GRANDE RIO UNIVERSITY
POST-GRADUATE PROGRAM IN DENTISTRY

COMPARISON OF FILLING MATERIAL REMOVAL USING HYFLEX REMOVER AND RECIPROC: MICROTOMOGRAPHIC STUDY IN HUMAN CADAVERS

DISSERTATION

VICTOR OCTAVIO CORTES CID

2023

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Dissertation presented to the Post-Graduate Program in Dentistry, Grande Rio University (UNIGRANRIO), as part of the requirements to obtain the degree of Master in Dentistry (Concentration area: Endodontics).

Supervisor
Prof. Dr. Flávio Rodrigues Ferreira Alves

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DEDICATION

To my children Elisheba Cortes and Donovan Victor Cortes

without whom this dissertation would have been completed in this time.

ACKNOWLEDGMENTS

As with any piece of research that results in the production of a dissertation, on the cover, there should be not only the name of the research but also the name of all these unsung heroes, those who varying degrees, provided assistance, encouragement, and guidance and without whom I would not have succeeded. I am very grateful to all those heroes who have given me so much of their time, love, and energy in producing this dissertation, I faced an academic challenge to gain a Master of Science (MSc).

There are so many people I would like to give thanks to. I am so grateful for the time these people have given me to produce this dissertation and finish my MSc. Firstly, I must thank Professor Dr. Flávio Rodrigues Ferreira Alves and associates Professor José Siqueira and Isabela Rôças, for their help and support throughout this process and Unigranrio University, which awarded me the MSc study.

Secondly, I must thank the participants who contributed time. Without their participation in this dissertation could never have been completed, especially Thamyres Magalhães Monteiro, Luis Felipe Jimenez Rojas, Andrea Fagundes Campello, and Marilia Fagury Marceliano Alves.

Thirdly, without the support and love of my family and friends, especially to Karen Brisson, Erica Dennise Morales, Oscar David Rivera Maldonado and Rafaela De Fatima Herrera Solorzano. Thanks, must also go to my brother Omar Cortes and my uncle Jorge Arturo Cortes Rodriguez for the endless love and support they have given me throughout my life.

Also, a big thank you to my children Elisheba Cortes and Donovan Victor Cortes Martinez for the endless amount of support, love, and encouragement to complete my academic journey. They are amazing.

And lastly, I have dedicated this thesis to the Almighty God. Thank you for the guidance, strength, power of the mind, protection, and skills and for giving me a healthy life. For all these gifts, I am thankful to you.

EPIGRAPH

“In questions of science, the authority of a thousand is not worth the humble reasoning of a single individual”

Galileo Galilei

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RESUMO

Objetivo: Comparar a remoção o volume de material obturador removido após o retratamento com os sistemas HyFlex e Reciproc em dentes de mandíbulas de cadáveres. **Materiais e Métodos:** Segmentos mandibulares contendo pré-molares e caninos foram removidos de cadáveres humanos. Destas amostras, 28 dentes unirradiculares inferiores foram selecionados e pareados de acordo com seu tipo e anatomia. Os dentes foram instrumentados com Reciproc R40 e obturados com a técnica de compactação lateral. Na sequência, os segmentos mandibulares foram escaneados com microtomografia computadorizada (micro-CT), e os pares foram divididos em 2 grupos (n = 14), de acordo com o protocolo de retratamento: HyFlex e Reciproc. No grupo HyFlex, o instrumento HyFlex Remover foi utilizado em 2/3 do canal, seguido pelos instrumentos HyFlex CM 40.04 e 50.04 até o comprimento de trabalho (CT). No grupo Reciproc, o R50 trabalhou 2/3 do canal, seguido de mais 2 ciclos até atingir o CT. Em seguida, os blocos de osso foram escaneados novamente. Imagens micro-CT pré e pós-operatórias foram analisadas. **Resultados:** Verificou-se uma diminuição significativa no volume da obturação original após retratamento com ambos os sistemas testados ($P < 0,05$), mas material obturador residual foi encontrado em todos os dentes após o retratamento, independentemente do sistema. A porcentagem de material obturador removido (80,79% para HyFlex e 65,92% para Reciproc) e o tempo de operação foram semelhantes entre os sistemas ($P > 0,05$). **Conclusões:** Ambos os protocolos obtiveram eficácia semelhante nos procedimentos de remoção do material obturador, embora nenhum sistema tenha removido completamente o material obturador.

ABSTRACT

Aim: To compare the volume of intracanal filling material removed after retreatment with HyFlex and Reciproc systems in teeth from cadaveric mandibles. **Materials and Methods:** Mandibular segments containing premolars and canines were removed from human cadavers. From these samples, 28 lower single-rooted teeth were selected and matched according to their type and anatomy. The teeth were instrumented with Reciproc R40 and filled using the lateral condensation. Cadaveric mandibular segments were scanned by micro-computed tomography (micro-CT), and homologous teeth were assigned to 2 groups (n = 14) according to the retreatment protocol: HyFlex and Reciproc. In the HyFlex group, the HyFlex Remover instrument worked 2/3 of the canal, followed by HyFlex CM 40.04 and 50.04 at the working length (WL). In the Reciproc group, R50 worked 2/3 of the canal, followed by more 2 cycles until the WL was reached. Then, the bone blocks were scanned again. Pre- and postoperative micro-CT images were analyzed. **Results**: A significant decrease in the original filling volume was verified after retreatment with both tested systems ($P < .05$), but residual filling material was found in all teeth after the retreatment, independently of the system. The percentage of filling material removed (80,79% for HyFlex and 65.92% for Reciproc) and the operation time were similar between the systems ($P > .05$). **Conclusions:** Both protocols obtained similar efficacy in filling material removal procedures, although no system completely removed the filling material.

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LIST OF ABBREVIATIONS, SYMBOLS AND ACRONYMS

NaOCl	Sodium hypochlorite
DNA	Deoxyribonucleic acid
NiTi	Nickel-Titanium
mCT	Microcomputed tomography
M Wire	International Standards Organization
CM Wire	Light Amplification by Stimulated Emission

1. INTRODUCTION AND LITERATURE REVIEW

Conservative endodontic therapy works on eliminating irritation of the periapical tissues by root canal infection. This can be accomplished by chemomechanical debridement and complete sealing of the root canal system. The first phase is paramount for root canal disinfection because instruments and irrigants act primarily on the main canal, the most voluminous area of the system and harbors the largest number of bacterial cells. Bacterial elimination from the root canal is performed using the mechanical action of instruments and irrigation, as well as the antibacterial effects of the irrigants. Endodontic therapy may not, however, invariably lead to a desirable healing result. Hence, periapical bone destruction, sometimes accompanied by clinical symptoms, may persist or appear following endodontic treatment (BERGENHOLTZ *et al*., 1979). Hundreds of millions of teeth are saved through endodontics, periodontics, and restorative treatments. However, tens of millions of endodontically treated teeth are failing each year for a variety of reasons. Therefore, the future of endodontics will include dealing with the treatment of its failures (WASNIK & BANGA, 2010).

Endodontic failures have been variously ascribed to such local factors as infection, poor debridement, broken instruments, poorly filled root canals, treatment of teeth with open flaring apices, severely curved root ends, perforating internal or external resorptions, fractures in the apical third of the root with the displacement of the separated segments, infected cysts, adjacent infected pulpless teeth, coexisting periodontal disease, occlusal trauma, and rarely, to such systemic factors as age, nutritional deficiencies, hormonal influences, and debilitating diseases. Coronal leakage due to loss of a restoration or recurrent decay may also contribute to endodontic failure (WASNIK & BANGA, 2010).

In 1986, Dr. Herbert Schilder quoted the term “retreatodontics” and discussed that the future of endodontics lies in the “retreatment of endodontic failures.” (JAGTAP *et al.,* 2022). In 1998, the American Association of Endodontists Glossary of Contemporary Terminology for Endodontics defined retreatment as a procedure to remove filling material from the pulp cavity and also to clean and shape the root canal system again (AAE, 2003).

There has been a recent increase in endodontic retreatment, mainly due to the increased emphasis on the preservation of teeth, including those cases in which endodontic therapy has failed. Large cross-sectional studies from different countries have reported that the prevalence of apical periodontitis and other post-treatment periradicular diseases can exceed 30% of all root-filled teeth (BOUCHER *et al*., 2002; DUGAS *et al*., 2003). Post-treatment apical periodontitis is a disease associated with root canal–treated teeth and is primarily caused by a bacterial infection that persists in the root canal system and sometimes in the periradicular tissues. Several studies have reported that the large majority of cases with post-treatment disease are related to clinical procedures that do not meet acceptable standards and consequently fail to control the root canal infection properly. However, even when adequately performed, root canal treatment may result in failure in about 5%–15% of cases (SIQUEIRA *et al*., 2020). These data suggest a considerable need for the treatment of this condition.

Retreatment planning must include a careful evaluation of periapical condition so that a decision can be made among non-surgical (orthograde) re-treatment, surgical (retrograde) procedures or tooth extraction (RUDDLE, 2004).

The main goals of non-surgical root canal retreatment are to re-establish healthy periapical tissues and to completely remove all filling from the root canal system to provide effective cleaning, shaping, and refilling (HAMMAD *et al*., 2008). According to a study, the success rate for surgical treatment after one year is slightly better than

non-surgical: 90.7% versus 80.6%, respectively, according to functional criteria. The outcomes were similar at the four-year evaluation (40 surgically treated and 42 non-surgically treated cases from 1 root canal treatment). Non-surgical retreatment should be considered a primary treatment approach because it offers a more favorable long-term outcome compared with endodontic surgery (TORABINEJAD, 2009; NUDERA, 2015; RODRIGUES *et al*., 2016).

Gutta-percha and endodontic sealer are the most widely used filling materials, and their effective removal in endodontic retreatments is considered essential for success (FRIEDMAN *et al.,* 1993, DUNCAN & CHONG, 2008). The permanence of filling materials in the root canal can compromise the success of an endodontic retreatment procedure. The remaining filling materials that adhere to the dentin walls can shelter microorganisms and necrotic remains, leading to the development of intra-radicular infection (WU *et al*., 2006; VIRDEE & THOMAS, 2017; AZEVEDO *et al.*, 2020).

Besides, necrotic tissue or bacteria covered by filling materials can interfere with the adhesion of new filling materials to the walls. Numerous techniques have been proposed for removing root filling materials, including stainless steel hand files (TAKAHASHI *et al.,* 2009; BRAMANTE *et al.,* 2010) such as the nickel–titanium rotary instruments (BARATTO FILHO *et al.,* 2002; BRAMANTE *et al.,* 2010; MARFISI *et al.,* 2010). Ni-Ti rotary retreatment systems have recently been developed (GERGI & SABBAGH, 2007). These instruments are more efficient than hand instrumentation as they reduce clinical time and operator and patient fatigue (SOMMA *et al.,* 2008). However, none of these techniques effectively remove filling material (HAMMAD *et al.,* 2008; PIRANI *et al.,* 2009).

In 2020, a new rotary instrument designed for the removal of intracanal root filling materials was launched, the HyFlex Remover (Coltene/Whaledent, Altstatten,

Switzerland). This file consists of a 30.07 NiTi instrument with a triple helix design, an open flute, a noncutting tip, and a triple helix section (Figure 1). According to the manufacturer, the HyFlex Remover is treated with a patented heat process (C-Wire) to grant an improved flexibility and an enhanced shape memory that renders the instrument prebendable (PIRANI *et al.,* 2021).

Another alternative to retreatments is the reciprocating systems, which have been widely linked with the single file technique (BARLETTA *et al.,* 2008). However, recent studies showed that reciprocal motion increased the life span of the full sequence instruments and maintained the original canal shape (VARELA-PATIÑO *et al*., 2010; YOU *et al.,* 2010; CAPAR *et al*., 2015). One of the most popular systems is Reciproc (VDW, Munich, Germany). The Reciproc is a novel single-file reciprocating root canal instrumentation system primarily produced for preparation. Recent reports evaluating the gutta-percha removal efficacy of the Reciproc system have demonstrated favorable results (AKBULUT *et al.,* 2016) (Figure 1).

Reciprocating instruments have shown favorable results in retreatment procedures when used with a brushing motion against the root canal walls to remove filling material. Thermo-mechanical treatment of NiTi files provides significant benefits concerning the efficacy and safety of endodontic instruments. Several thermal treatments of NiTi alloys, such as M-wire and CM-wire, have been used to optimize the microstructure of NiTi alloys because they have a great influence on the reliability and mechanical properties of NiTi files (ZUOLO *et al.,* 2013; FRUCHI *et al.,* 2014; RIOS *et al*., 2014; YÜRÜKER *et al.,* 2016; RODRIGUES *et al.,* 2016).

Micro–computed tomographic (micro-CT) imaging is a high-resolution research technology that allows the development of accurate 3-dimensional models and the acquisition of quantitative data. The micro-CT nondestructive imaging process allows repeated exposures and acquisition of information. As such, this imaging mode

renders the assessment of experimental endodontics particularly advantageous, including the assessment of previous canal filling materials (ROSSI-FEDELE *et al*., 2016).

The ability of the micro-CT technique to reveal the detailed three-dimensional anatomy of the root canal space and to allow a reliable quantitative evaluation of various outcome variables involved in the study of canal preparation techniques has been demonstrated (PETERS *et al*. 2000; BERGMANS *et al*. 2001; YANG *et al*. 2011; DE-DEUS *et al*. 2014). Using micro-CT in conjunction with image processing and 3D visualization, it is possible to assess several canal preparation outcomes, such as (i) the area of mechanically untreated (non-instrumented) canal wall (PAQUÉ *et al.,* 2011), (ii) the volume of removed dentine and accumulation of hard-tissue debris resulting from canal preparation (DE-DEUS *et al.,* 2014), (iii) risk areas for perforation, and (iv) root canal transportation (YAMAMURA *et al.,* 2012). Within updated micro-CT-based endodontic research, hard-tissue debris accumulation can be considered soft tissue, liquid, or air (empty canal volume) voxels in the preoperative scan, which are then filled with radiopaque material in the postoperative scan (PAQUÉ *et al.,* 2011).

Non-instrumented canal areas are identified as surface voxels unaffected by mechanical root canal preparation, and, in other words, surface voxels remain in the same place after instrumentation (PETERS *et al*. 2000).

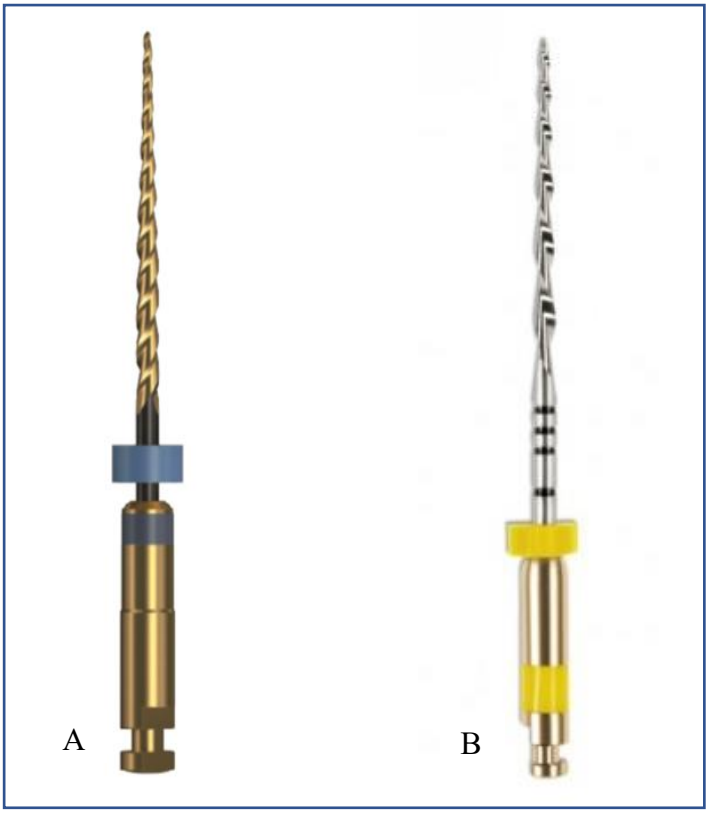

Figure 1. (A) HyFlex Remover and (B) Reciproc R50

2. JUSTIFICATION

The effective removal of filling material from the root canal system is essential to ensure a successful outcome of the retreatment procedure. Until now, the evidence produced regarding this topic is limited to in vitro or ex vivo studies with conflicting results and distant from the clinical reality. In this context, a new methodological design using human cadavers could overcome these limitations. Also, there are few studies on the performance of a Hyflex Remover system, recently launched on the market, in terms of filling material removal. Comparing this new system with another very popular one among clinicians could help them choose the best option.

3. OBJECTIVE

To evaluate the cleaning ability and time required for HyFlex Remover and Reciproc retreatment systems to remove filling material from endodontically treated mandibular premolars of human cadavers.

4. MATERIALS AND METHODS

4.1. Specimen selection and initial preparation

The study protocol was approved by an Institutional Research Ethics Committee (Appendix). The Institutional Laboratory of Human Anatomy of Iguaçu University contributed with human mandible segments, which were obtained from cadavers of 60 to 80 years old at the time of death and had agreed to donate their deceased bodies for teaching and scientific purposes. The human corpses were preserved by infusion and immersion in 10% formalin from 6 to 24 months after arrival at the institution (Figure 2). Twenty-eight uniradicular mandibular premolars and canines were used in the present study, separated into contralateral pairs. The teeth were obtained together with 18 hemimandible segments, which were removed from bodies by sectioning with a diamond disk (Brasseler, Savannah, GA) on a low-speed handpiece and a hand-held saw (Platinum Saw: Han-A tools, Los Angeles, CA). The mandibular segments were kept in 10% formalin while not being used (Figure 2).

All teeth were submitted to preoperative digital periapical radiograph by the paralleling technique, using a dental digital sensor NanoPix (MKLife, Porto Alegre, RS) and a Spectro 70X Seletronic X-ray source (Dabi Atlante Ltda., Ribeirão Preto, SP). The setting parameters included 70 Kvp, 8 mA, and 0.3 exposure. The tooth length was obtained by using the software provided by the device.

The exclusion criteria for the teeth were: apparent signs of cracks or fractures, extensive restorations or caries, internal or external resorption, incomplete rhizogenesis, and more than one main canal.

Figure 2. Cadaveric mandible before removal of the segment

Figure 3. Human cadaver samples immersed in formalin.

4.2. Endodontic treatment

Each tooth was isolated with a rubber dam, and conventional endodontic access cavities were performed using 1012 and 3083 burs (KG Sorensen, Cotia, SP) at high-speed, under water spray. Next, the patency of each canal was established by gently passing a K-type file #10, and the working length (WL) was determined radiographically by using a stainless-steel K-type file #15 (VDW, Munique, Germany). The working length was established at 1 mm short of the apex.

The canals were instrumented by using Reciproc R40 (VDW, Munique, Germany) powered by a VDW Gold motor (VDW) in the reciprocating mode and irrigation with 6 ml de NaOCl 2,5% using a 30-G needle NaviTip (Ultradent, South Jordan, UT). A metal stop, developed in a previous study (CAMPELLO *et al*., 2021), was used to ensure the accuracy and maintenance of the WL during instrumentation. The stop was maintained and fixed at the instrument using two metal screws.

The smear layer was removed with 5 ml de EDTA 17% (Biodinâmica Química e Farmacêutica, Ibiporã, PR) for 3 minutes, and the canals were irrigated again with 2.5 % NaOCl and dried with paper points #40 (All prime, Sao José, SC). Then, the canals were filled with Reciproc 40 gutta-percha cone and AH Plus sealer (Dentsply Sirona, Charlotte, Carolina do Norte, EUA), using the lateral condensation technique with accessories cones FM (Dentsply Sirona, Charlotte, Carolina do Norte, EUA). All access cavities were sealed with Coltosol (Coltene, OH, EUA). The same operator performed all treatment procedures.

4.3. Initial Micro-CT Analysis

All the mandibular anterior segments were scanned in the SkyScan 1273 v.2 (Bruker microCT, Kontich, Belgium) with a 70 μA and 114 μA. The specimens were mounted on metal support for stabilization during scanning. The parameters used for scanning were as follows: 0.5 rotation step, 360° rotation around the vertical axis, and isotropic resolution of 14 μm, and a 1.0-mm-thick aluminum filter. The images of each specimen were reconstructed using NRecon v.1.6.9.16 software (Bruker micro-CT) adjusted with the following parameters: smoothing=8, ring artifact correction=5, and beam hardening correction=50%. For evaluation, the image of each tooth was cropped off the mandible and saved in an individual .nrrd file format. Then, quantitative 3D

analysis was performed using CTAn v1.5.4.0 software (Bruker micro-CT). Finally, the pairing of the samples was defined, and the teeth were portrayed with two different systems.

4.4. Root canal retreatment

On all teeth, absolute isolation was performed before the retreatment procedures, with a rubber dam and clamp number 209, to avoid NaOCl contact with adjacent tissues and simulate clinical conditions.

When the access cavity was reopened, the Gates-Glidden #2 drill (Dentsply Maillefer, Tulsa, Oklahoma, USA) was introduced into the obturator mass to a depth of 2 to 3 mm, in an apical direction. This drill was coupled to a contra-angle and was driven with an E-CONNECT motor in continuous rotation at 1,000 rpm, and torque 1.0 N, creating a guide for the next instruments (Figure 4).

After using the GG drills, the canals were irrigated with NaOCl, and two different systems were used for the retreatment of the canals, one in each mandibular hemiarch: HyFlex (Coltene/Whaledent, Altstätten, Switzerland) in one of the hemiarch, and Reciproc R50 (VDW, Munich, Germany) in another hemiarch from a same individual.

4.5 HyFlex Remover system

The Remover instrument 30/07 (Coltene) was used in continuous rotation at 800 rpm and 2.0 Ncm with very light apical pressure. The 19 mm Remover was introduced into the opening created and moved apically until 2–3 mm from the WL until slight resistance to the inward movement was felt. Then it was pulled out while leaning on selective canal walls to dislodge all the gutta-percha. The filling material was removed with three to four in-and-out motions in a downward apical direction. At each file

changing, the root canals were irrigated with 6 mL/1 min of 2.5% NaOCL to wash away all the debris and filling residue. The irrigant was delivered with a peristaltic pump (VATEA, ReDENT Nova, Ranana, Israel). Once all the filling material was removed, scouting and glide path creation was done using manual K-type file #15 (Figure 4).

Once all the filling material was removed, scouting and glide path creation was carried out using manual K-type file #15. With the HyFlex EDM, 40/.04 and 50/.03 files were used for apical preparation in this sequence until they reached the WL. All the files were used according to the manufacturer's recommendations, driven with an electric motor (E-Connect Pro, MKLife, Brasil) at 400 rpm and 2 Ncm. At each file changing or pecking motion, the root canals were irrigated with 6 mL 2.5% sodium hypochlorite to wash away all the debris and filling residue. The irrigant was delivered with a peristaltic pump (VATEA, ReDENT Nova, Ranana, Israel) to keep a constant flow rate of 6 ml/min (Figure 4).

4.6. Reciproc system

The Reciproc R50 (VDW) was used in 2/3 of the root canal operated by an electric endodontic motor (VDW, Sirona) in the reciprocation mode. The instrument was advanced in apical direction with in-and-out movements not exceeding 3 mm. Light pressure was applied during the use.

After 3 gentle in-and-out motion strokes, the instruments were removed from the canal and cleaned off by inserting them into a clean stand with a sponge until the WL was reached. The use of the instrument was followed by irrigation of the root canal with NaOCl. After each file change, the root canals were irrigated with 6 mL 2.5% sodium hypochlorite to wash away all the debris and filling residue. The irrigant was delivered with a peristaltic pump (VATEA, ReDENT Nova, Ranana, Israel) to keep the

flow rate at 6 ml/min. The Reciproc R50 was used to remove the filling material until the file was 3 mm short of the apex according to the manufacturer's instructions.

In the end, irrigation with 2.5% NaOCl was performed, and the canal was dried with #50 paper cones (AllPrime, São José, SC), and the access cavity was sealed with Coltosol. The total volume of 2.5% NaOCl used was 30 ml (Figure 4).

The retreatment procedures were considered complete when the last instrument of the HyFlex sequence or the Reciproc reached the WL, no more filling material was observed on their flutes, and final patency checking and irrigation were performed. The time of the intracanal procedures with instruments was registered, not including the time spent on irrigation instrument changes and radiographs (Figure 4).

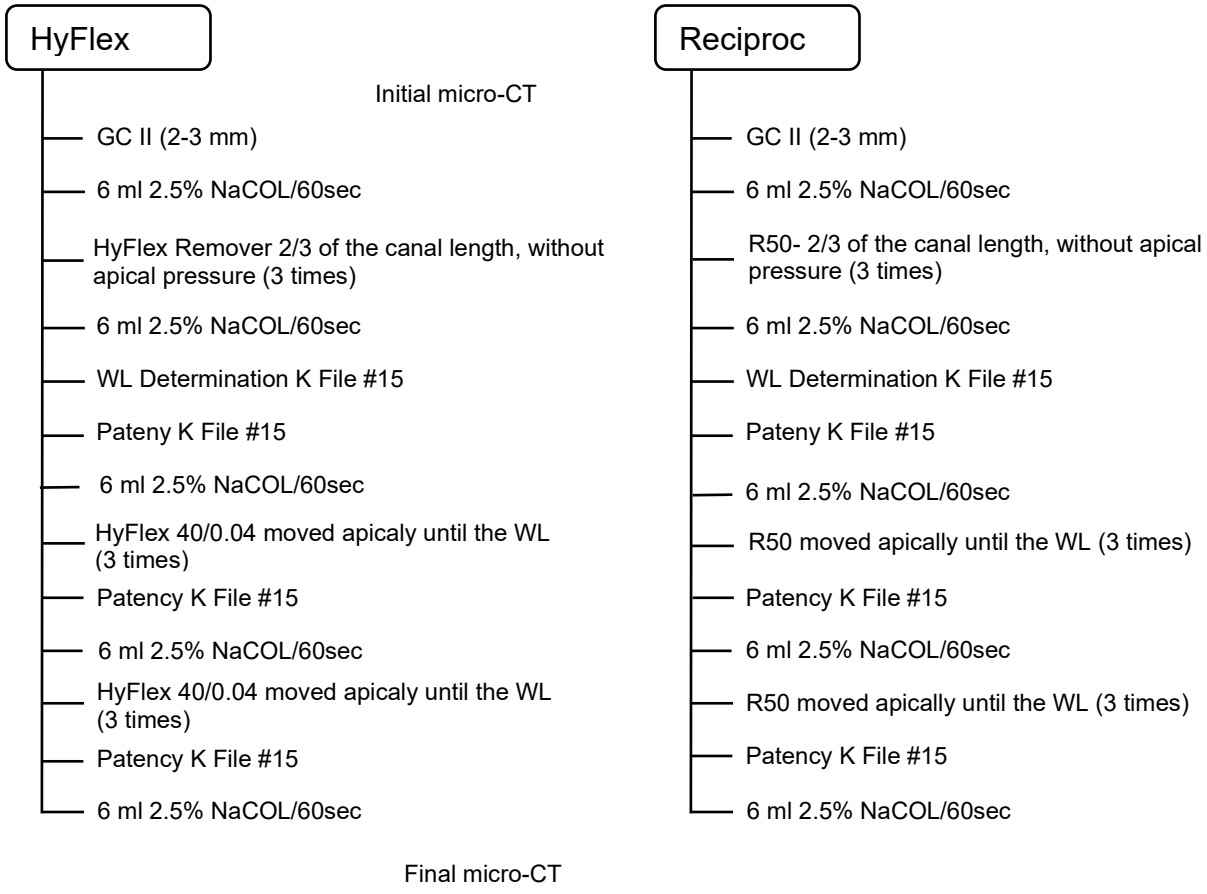

Figure 4. Workflow diagram.

4.7. Final microtomography

A second micro-CT scan was performed using the same parameters described for the initial micro-CT.

4.8. Statistical analysis

Initially, the Shapiro-Wilk test was used to check for data normality. The initial filling volume and time required for retreatment were compared between groups using the t-test for independent samples. The intragroup reduction in filling material volume before and after HyFlex Remover or Reciproc was assessed using the Wilcoxon matched-pair test. The percentage of filling material removed between HyFlex Remover and Reciproc were compared using the Mann-Whitney test. All tests were conducted using the Windows version of SPSS 13.0, (SPSS Inc., Chicago, IL). The threshold for significance was set at 5% ($P < 0.05$).

5. RESULTS

There was no significant difference in the initial filling material volumes between groups ($P > .05$). The mean volume before retreatment was 10.82 mm^3 and 14.02 mm^3 for HyfFlex Remover and Reciproc, respectively. A significant decrease in the original filling volume was verified after retreatment with both tested systems ($P < 0.05$) (Table 1 and Figure 5), with a mean of 80.79% for HyFlex Remover and 65.92% for Reciproc. However, no significant statistical difference was observed in the intergroup analysis ($P > 0.05$) (Table 1, Figure 5 and Figure 6). Residual filling material was found in all teeth after the retreatment, independently of the system.

The retreatment expended time was not different between HyFlex Remover (mean = 48.48 seconds) and Reciproc (mean = 47.64 seconds) ($P > 0.05$) (Table 2). Also, no instrument fracture occurred in both groups.

Table 1. Data from micro-computed tomographic analyses before and after the root canal retreatment.

Tooth pair	HF_ Percentage Removed	REC_ Percentage Removed	HF_Initial Filling Volume	REC_Initial Filling Volume	HF_Post Retreat Filling Volume	REC_Post Retreat Filling Volume
1	71,43	75,25	17,15	19,88	4,90	4,92
2	55,94	50,03	15,73	15,93	6,93	7,96
3	96,43	32,81	9,52	15,85	,34	10,65
4	99,52	35,15	8,25	16,70	,04	10,83
5	68,76	26,01	4,61	4,96	1,44	3,67
6	96,01	96,76	10,78	6,49	,43	,21
7	95,59	84,42	9,74	9,69	,43	1,51
8	87,62	53,10	11,07	11,79	1,37	5,53
9	97,66	52,10	14,13	12,17	,33	5,83
10	98,41	76,59	8,78	6,15	,14	1,44
11	65,28	95,04	13,68	23,37	4,75	1,16
12	86,98	91,86	14,36	25,06	1,87	2,04
13	37,83	77,38	8,38	18,48	5,21	4,18
14	73,64	76,43	5,35	9,80	1,41	2,31
N	14	14	14	14	14	14
Mean	80,79	65,92	10,82	14,02	2,11	4,44
Standard Deviation	19,04	24,02	3,76	6,34	2,30	3,42
Median	87,30	75,84	10,26	14,01	1,39	3,92
Minimum	37,83	26,01	4,61	4,96	,04	,21
Maximum	99,52	96,76	17,15	25,06	6,93	10,83

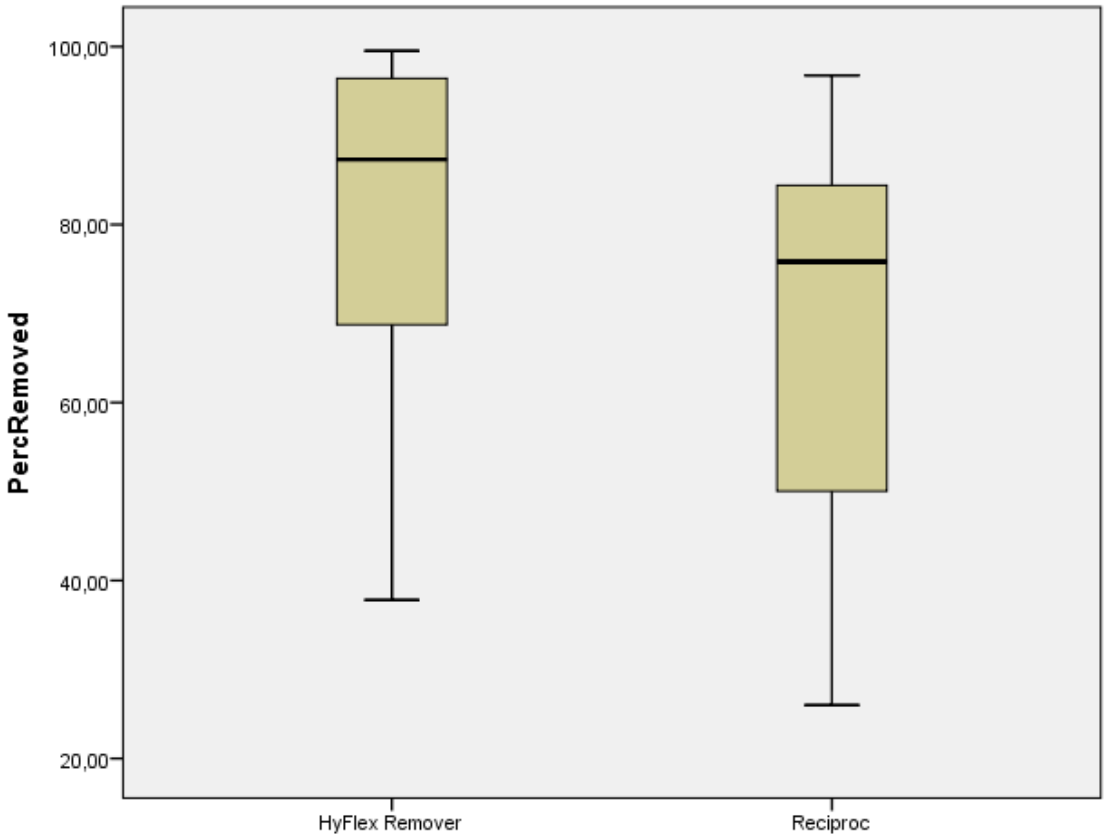

Figure 5. Box plot showing the removed filling material volumes (mm^3) regarding retreatment with HyFlex remover and Reciproc.

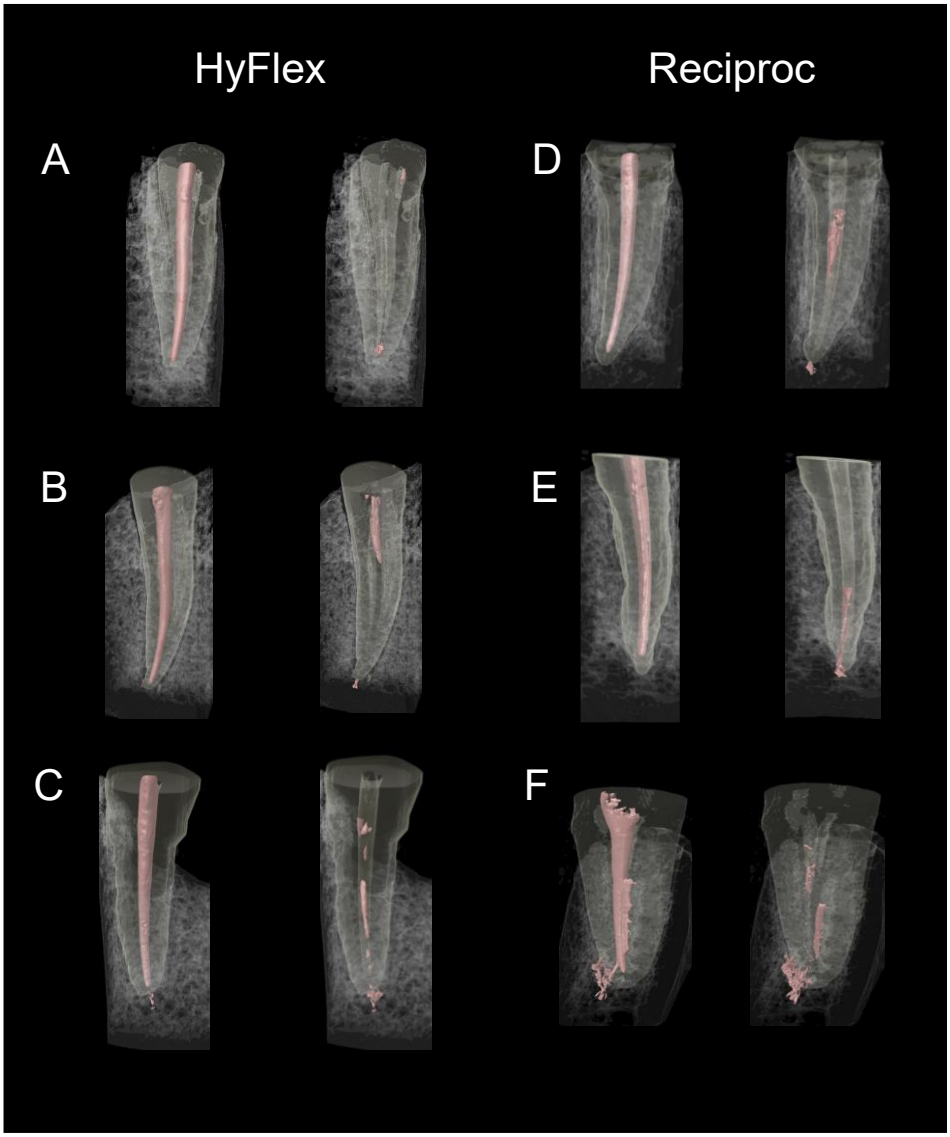

Figure 6. Micro-CT 3-dimensional reconstructions of samples from both HyFlex and Reciproc groups before and after retreatment, showing intracanal filling material removal.

Table 2. Retreatment time and amount (%) of filling material removed after retreatment using HyFlex Remover and Reciproc R50**.**

Group	***n***	**Retreatment time (seconds)**	**Volume before**			**Volume after**			**% Removed**		
			Mean ± SD	**Median**	**Range**	**Mean ± SD**	**Median**	**Range**	**Mean ± SD**	**Median**	**Range**
HyFlex	14	48.48	10.82 ± 3.76	10.26	4.61-17.15	2.11 ± 2.31	1.39	0.04-6.93	80.79 ± 19.04	87.30	37.83-99.52
Reciproc	14	47.64	14.02 ± 6.35	14.01	4.96-25.06	4.45 ± 3.42	3.93	0.21-10.83	65.92 ± 24.02	75.84	26.01-96.76

6. DISCUSSION

The disease associated with root canal-treated teeth can be termed post-treatment apical periodontitis. However, the development of apical periodontitis has been reported in 44.9% of studied cases (KIELBASSA *et al*., 2017), mainly related to persistent or secondary endodontic infections (SIQUEIRA, 2001). In context, non-surgical endodontic retreatment is recommended after unsuccessful root canal treatment (TORABINEJAD *et al*., 2009), and surgical retreatment should be the last resort to save a tooth when all previous treatment modalities failed (HORVATH *et al.,* 2009).

Removal of the previous filling material in retreatments should ideally be complete to expose areas of the root canal system where infection foci may persist, allowing instruments and irrigant solutions to act in the entire root canal space. However, even with recent technological advances, which include the development of different instruments specially designed for retreatment, no technique has been shown to promote thorough filling removal predictably.

This study analyzed and compared two non-surgical endodontic retreatment file systems: the HyFlex Remover and the Reciproc. The study design was innovative, highlighting the use of teeth in their original alveolar bone, with the preserved periodontal ligament. No previous retreatment study has used human cadavers to evaluate extrusion or filling removal. The advantage of these samples is the presence of the periodontal ligament, which offers natural resistance to the (ALVES *et al*., 2018; CAMPELLO *et al*., 2021).

Indeed, the clinical conditions could be better simulated in comparison with dry teeth, which are usually used in retreatment studies without any bulkhead to represent the periapical tissues (SILVA *et al.,* 2014; TOPÇUOĞLU *et al*., 2014). Another strength

was using contralateral teeth, making comparing both systems in homologous teeth possible.

In the present study, the Reciproc conventional was chosen because one study reported a higher capability of the Reciproc endodontic reciprocating system to remove the root canal filling material from the root canal system than Reciproc Blue endodontic reciprocating system and ProTaper Retreatment endodontic rotary system (BAGO *et al.,* 2019).

Several methods have been used for the quantification and volume of filling material remaining after endodontic retreatment, including tooth splitting, diaphanization, radiographic imaging, longitudinal cleavage of the roots for microscopic analysis or photographic records, computed tomography (CT), and more recently micro-CT (CROZETA *et al*., 2016). However, tooth splitting is an invasive procedure that may spread the root canal filling material (BARLETTA *et al*., 2007). The radiological method has known restrictions, like enabling only two-dimensional evaluation of a three-dimensional structure and limited detection of small volumes of the remnants.

We believe that we minimized these disadvantages and obtained standardization by using micro-CT for all samples. In recent years, micro-computed tomographic imaging (micro-CT) has gained increasing significance in the study of hard tissues in endodontics as it offers a reproducible 3D technique for the assessment of the root canal anatomy (ORDINOLA-ZAPATA *et al.,* 2013; LEONI *et al*., 2014).

In this way, non-destructive micro-CT technology can allow the development of accurate 3D models of the internal anatomy and assist in obtaining quantitative morphometric data that are impossible to acquire using conventional methodologies such as clearing, radiography or sectioning techniques. Nevertheless, as with any other methodological approach, micro-CT technology has also limitations: (i) scanning

and reconstruction procedures take considerable time; (ii) the technique is not suitable for clinical use; (iii) the equipment is quite expensive; and (iv) the complexity of the technical procedures requires a high learning curve and an in-depth knowledge of dedicated software.

A significant decrease in the original intracanal filling volume was verified after retreatment with both tested systems, with a mean of 80,79% for HyFlex and 65.92% for Reciproc. For Reciproc, the presented finding is in a middle position compared with two previous studies that found 56.1% (CROZETA *et al.,* 2016) and 76.6% (CROZETA *et al*., 2016), both using distal roots of mandibular molars. However, no significant statistical difference was observed in the intergroup analysis. This result corroborates other studies comparing rotary and reciprocating systems for filing material removal during retreatment, which have shown a similar performance (RÖDIG *et al*., 2014; DE SOUZA *et al*., 2015). Also, a systematic review concluded that NiTi instruments specially designed for retreatment were similar to conventional instruments in filling material removal (ROSSI-FEDELE *et al*., 2017). Therefore, even though they may penetrate the filling mass easily, these instruments are not essential in retreatments, as verified, and the expected reduction of operation time for HyFlex Remover was not observed.

Because these systems are often compared in teeth with similar anatomy, under standardized irrigation conditions, working length and apical preparation sizes, the isolated effects of the operation mode on filling removal may not be of great significance.

Among the few published studies regarding the HyFlex Removes, only two evaluated the filling material removal by this new system (PIRANI *et al*., 2021; KIM *et al*., 2023). Similar to the present study, the authors from the most recent did not find differences comparing HyFlex Remover with other systems. KIM *et al*., (2023) compared

HyFlex remover, D-Race and Mtwo in this case the percentage of residual filling material in the canal in the D-Race, HyFlex Remover, and MTwo groups was 10.58, 12.43, and 7.60%, respectively, without significant inter-group differences ($p > 0.05$). On the other hand, PIRANI *et al.* (2021) find the presence of residual filling material was mainly located in the coronal third (33%), followed by the middle third (28%) and apical third (10%). Also, one Remover instrument fractured, different from the other studies including the present one.

Finding of the present study are also consistent with many others who reported the impossibility of removing 100% of the residual gutta-percha and sealer from root canal walls, irrespective of the technique used for filling material removal (BRAMANTE *et al*., 2010; RÖDIG *et al*., 2014; SILVA *et al*., 2014; KHALIGHINEJAD *et al*., 2017; KIKLY *et al*., 2020).

7. CONCLUSION

Both tested systems performed similarly in the amount of filling material removed and time required for the retreatment. However, none of them completely removed the filling material. The methodological design using human cadavers proved be adequate to evaluate retreatment procedures, better simulating the clinical reality.

8. REFERENCES

American Association of Endodontists. Glossary of Contemporary Terminology for Endodontics. 2020 www.aae.org/specialty/clinical-resources/glossary-endodontic-terms/

Akbulut MB, Akman M, Terlemez A, Magat G, Sener S, Shetty H (2016). Efficacy of Twisted File Adaptive, Reciproc and ProTaper Universal Retreatment instruments for root-canal-filling removal: a cone-beam computed tomography study. Dental Materials Journal 35, 126–131.

Alves FRF, Rôças IN, Provenzano JC, Siqueira JF Jr (2022). Removal of the previous root canal filling material for retreatment: implications and techniques. Applied Sciences (Basel, Switzerland) 12, 102-17.

Azevedo MAD, Silva TG, Fernandes Â, Piasecki L, Fariniuk LF, Silva Neto UX (2020). Endodontic Retreatment Using a Single Instrument from four Nickel-Titanium Systems - A Micro-CT Study. Brazilian Dental Journal 31, 605–610.

Bago I, Suk M, Katić M, Gabrić D, Anić I (2019). Comparison of the effectiveness of various rotary and reciprocating systems with different surface treatments to remove gutta-percha and an epoxy resin-based sealer from straight root canals. International Endodontic Journal 52, 105–113.

Baratto Filho F, Ferreira EL, Fariniuk LF (2002). Efficiency of the 0.04 taper ProFile during the re-treatment of gutta-percha-filled root canals. International Endodontic Journal 35, 651–654.

Barletta FB, de Sousa Reis M, Wagner M, Borges JC, Dall'Agnol C (2008). Computed tomography assessment of three techniques for removal of filling material. Australian Endodontic Journal 34, 101–105.

Barletta, FB, Rahde N de M, Limongi O, Moura AA, Zanesco C, Mazocatto G (2007). In vitro comparative analysis of 2 mechanical techniques for removing gutta-percha during retreatment. Journal Canadian Dental Association 73, 65.

Bergenholtz G, Lekholm U, Milthon R, Heden, G, Odesjö B, Engström B (1979). Retreatment of endodontic fillings. Scandinavian Journal of Dental Research 87, 217–224.

Bergmans L, Van Cleynenbreugel J, Wevers M, Lambrechts, P (2001). A methodology for quantitative evaluation of root canal instrumentation using microcomputed tomography: Evaluation of instrumentation. International Endodontic Journal 34, 390–398.

Boucher Y, Matossian L, Rilliard F, Machtou P (2002). Radiographic evaluation of the prevalence and technical quality of root canal treatment in a French subpopulation. International Endodontic Journal 35, 229–238.

Bramante CM, Fidelis NS, Assumpção TS, Bernardineli N, Garcia RB, Bramante AS, de Moraes IG (2010). Heat release, time required, and cleaning ability of MTwo R and ProTaper universal retreatment systems in the removal of filling material. Journal of Endodontics *36*, 1870–1873.

Capar ID, Gok T, Orhan E (2015). Comparison of retreatment ability of full-sequence reciprocating instrumentation and 360° rotary instrumentation. Clinical Oral Investigations 19, 2219–2222.

Crozeta, BM, Silva-Sousa YT, Leoni GB, Mazzi-Chaves JF, Fantinato T, Baratto-Filho F, Sousa-Neto MD (2016). Micro-computed tomography study of filling material removal from oval-shaped canals by using rotary, reciprocating, and adaptive motion systems. Journal of Endodontics 42, 793–797.

De Souza PF, Goncalves LCO, Marques AAF, Junior ECS, Garcia LDFR, de Carvalho, FMA (2015). Root canal retreatment using reciprocating and continuous rotary nickel-titanium instruments. European Journal of Dentistry 9, 234–239.

De-Deus G, Marins J, Neves AdA., Reis C, Fidel S, Versiani MA, Alves H, Lopes RT, Paciornik S (2014). Assessing accumulated hard-tissue debris using micro-computed tomography and free software for image processing and analysis. Journal of Endodontics 40, 271–276.

Dugas NN, Lawrence HP, Teplitsky PE, Pharoah MJ, Friedman S (2003). Periapical health and treatment quality assessment of root-filled teeth in two Canadian populations: prevalence of apical disease. International Endodontic Journal 36, 181–192.

Duncan, HF, Chong BS (2008). Removal of root filling materials: root filling removal. Endodontic Topics 19, 33–57.

Friedman S, Moshonov J, Trope M (1993). Residue of gutta-percha and a glass ionomer cement sealer following root canal retreatment. International Endodontic Journal 26, 169–172.

Fruchi Lde C, Ordinola-Zapata R, Cavenago BC, Hungaro Duarte MA., Bueno CE, De Martin AS (2014). Efficacy of reciprocating instruments for removing filling material in curved canals obturated with a single-cone technique: a micro-computed tomographic analysis. Journal of Endodontics 40, 1000–1004.

Gergi R, Sabbagh C (2007). Effectiveness of two nickel-titanium rotary instruments and a hand file for removing gutta-percha in severely curved root canals during retreatment: an ex vivo study. International Endodontic Journal 40, 532–537.

Hammad M, Qualtrough A, Silikas N (2008). Three-dimensional evaluation of effectiveness of hand and rotary instrumentation for retreatment of canals filled with different materials. Journal of Endodontics 34, 1370–1373.

Horvath SD, Altenburger MJ, Naumann M, Wolkewitz M, Schirrmeister JF (2009). Cleanliness of dentinal tubules following gutta-percha removal with and without solvents: a scanning electron microscopic study. International Endodontic Journal, 42, 1032–1038.

Jagtap A, Aher G, Gulve M, Kolhe S (2022). Comparative evaluation of effectiveness of manual and various rotary retreatment techniques for removal of root canal filling material: An in-vitro study. Endodontology 34, 184.

Khalighinejad N, Aminoshariae A, Kulild JC, Williams KA, Wang J, Mickel A (2017). The effect of the dental operating microscope on the outcome of nonsurgical root canal treatment: A retrospective case-control study. Journal of Endodontics 43, 728–732.

Kielbassa AM, Frank W, Madaus T (2017). Radiologic assessment of quality of root canal fillings and periapical status in an austrian subpopulation - an observational study. PloS one 12, e0176724.

Kikly A, Jaâfoura S, Kammoun D, Sahtout S (2020). Sealing ability of endodontic cements: an in vitro study. International Journal of Dentistry 2020, 5862598.

Kim Y, Chang SW, Oh S (2023). Buckling resistance, torque, and force generation during retreatment with D-RaCe, HyFlex Remover, and Mtwo retreatment files. Restorative Dentistry & Endodontics 48, e10.

Leoni GB, Versiani MA, Pécora JD, Damião de Sousa-Neto M (2014). Micro-computed tomographic analysis of the root canal morphology of mandibular incisors. Journal of Endodontics 40, 710–716.

Marfisi K, Mercade M, Plotino G, Duran-Sindreu F, Bueno R, Roig M (2010). Efficacy of three different rotary files to remove gutta-percha and Resilon from root canals: efficacy of retreatment files to remove filling materials. International Endodontic Journal 43, 1022–1028.

Nudera WJ (2015). Selective root retreatment: a novel approach. Journal of Endodontics 41, 1382–1388.

Ordinola-Zapata R, Bramante CM, Villas-Boas MH, Cavenago BC, Duarte MH, Versiani MA (2013). Morphologic micro-computed tomography analysis of mandibular premolars with three root canals. Journal of endodontics 39, 1130–1135.

Paqué F, Boessler C, Zehnder, M (2011). Accumulated hard tissue debris levels in mesial roots of mandibular molars after sequential irrigation steps: Debris reduction. International Endodontic Journal 44, 148–153.

Peters OA, Laib A, Rüegsegger P, Barbakow F (2000). Three-dimensional analysis of root canal geometry by high-resolution computed tomography. Journal of Dental Research 79, 1405–1409.

Pirani C, Generali L, Iacono F, Cavani F, Prati C (2021). Evaluation of the root filling quality with experimental carrier-based obturators: a CLSM and FEG-SEM analysis. Australian Endodontic Journal 48,400-408

Pirani C, Iacono F, Chersoni S, Sword J, Pashley DH, Tay FR, Looney S, Gandolfi MG, Prati C (2009). The effect of ultrasonic removal of various root-end filling materials. International Endodontic Journal 42, 1015–1025.

Pirani C, Iacono F, Zamparini F, Generali L, Prati C (2021). Retreatment of experimental carrier-based obturators with the Remover NiTi instrument: evaluation of apical extrusion and effects of new kinematics. International Journal of Dentistry 23, 2755680.

Rios Mde A, Villela A M, Cunha RS, Velasco RC, De Martin AS, Kato AS, Bueno CE (2014). Efficacy of 2 reciprocating systems compared with a rotary retreatment system for gutta-percha removal. Journal of Endodontics 40, 543–546.

Rödig T, Reicherts P, Konietschke F, Dullin C, Hahn W, Hülsmann M (2014). Efficacy of reciprocating and rotary NiTi instruments for retreatment of curved root canals assessed by micro-CT. International Endodontic Journal 47, 942–948.

Rodrigues CT, Duarte MAH, de Almeida MM, de Andrade FB, Bernardineli N (2016). Efficacy of CM-wire, M-wire, and nickel-titanium instruments for removing filling material from curved root canals: A micro-computed tomography study. Journal of Endodontics 42, 1651–1655.

Rossi-Fedele G, Ahmed HMA (2017). Assessment of root canal filling removal effectiveness using micro-computed tomography: a systematic review. Journal of Endodontics 43, 520–526.

Ruddle CJ (2004). Nonsurgical retreatment. Journal of Endodontics 30, 827–845.

Seltzer S, Bender IB, Smith J, Freedman I, Nazimov H (1967). Endodontic failures - an analysis based on clinical, roentgenographic and histologic findings. Oral Surgery, Oral Medicine, and Oral Pathology 23, 517–530.

Silva EJ, Sá L, Belladonna FG, Neves AA., Accorsi-Mendonça T, Vieira, VTL, De-Deus G, Moreira EJ (2014). Reciprocating versus rotary systems for root filling removal: assessment of the apically extruded material. Journal of Endodontics 40, 2077–2080.

Siqueira JF Jr (2001). Aetiology of root canal treatment failure: why well-treated teeth can fail: Aetiology of endodontic failure. International Endodontic Journal 34, 1–10.

Siqueira JF Jr, José F Jr, Antunes HS, Pérez AR, Alves FRF, Mdala I, Silva EJ, Belladonna FG, Rôças IN (2020). The apical root canal system of teeth with posttreatment apical periodontitis: Correlating microbiologic, tomographic, and histopathologic findings. Journal of Endodontics 46, 1195–1203.

Somma F, Cammarota G, Plotino G, Grande NM, Pameijer CH (2008). The effectiveness of manual and mechanical instrumentation for the retreatment of three different root canal filling materials. Journal of Endodontics 34, 466–469.

Takahashi CM, Cunha RS, de Martin AS, Fontana CE, Silveira CFM, da Silveira Bueno CE (2009). In vitro evaluation of the effectiveness of ProTaper universal rotary retreatment system for gutta-percha removal with or without a solvent. Journal of Endodontics 35, 1580–1583.

Topçuoğlu HS, Akti A, Tuncay Ö, Dinçer AN, Düzgün S, Topçuoğlu G (2014). 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. Journal of Endodontics 40, 2066-2069.

Torabinejad M, Corr R, Handysides R, Shabahang S (2009). Outcomes of nonsurgical retreatment and endodontic surgery: a systematic review. Journal of Endodontics 35, 930–937.

Varela-Patiño P, Ibañez-Párraga A, Rivas-Mundiña B, Cantatore G, Otero, XL, Martin-Biedma B (2010). Alternating versus continuous rotation: a comparative study of the effect on instrument life. Journal of Endodontics 36, 157–159.

Virdee SS, Thomas MBM (2017). A practitioner's guide to gutta-percha removal during endodontic retreatment. British Dental Journal 222, 251–257.

Wasnik PB, Banga K (2010). Endodontic retreatment Effectiveness of nickel - titanium rotary instruments versus stainless steel hand files: An in vitro study. Endodontology 28,454-6.

Wu MK, Dummer PMH, Wesselink PR (2006). Consequences of and strategies to deal with residual post-treatment root canal infection. International Endodontic Journal 39, 343–356.

Yamamura B, Cox TC, Heddaya B, Flake NM, Johnson JD, Paranjpe A (2012). Comparing canal transportation and centering ability of endosequence and vortex rotary files by using micro-computed tomography. Journal of Endodontics 38, 1121–1125.

Yang G, Yuan G, Yun X, Zhou X, Liu B, Wu H (2011). Effects of two nickel-titanium instrument systems, Mtwo versus ProTaper universal, on root canal geometry assessed by micro-computed tomography. Journal of Endodontics 37, 1412–1416.

You SY, Bae KS, Baek SH, Kum KY, Shon WJ, Lee W (2010). Lifespan of one nickel-titanium rotary file with reciprocating motion in curved root canals. Journal of Endodontics 36, 1991–1994.

Yürüker S, Görduysus M, Küçükkaya S, Uzunoğlu E, Ilgın C, Gülen O, Tuncel B, Görduysus MÖ (2016). Efficacy of combined use of different nickel-titanium files on removing root canal filling materials. Journal of Endodontics 42, 487–492.

Zuolo AS, Mello JE, Jr Cunha RS, Zuolo ML, Bueno CES (2013). Efficacy of reciprocating and rotary techniques for removing filling material during root canal retreatment. International Endodontic Journal 46, 947–953.

9. APPENDIX

Appendix A. Approval from Ethics Committee.

UNIVERSIDADE ESTÁCIO DE SÁ/ UNESA/RJ

Continuação do Parecer: 1.666.413

Considerações sobre os Termos de apresentação obrigatória:

Solicita dispensa de TCLE pois a pesquisa será realizada em peças anatômicas pertencentes ao Departamento de Anatomia Humana da Universidade Iguaçu. É apresentado um documento coma autorização do responsável pelo referido departamento para que a pesquisa seja desenvolvida.

Recomendações:

Não há.

Conclusões ou Pendências e Lista de Inadequações:

Não há.

Considerações Finais a critério do CEP:

Este comitê aprova o projeto e solicita envio de relatório ao final da pesquisa.

Este parecer foi elaborado baseado nos documentos abaixo relacionados:

Tipo Documento	Arquivo	Postagem	Autor	Situação
Informações Básicas do Projeto	PB_INFORMAÇÕES_BÁSICAS_DO_PROJETO_723177.pdf	04/07/2016 21:23:28		Aceito
Folha de Rosto	folhaderosto040716.pdf	04/07/2016 21:22:59	Andrea Fagundes Campello	Aceito
Outros	autorizacaodois.pdf	27/06/2016 14:28:19	Andrea Fagundes Campello	Aceito
Outros	autorizacaoum.pdf	27/06/2016 14:27:49	Andrea Fagundes Campello	Aceito
Projeto Detalhado / Brochura Investigador	projetopb.docx	27/06/2016 14:25:31	Andrea Fagundes Campello	Aceito

Situação do Parecer:

Aprovado

Necessita Apreciação da CONEP:

Não

RIO DE JANEIRO, 25 de Agosto de 2016

Assinado por:
Luciana de Paula Lima e Schmidt de Andrade
(Coordenador)

Endereço: Avenida Presidente Vargas, 642, 22o andar
Bairro: Centro **CEP:** 20.071-001
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Appendix A. Scientific article to submission

Article 01. Monteiro TM, Cid VOC, Marceliano-Alves MF, Campello AF, Bastos LF, Lopes RT, Siqueira Jr JF, Alves FRF. Filling material extrusion and intracanal removal after retreatment with rotary or reciprocating: a new approach using human cadavers.

Filling material extrusion and intracanal removal after retreatment with rotary or reciprocating: a new approach using human cadavers

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Running title: Filling material extrusion and intracanal removal during retreatment

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Acknowledgments

Our respect and gratitude to the donor-cadaver patients. This study was supported by grants from Fundação Carlos Chagas Filho de Amparo à Pesquisa do Estado do Rio de Janeiro (FAPERJ) and Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), Brazilian Governmental Institutions.

The authors deny any conflict of interest.

ABSTRACT

Aim: To compare the frequency and volume of extruded filling material and the intracanal filling removal after retreatment with HyFlex and Reciproc systems in teeth from cadaveric mandibles. **Materials and Methods:** The root canals of 28 mandibular single-rooted teeth were instrumented with Reciproc R40 and filled using lateral condensation. Cadaveric mandibular segments were scanned by micro–computed tomography, and homologous teeth were assigned to 2 groups (n = 14) according to the retreatment protocol: HyFlex and Reciproc. In the HyFlex group, the HyFlex Remover instrument worked 2/3 of the canal, followed by HyFlex CM 40.04 and 50.04 at the working length (WL). In the Reciproc group, R50 worked 2/3 of the canal, followed by more 2 cycles until the WL was reached. Then, the bone blocks were scanned again. Pre- and postoperative micro-CT images were analyzed. **Results**: Extruded filling materials were detected in 3 teeth of each group before retreatment (21.43%). This frequency significantly increased after retreatment to 11 (78%) and 14 (100%) teeth for HyFlex and Reciproc, respectively (P < .05), but with no differences between systems (P > .05). A similar volume of extruded material before or after retreatment was observed in the intergroup analyses (P > .05). However, this volume significantly increased with retreatment, regardless of the system (P < .05). On average, the extruded volume increased more than 3-fold with HyFlex and almost 2-fold with Reciproc. A significant decrease in the original filling volume was verified after retreatment with both tested systems (P < .05), and residual filling material was found in all teeth after the retreatment, independently of the system. The percentage of filling material removed (80,79% for HyFlex and 65.92% for Reciproc) and the operation time were similar between the systems (P > .05). **Conclusions:** The filling material extrusion was significantly increased in retreatments compared to the first intervention. Both

systems caused apical extrusion without difference between them. Both protocols obtained similar efficacy in filling material removal procedures, although no system completely removed the filling material.

INTRODUCTION

Although endodontic treatment has a high success rate, failures remain an unfortunate possibility, as with any healthcare procedure. In order to prevent tooth loss, non-surgical endodontic retreatment is the first option in most of these cases (1,2).

One of the most critical and challenging stages of endodontic retreatment is removing the previous filling material because of the risk of accidents such as zip, deviations, difficulty in achieving patency, and extrusion of debris. Extruded products can result in flare-ups, postoperative pain, or even compromise the long-term outcome (3). Furthermore, the presence of intracanal filling material after retreatment may harbor bacteria and perpetuate the infection (4).

It is also known that regardless of the protocol, the retreatment may cause apical extrusion of filling material. Numerous laboratory studies have been conducted to determine which retreatment technique results in less extrusion of filling material (5-9). However, the majority have not simulated the resistance imposed by the periapical tissues to apical extrusion; consequently, the results may have limited relevance. Since it is impossible to determine the amount of apical extrusion of filling material clinically, the use of teeth still inserted in human jaws seems to be the best model to represent the clinical reality due to the presence of periradicular tissues, promoting the natural resistance against extrusion (10,11).

To evaluate apically extruded debris, Alves *et al*. (11) recently proposed a new method that consists of a quantitative analysis of the extruded debris volume through micro-computed tomography (micro-CT) scanning. However, no study evaluated the apical extrusion of filling material using this method. Because of its non-destructive nature, preoperative and postoperative scans can be superimposed to evaluate and compare the filling material between the first and second treatment attempts.

Reciprocating instruments are very popular among clinicians, and despite being designed for root canal instrumentation, they are shown promising results in retreatments (12,13). However, as retreatments pose additional challenges related to removing the intracanal filling material, efforts have been made to develop specific instruments for retreatment. In this regard, the company Coltene/Whaledent (Altstätten, Switzerland) has recently introduced a new instrument named HyFlex Remover®**,** designed to remove gutta-percha during retreatment. This file consists of a 30/0.07 single instrument with a variable offset blade, noncutting tip, and triple helix section. It is treated with a patented heat process (C-Wire) to improve flexibility and enhance shape memory (14). The manufacturer recommends using conventional instruments, such as HyFlex EDM or CM instruments, to promote canal remodeling after filling material removal.

When different kinematics are compared in retreatments, the results of filling material extrusion are conflicting. Some studies have shown reciprocating instruments causing more significant extrusion (6,9,15), while others showed greater extrusion with rotary files (7,8,16). In addition, some studies did not show differences between the motions (17,18).

The present study aimed to compare the frequency and volume of extruded filling material and the intracanal filling removal after retreatment with HyFlex and Reciproc systems in teeth from cadaveric mandibles.

MATERIALS AND METHODS

Specimen Selection

The Institutional Committee in Research approved the study protocol. Human cadavers from the Department of Human Anatomy of the Iguaçu University (UNIG, Nova Iguaçu, RJ, Brazil) were inspected and, after initial evaluation, cadavers that had mandibular canines and premolars, with their respective homologous, were selected. Tooth exclusion criteria were: apparent signs of cracks or fractures, extensive restorations or caries, internal or external resorption, incomplete rhizogenesis, and more than one main canal. Cadaveric segments containing the premolars and canines were removed from the selected cadavers through soft tissue dissection with scalpel blades number 15 (Lamedid, Barueri, SP, Brazil) and bone section with the aid of double-sided duraflex diamond discs (American Burrs, Porto Alegre, RS, Brazil). Vertical sections were made distally to the second premolars, and horizontal sections were 1 cm from the base of the jaw. The specimens were kept in 10% formalin while not in use. Altogether, 17 cadaveric segments were obtained, totaling 28 single-rooted teeth selected according to the criteria.

Initial X-ray

All selected teeth were radiographed using a NanoPix digital sensor (MKLife, Porto Alegre, RS, Brazil) and an X-ray Spectro 70X Seletronic source (Dabi Atlante Ltda.,

Ribeirão Preto, SP, Brazil) with a power of 70 Kvp and 8 mA. The apparent length of the tooth and the number of canals were confirmed in the digital images.

Root Canal Treatment

The same operator performed the root canal preparations and obturations. Coronal access cavities were made using diamond burs #1012/1014 and #3082 (KG SORENSE, São Paulo, SP, Brazil). Before root canal preparation, each specimen was isolated with a rubber dam to avoid contact of sodium hypochlorite (NaOCl) with adjacent tissues and simulate clinical conditions. The canal was irrigated with 5 mL of 2.5% NaOCl for 1 minute with a NaviTip 30-G needle (Ultradent, South Jordan, UT). Afterward, it was explored using a K-file #15 (Kendo, VDW, Munich, Germany), and the working length (WL) was determined to be 1 mm below the radiographic apex. The Reciproc R40 instrument (VDW) was powered by a torque-limited electric motor in reciprocating movement, with rpm and torque recommended by the manufacturer. Metallic cursors were used in all instruments to guarantee the maintenance of the WL and prevent enlargement of the foramen. The R40 instrument (40/0.06) was moved apically using in-and-out pecking motions. After 3 pecking motions, the instrument was cleaned, the canal irrigated with 6 mL of 2.5% NaOCl for 1 minute, and patency was checked with a K-file #15. These approaches were performed three times until the R40 instrument reach the WL. After completion of the instrumentation, each canal was irrigated with 6 mL of 17% EDTA (Biodinâmica Química e Farmacêutica, Ibiporã, PR, Brazil), followed by 6 mL of 2.5% NaOCl for 1 minute. Subsequently, the root canals were dried with #40 paper cones (AllPrime, São José, SC, Brazil) before filling. The cold lateral compaction technique was chosen for obturation, with AH Plus Jet endodontic sealer (Dentsply Sirona, Charlotte, North Carolina),

associated with a gutta-percha cone Reciproc R40 (VDW) and an accessory cone (#FM, Dentsply Sirona). All accesses cavities were sealed temporarily with Coltosol (Vigodent, Rio de Janeiro, RJ, Brazil), and the specimens were kept in 10% formaldehyde for 7 days to ensure a complete set of the sealer.

Micro-CT Scanning (initial)

All cadaveric segments were scanned in a micro-CT scanner (SkyScan 1273.v2; Brucker micro-CT, Kontich, Belgium) at 70 kV, 114 mA, 14 µm pixel size, 360° around the vertical axis, rotation step of 0.5, and 2 average frames using a 1.0-mm-thick aluminum filter. After scanning, the images were reconstructed using N. Recon v.1.6.9.16 software (Bruker micro-CT), with ring artifact correction of 5, beam hardening correction of 50%, and smoothing of 8 to create axial and transverse slices of the internal structure of all root canals. Next, the 3-dimensional quantitative analysis was performed using CTAn v1.14.4.1 software (Bruker micro-CT). Finally, the pairing of the specimens was defined, and the teeth were retreated with two different systems.

Root Canal Retreatment

The same operator, previously trained with the tested systems, performed all retreatment procedures. Before that, each specimen was isolated with a rubber dam. When the access cavity was reopened, the gutta-percha in the coronal third was removed (2-3 mm) using a number 2 Gates Glidden drill (Dentsply Maillefer, Tulsa, Oklahoma, USA). This drill was powered by a torque-limited electric motor in continuous rotation at 1,000 rpm and 1 Ncm, creating a guide for the next instruments. The canal was irrigated with 6 mL of 2.5% NaOCl for 1 minute. Then, root canal retreatment was continued by

HyFlex Remover (Coltene/Whaledent) associated with HyFlex CM (Coltene/Whaledent) or Reciproc R50 (VDW), alternating the system and side of mandibular segments of the same cadaver to have an optimal group paring.

HyFlex

The Hyflex Remover instrument (30/0.07) was powered by a torque-limited electric motor at 800 rpm and 2 Ncm and moved up to two-thirds of the canal length. The instrument was used with a back-and-forth motion without apical pressure. This approach was performed 3 times, and the instrument was removed and cleaned. Then, the canal was irrigated with 6 mL of 2.5% NaOCl for 1 minute, the WL was radiographically confirmed with a K-file #15, and then patency was checked with the same instrument. The canal irrigated again and HyFlex CM 40/ 0.04 and 50/ 0.04 were used for final apical preparation, powered at 400 rpm and 2 Ncm. These instruments were moved apically until the WL, in sequence, in the same way previously described for HyFlex Remover. The same protocol of irrigation and patency was performed after each instrument. Finally, the canal was dried with #50 paper points, and the access cavity was sealed with Coltosol (Vigodent). All HyFlex instruments were single-use.

Reciproc

The R50 instrument (50/0.05) was powered by a torque-limited electric motor (VDW Silver, VDW) in reciprocating mode. The instrument was moved up to two-thirds of the canal length in the first stage. The instrument was used with a back-and-forth motion without apical pressure. This approach was repeated 3 times to complete 1 cycle of work and after that, the instrument was removed and cleaned. Then, the canal was irrigated

with 6 mL of 2.5% NaOCl for 1 minute, the WL was verified with a K-file #15, radiographically confirmed, and then patency was checked with the same instrument. The canal irrigated again and two more cycles conducted the instruments until the WL. The same protocol of irrigation and patency checking was performed after each cycle. Ultimately, the canal was dried with #50 paper points, and the access cavity was sealed with Coltosol (Vigodent).

The retreatment procedures were considered complete when the last instrument of the HyFlex sequence or the Reciproc reached the WL, no more filling material was observed on their flutes, and final patency checking and irrigation were performed. The time of the intracanal procedures with instruments was registered, not including the time spent on irrigation instrument changes and radiographs.

Irrigation conditions

Irrigation was performed with a NaviTip needle positioned at two different depths: at two-thirds of the canal length after clearing this portion and 3 mm from the WL after reaching it. The needle was gently moved during the irrigant injection (1-2 mm). The irrigant was delivered with a peristaltic pump (VATEA, ReDent-Nova, Ra'nana, Israel) to keep the flow rate at 6 mL/min. The irrigant was simultaneously aspirated by a cannula positioned at the canal orifice. In both groups, the total volume of NaOCl was 30 mL.

Micro-CT Scanning (final) and analysis

This second scanning procedure used the parameters previously described for the initial micro-CT and images reconstruction. The volume of filling material and the remnants in the entire root canal and the extruded sealer were quantified (mm3) by the CTAn

software (Bruker-microCT) using the morphometry plug-in. The operator was blinded to the experimental groups during scanning and analysis.

Statistical analysis

Initially, the Shapiro-Wilk test was used to check for data normality. The initial filling volume and time required for retreatment were compared between groups using the t-test for independent samples. The intragroup reduction in filling material volume before and after HyFlex or Reciproc groups was assessed using the Wilcoxon matched-pair test. The volume of extruded filling material between HyFlex or Reciproc and the percentage of filling material removed were compared using the Mann-Whitney test. The frequencies of extrusion were evaluated using Fisher's or McNemar's test. All tests were conducted using the Windows version of SPSS 13.0 (SPSS Inc., Chicago, IL). The threshold for significance was set at 5% ($P < .05$).

RESULTS

Filling Material Extrusion

Extruded filling materials were detected in 3 teeth of each group before the retreatment (21.43%). This frequency was significantly increased after retreatment to 11 (78%) and 14 (100%) for HyFlex and Reciproc, respectively ($P < .05$ for both groups in intragroup analysis), but without differences between groups ($P > .05$). Although both groups presented a similar volume of extruded material was observed in the intergroup analyses (P > .05). However, this volume significantly increased retreatment ($P > .05$), this volume was significantly increased with the retreatment, independently of the system ($P < .05$). The volume of extruded material was increased more than 3-fold with HyFlex

and almost 2-fold with Reciproc, in mean. However, the difference of extruded material, subtracting the volume after and before the retreatment, was similar for HyFlex and Reciproc ($P > .05$) (Table 1).

Filling Material Removal

There was no significant difference in the initial filling material volumes between groups ($P > .05$). The mean volume before retreatment was 10.82 mm^3 and 14.02 mm^3 for HyFlex and Reciproc, respectively. A significant decrease in the original filling volume was verified after retreatment with both tested systems ($P < .05$) (Table 2 and Fig. 1), with a mean reduction of 80,79% for HyFlex and 65.92% for Reciproc. However, no significant statistical difference was observed in the intergroup analysis ($P > .05$) (Figure 1). Residual filling materials were found in all teeth after the retreatment, independently of the system.

Retreatment Time

The retreatment expended time was not different between HyFlex (mean = 48.48 seconds) and Reciproc systems (mean = 47.64 seconds) ($P > .05$).

DISCUSSION

The present study evaluated the apical extrusion and the filling material removal after endodontic retreatment using one new rotary mechanized system, HyFlex Remover and compared it with a popular reciprocating system, Reciproc. An innovative experimental model was devised, highlighting the use of teeth in their original alveolar bone, with the preserved periodontal ligament. No previous retreatment study used human cadavers to evaluate extrusion or filling removal. The advantage of these samples

is the presence of the periodontal ligament, which offers natural resistance to the filling material extrusion to the apical region (10,11). Indeed, the clinical conditions could be better simulated in comparison with dry teeth, usually used in retreatment studies without any bulkhead to represent the periapical tissues (7,8,16,19). Another strength was using contralateral teeth, making comparing both systems in homologous teeth possible. In order to ensure standardization, only uniradicular teeth with a single canal were included to reduce the risks of pushing filling material through isthmuses or other canals, which could influence the extrusion by creating an alternative pathway for filling remnants (20).

Some previous studies simulated the periapical tissues (6,11,20,21), and one study (6) proved that extrusion in retreatments is more significant in groups where this simulation was not performed. This evidence puts in check findings from studies using dry teeth without any apparatus to simulate the periradicular tissues because the results could be overestimated. Other common biases of extrusion studies are related to the weighing method, where extruded materials are collected using empty tubes. Not only extruded material on the outer root surface is not usually sampled, sub estimating the extrusion, but also extruded irrigants cannot be easily dried before weighing, overestimating the extrusion.

Micro-CT imaging has been widely used to evaluate the reduction of filling material after endodontic retreatment (12,13,22,23) but has been rarely used to detect and quantify apically extruded debris (11,21,24,25). In the present study, micro-CT analysis showed that both instrument systems produced a similar frequency and volume of apically extruded filling material. This corroborates other studies that found no statistically significant differences between reciprocating and rotatory instruments regarding the weight of extruded filling material (17,18).

At the end of the retreatment, although the Reciproc R50 (50/0.05) has a larger apical taper than the HyFlex CM 50 (50/0.04), the volume of extruded material was similar between groups ($P > 0.05$). No other study compared these systems regarding filling material extrusion, making any comparison difficult. Also, despite the high number of studies testing Reciproc against other rotary systems regarding filling material extrusion (6-8,15,16,18), the results are conflicting. Only one used an apparatus to simulate the resistance of the periapical tissues (6). Besides, these studies used the weighing method, making any comparison with the present results misleading.

A significant decrease in the original intracanal filling volume was verified after retreatment with both tested systems, with a mean of 80,79% for HyFlex and 65.92% for Reciproc. For Reciproc, the presented finding is in a middle position compared with two previous studies that found 56.1% (26) and 76.6% (27), both using distal roots of mandibular molars. However, no significant statistical difference was observed in the intergroup analysis. This result corroborates other studies comparing rotary and reciprocating systems for filing material removal during retreatment, which have shown a similar performance (12,23,28-30). Also, a systematic review concluded that NiTi instruments specially designed for retreatment were similar to conventional instruments in filling material removal (31). Therefore, even though they may penetrate the filling mass easily, these instruments are not essential in retreatments, as verified, and the expected reduction of operation time for HyFlex Remover was not observed.

The absence of significant differences between the tested systems not only regarding filling material extrusion but also intracanal removal could also be associated with the standardized conditions of root canal anatomy, irrigation, and working length (32). In these conditions, studies have shown that differences in taper, tip, and cross-sectional

shape, as well as the operation mode and the number of instruments used, failed to promote significant differences in filling extrusion and removal (12,17,28-30,33,34).

In conclusion, the volume of filling material extrusion significantly increased after root canal retreatment. Also, the frequency of extrusion was higher in retreatment compared with the first intervention. Both tested techniques caused apical extrusion of obturation debris without difference between them. All tested instruments performed similarly in filling material removal procedures, although no system completely removed the filling material.

REFERENCES

1. Friedman S, Stabholz A. Endodontic retreatment--case selection and technique. Part 1: Criteria for case selection. J Endod 1986;12:28-33.
2. Ajina MA, Shah PK, Chong BS. Critical analysis of research methods and experimental models to study removal of root filling materials. Int Endod J 2021.
3. Arias A, de la Macorra JC, Hidalgo JJ, Azabal M. Predictive models of pain following root canal treatment: a prospective clinical study. Int Endod J 2013;46:784-93.
4. Arnold M, Ricucci D, Siqueira JF, Jr. Infection in a complex network of apical ramifications as the cause of persistent apical periodontitis: a case report. J Endod 2013;39:1179-84.
5. 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;33:1102-5.
6. Lu Y, Wang R, Zhang L, 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.
7. Silva EJ, Sa L, Belladonna FG, et al. Reciprocating versus rotary systems for root filling removal: assessment of the apically extruded material. J Endod 2014;40:2077-80.
8. Kasikci Bilgi I, Koseler I, Guneri P, Hulsmann M, Caliskan MK. Efficiency and apical extrusion of debris: a comparative ex vivo study of four retreatment techniques in severely curved root canals. Int Endod J 2017;50:910-8.
9. Yilmaz K, Ozyurek T. Apically Extruded Debris after Retreatment Procedure with Reciproc, ProTaper Next, and Twisted File Adaptive Instruments. J Endod 2017;43:648-51.
10. Campello AF, Marceliano-Alves MF, Siqueira JF, Jr., et al. Unprepared surface areas, accumulated hard tissue debris, and dentinal crack formation after preparation using reciprocating or rotary instruments: a study in human cadavers. Clin Oral Investig 2021;25:6239-48.
11. Alves FRF, Paiva PL, Marceliano-Alves MF, et al. Bacteria and Hard Tissue Debris Extrusion and Intracanal Bacterial Reduction Promoted by XP-endo Shaper and Reciproc Instruments. J Endod 2018;44:1173-8.
12. Rodig T, Reicherts P, Konietschke F, et al. Efficacy of reciprocating and rotary NiTi instruments for retreatment of curved root canals assessed by micro-CT. Int Endod J 2014;47:942-8.
13. Donnermeyer D, Bunne C, Schafer E, Dammaschke T. Retreatability of three calcium silicate-containing sealers and one epoxy resin-based root canal sealer with four different root canal instruments. Clin Oral Investig 2018;22:811-7.

14. Pirani C, Iacono F, Zamparini F, Generali L, Prati C. Retreatment of Experimental Carrier-Based Obturators with the Remover NiTi Instrument: Evaluation of Apical Extrusion and Effects of New Kinematics. Int J Dent 2021;2021:2755680.
15. Serefoglu B, Kandemir Demirci G, Micoogullari Kurt S, Kasikci Bilgi I, Caliskan MK. Impact of root canal curvature and instrument type on the amount of extruded debris during retreatment. Restor Dent Endod 2021;46:e5.
16. Dincer AN, Er O, Canakci BC. Evaluation of apically extruded debris during root canal retreatment with several NiTi systems. Int Endod J 2015;48:1194-8.
17. Nevares G, Romeiro K, Albuquerque D, et al. Evaluation of Apically Extruded Debris during Root Canal Retreatment Using ProTaper Next and Reciproc in Severely Curved Canals. Iran Endod J 2017;12:323-8.
18. AlOmari T, Mustafa R, Al-Fodeh R, et al. Debris Extrusion Using Reciproc Blue and XP Endo Shaper Systems in Root Canal Retreatment. Int J Dent 2021;2021:6697587.
19. Topcuoglu HS, Akti A, Tuncay O, et al. 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;40:2066-9.
20. Cabreira LJ, Gominho LF, Rocas IN, et al. Quantitative analysis of apically extruded bacteria following preparation of curved canals with three systems. Aust Endod J 2019;45:79-85.
21. da Silva E, de Moura SG, de Lima CO, et al. Shaping ability and apical debris extrusion after root canal preparation with rotary or reciprocating instruments: a micro-CT study. Restorative Dentistry and Endodontics 2021;46:e16.
22. Zuolo AS, Mello JE, Jr., Cunha RS, Zuolo ML, Bueno CE. Efficacy of reciprocating and rotary techniques for removing filling material during root canal retreatment. Int Endod J 2013;46:947-53.
23. Martins MP, Duarte MA, Cavenago BC, Kato AS, da Silveira Bueno CE. Effectiveness of the ProTaper Next and Reciproc Systems in Removing Root Canal Filling Material with Sonic or Ultrasonic Irrigation: A Micro-computed Tomographic Study. J Endod 2017;43:467-71.
24. Gomes TC, Coelho JA, Pinheiro LR, Duarte MAH, Rodrigues PA. Influence of Apical Diameter on Filling Material Extrusion during Retreatment - A Micro-CT and CBCT evaluation. Braz Dent J 2022;33:13-9.
25. Canali LCF, Duque JA, Vivan RR, et al. Comparison of efficiency of the retreatment procedure between Wave One Gold and Wave One systems by Micro-CT and confocal microscopy: an in vitro study. Clin Oral Investig 2019;23:337-43.
26. Crozeta BM, Silva-Sousa YT, Leoni GB, et al. Micro-Computed Tomography Study of Filling Material Removal from Oval-shaped Canals by Using Rotary, Reciprocating, and Adaptive Motion Systems. J Endod 2016;42:793-7.
27. Monguilhott Crozeta B, Damiao de Sousa-Neto M, Bianchi Leoni G, et al. A micro-computed tomography assessment of the efficacy of rotary and reciprocating techniques for filling material removal in root canal retreatment. Clin Oral Investig 2016;20:2235-40.
28. de Souza PF, Gonçalves LCO, Marques AAF, et al. Root canal retreatment using reciprocating and continuous rotary nickel-titanium instruments. Eur J Dent 2015;9:234-9.
29. de Siqueira Zuolo A, Zuolo ML, da Silveira Bueno CE, Chu R, Cunha RS. Evaluation of the Efficacy of TRUShape and Reciproc File Systems in the Removal of Root Filling Material: An Ex Vivo Micro-Computed Tomographic Study. J Endod 2016;42:315-9.
30. Rios Mde A, Villela AM, Cunha RS, et al. Efficacy of 2 reciprocating systems compared with a rotary retreatment system for gutta-percha removal. J Endod 2014;40:543-6.
31. Rossi-Fedele G, Ahmed HM. Assessment of Root Canal Filling Removal Effectiveness Using Micro-computed Tomography: A Systematic Review. J Endod 2017;43:520-6.
32. Alves FRF, Rôças IN, Provenzano JC, Siqueira JF, Jr. . Removal of the Previous Root Canal Filling Material for Retreatment: Implications and Techniques. Appl. Sci. 2022;12.

33. Alves FR, Ribeiro TO, Moreno JO, Lopes HP. Comparison of the efficacy of nickel-titanium rotary systems with or without the retreatment instruments in the removal of gutta-percha in the apical third. BMC Oral Health 2014;14:102.
34. Silveira SB, Alves FRF, Marceliano-Alves MF, et al. Removal of Root Canal Fillings in Curved Canals Using Either Mani GPR or HyFlex NT Followed by Passive Ultrasonic Irrigation. J Endod 2018;44:299-303 e1.

FIGURE LEGENDS

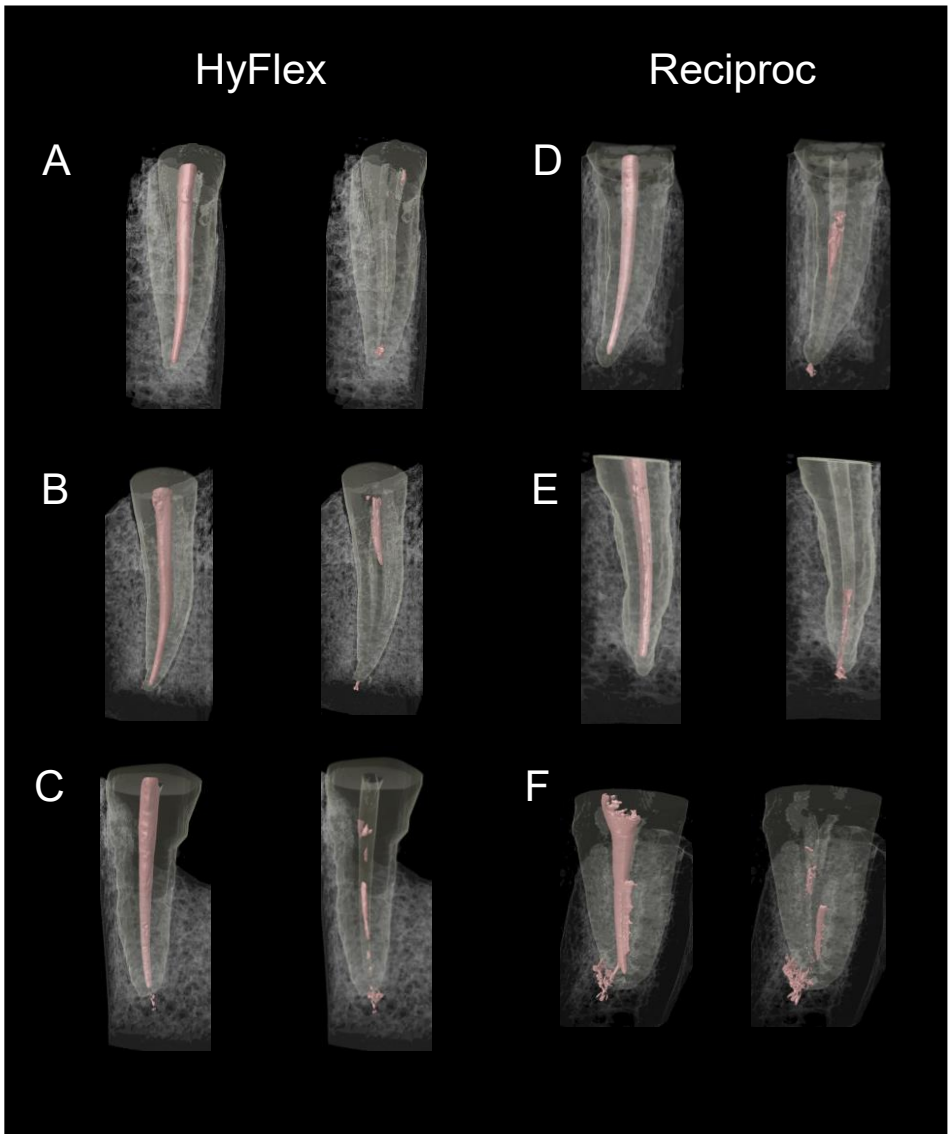
Figure 1. Micro-CT 3-dimensional reconstructions of samples from both HyFlex and Reciproc groups before and after retreatment, showing intracanal filling material removal and apical extrusion. **A**, without extrusion before and after retreatment. **B**, **D**, **E**, and **F**, without extrusion before but with extrusion after retreatment. **C**, with extrusion before that increased after retreatment.

Table 1. Apical extrusion of filling material before and after retreatment using HyFlex or Reciproc (mm^3).

Group	*n*	Volume before			Volume after			Difference		
		Mean ± SD	Median	Range	Mean ± SD	Median	Range	Mean ± SD	Median	Range
HyFlex	14	0.08 ± 0.17	0.00	0.00-0.48	0.27 ± 0.41	0.05	0.00-1.34	0.19 ± 0.36	0.05	0.00-1.34
Reciproc	14	0.14± 0.37	0.00	0.00-1.26	0.25 ± 0.37	0.09	0.01-1.29	0.10 ± 0.12	0.06	0.01-0.40

Table 2. Retreatment time and volume (mm^3) of filling material before and after retreatment using HyFlex or Reciproc.

Group	*n*	Retreatment time (seconds)	Volume before			Volume after			% Removed		
			Mean ± SD	Median	Range	Mean ± SD	Median	Range	Mean ± SD	Median	Range
HyFlex	14	48.48	10.82 ± 3.76	10.26	4.61-17.15	2.11 ± 2.31	1.39	0.04-6.93	80.79 ± 19.04	87.30	37.83-99.52
Reciproc	14	47.64	14.02 ± 6.35	14.01	4.96-25.06	4.45 ± 3.42	3.93	0.21-10.83	65.92 ± 24.02	75.84	26.01-96.76


HyFlex
Reciproc
A
D
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