SMI is used as a numerical representation of the canal's geometry. After PTN and WOG instrumentation, the SMI change was larger, indicating that these systems generate more rounded preparations[26].

It can be inferred that PTN instruments have a wider taper than those defined by their manufacturer due to their rectangular cross-section and the rotation outside the center of mass, producing a sinuous movement, resulting in a more conical shape preparation. With regard to the effect of the SMI and based on the root morphology, it could be expected that higher SMI values would be optimal from a clinical point of view, given that this would provide more free space for better obturation. In the case of flatter and thinner root canals, on the other hand, an increase in the SMI could contribute to root fragility[26].

WaveOne

Recently, in root canal enlargement, the emphasis is on the principle of "less is more," which implies that the entire cleaning and shaping of the root canal system can be achieved with just one single file[13]. Hence, WaveOne (WO), the single-file NiTi reciprocating system, was introduced into the dentistry market in 2010 by Dentsply Tulsa Dental Specialties. It is a straightforward concept in root canal preparation because unlike many ordinary complicated serial file systems in the market that advocate the application of several NiTi files of various tapers and size to gradually enlarge the canal, WO simply needs a single hand file accompanied by a single WaveOne file to rapidly instrument and prepare the root canal to an acceptable size, shape, and taper from the beginning to the end.

WO files are made out of a unique NiTi alloy so-called "memory wire" (M-wire), produced through a special advanced heat treatment method that gives more instrument flexibility and up to 4 times more resistance to cyclic fatigue as a considerable improvement when compared with other rotary NiTi files[27].

WaveOne instruments are single-use to prevent cross-contamination and to reduce file fatigue, which is even more significant since the work traditionally conducted by three or more rotary NiTi files is done by only one WO file. WO files are distinguished along the whole length of the file with multiple and different cross-sectional designs. At the apical end cross-section, a modified convex triangular geometry with radial land is designed, while at the coronal end, a convex triangular cross-section with a neutral rake angle is seen[28]. This design increases the files stiffness at the level of 5 mm from the apex, which results in lower centering abilities in spite of its reciprocal motion[1].

It should be noticed that WaveOne files should be used with progressive three to four times up and down pecking movements, with only little apical force. If the reproducible glide path is not possible in heavily curved root canals, preparation of apical third should be completed by hand[28]. On the contrary, the previous report paradoxically contradicts the results of Beak et al. (2014)[1] implying creation of a glide path before usage of WO in canals with a sharp curve is beneficial.

Bürklein et al. (2011)[15] demonstrated that the WO rotary instrument offers effective shaping of regularly curved canals in extracted teeth, displaying strong centering capabilities. In an investigation involving 18 extracted mandibular molars treated with the Twisted File (TF), WaveOne (WO), and ProFile (PF) systems, the study evaluated canal volume (CV) and surface area (SA) using micro-CT. Results found that instrumented canals were wider and larger than uninstrumented canals and had larger surface area. Yet, there was no significant difference in the quantity of the surface area canal the volume after instrumentation[15]. Consistent to this result, Nagendrababu and Ahmed (2019)[29] observed no difference between reciprocating and rotary systems in the canal volume and the surface area changes by instrumentation.

Another research showed no significant differences between One-Shape, PTU, TF Adaptive, Reciproc, PTN, and WO systems on transportation and canal curvature in curved mesiobuccal canals of lower molar[19].

Santa et al. (2016)[3] found no significant disparity in canal transportation and shaping efficacy when comparing two Single-file Systems (WO and OneShape) in the instrumentation of 10 maxillary molars featuring single mesiobuccal heavily curved canals, as assessed by micro-CT.

Çapar and Arslan (2016)[19] reported that compared with WaveOne system, PTN, and TF Adaptive systems shows fewer dentinal cracks.

Conclusion

Root canals cleaning and shaping efficiency has been significantly enhanced by NiTi files over the last two decades. Numerous brands are currently available in the market, each offering NiTi alloys with diverse characteristics, including variable cutting edges, cross-sectional shapes, tapering, and variations in the number and spacing of flutes. Appropriate evidence-based data of the shaping properties of reciprocation and rotary files is highly important to help the physicians choose effective systems for different clinical cases.

ProTaper Gold is primarily developed for users of ProTaper Universal who are reluctant to change their technique but would benefit from the improved safety offered by the new metallurgy innovation so-called “gold proprietary processing”.

ProTaper Next (5th generation of rotary systems) is designed for rotary users who want to reduce the number of employed files in practice and benefit from the advanced swaggering motion in order to adopt a minimally invasive technique[30].

WaveOne (4th generation of rotary systems) is designed for inexperienced rotary users who seek simplicity[30]. Single-file systems such as WO is recommended to save the time for both the clinicians and the patients, improve root canal shaping quality and prevent pulpal prion cross-contamination between different patients. The WO file has a different cross-sectional design over its entire active portion that despite the usage of a reciprocating motion, it can affect the centering ability of file. Therefore, tip size and taper of different instruments are suggested to be carefully considered[1]. According to Berutti et al. (2012)[31], when the glide path was created, less canal curvature modification was achieved by WO-reciprocating files. As a consequence, the glide path establishment before application of both reciprocating and rotary motion instrumentation tends to be necessary, particularly in canals with curvature[1,17].

Rotary NiTi systems preserve longitudinal root canal shape, but file separation remains the key disadvantage. In an effort to minimize torsional stress during rotation, various forms of reciprocation movements have been developed, and these have been used either in current or modern file systems. The results indicated better resistance to torsional stresses than rotary files; nevertheless, no existing system can fulfill all the requirements of the ideal instrumentation system[29].

Due to the increasing diversity of rotary and reciprocating systems that are continuously introduced into endodontic practice, well-organized micro-CT studies of root canal system are indispensable for investigating the shaping ability of these systems to explain the mechanisms behind the occurrence of the corresponding procedural errors

and therefore to help dentists to choose the system that fits their expectations and their clinical demands.

A large amount of data can be collected from a µCT scan. The slices can be reconstructed on any plane and the details can be viewed as 2D or 3D pictures. It is possible to display the internal and external anatomy simultaneously or separately, analyze the pictures quantitatively and qualitatively, and evaluate the root canal system32. As a consequence of micro-CT imaging, modifications in the root canal surfaces subjected to instrumentation, the procedural errors, the volume and width of the canal, and the volume of removed dentin can be evaluated to facilitate the comparison of post-instrumentation changes with pre-instrumentation condition[32].

In various research studies, acrylic blocks have been commonly employed to assess the efficacy and safety of different root canal enlargement systems[10,16]. The use of resin blocks in these investigations facilitates the standardization of root canal anatomy, including diameter, length, angle, and curvature radius, thus minimizing variations during the instrumentation process. Nevertheless, it's important to note that resin blocks exhibit distinct properties compared to human teeth, as they do not provide information about the residual dentin thickness after preparation[33]. Therefore, studies utilizing acrylic block specimens should be complemented by an analysis of the shaping capability of enlargement systems in human teeth[18].

Finally, automated rotary and reciprocating armamentaria are excellent aids to improve the efficiency of the endodontic therapy and to achieve good outcomes for patients, providing the considerations of their applications depending on the clinical case are carefully met. Considering the advantages and limitations of the systems, it is the practitioner's decision based on available research evidence to choose the best system that satisfy their requirements and their experience levels. Furthermore, despite many advances in the current root canal enlargement systems, more research conduction is indispensable for developing more effective mechanized root canal enlargement system in the future that would efficiently and quickly clean the entire root canal system with respect to the original anatomy of the canal.

Conflict of interests

The authors declare that there is no conflict of interests.

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