UNIVERSIDADE DE SÃO PAULO
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Assessment of rotatory and reciprocating movements in root canal filling material removal

Análise dos sistemas rotatório e reciprocante com diferentes ligas na desobturação em retratamentos endodônticos

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FOLHA DE APROVAÇÃO

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DADOS CURRICULARES

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ABSTRACT

Assessment of rotatory and reciprocating movements in root canal filling material removal

The aim of this study was to evaluate the effects of preparation, filling removal material, reinstrumentation and reobturation of root canals with different Ni-Ti alloys in endodontic retreatment. Firstly, the selection and pairing of mesial root canals of mandibular molars (n = 45) were performed by computerized micro-tomography (micro-CT). After pairing, the specimens were divided into three groups (n = 15), instrumented with the Mtwo® (up to file 25.06), ProDesign Logic (25.06) and ProDesign R (25.06) systems. After this, the specimens were scanned again for root canal deviation analysis at 2, 4, 6, 8 and 10 mm from the apex and the volume increase of these root canals was evaluated through CTan Then, the root canals were filled with Endofill® with 0.1% rhodamine B and scanned in micro-CT once again. For the retreatment of the specimens, 3 groups were established according to the system used (Reciproc®, Hyflex® and ProDesign Duo Hybrid®). During the retreatment, the specimens were scanned in micro-CT in two more phases, after removal of filling material and after reinstrumentation of the root canals. All the images obtained previous and post-retreatment were compared to evaluate the capacity of removal filling material of each system through the volume of material remaining at 3mm in the apical third. Possible deviation of the root canal was assessed at 2, 4, 6, 8 and 10 mm from the apex. In addition, the times of preparation, removal filling material and reinstrumentation of these files were also evaluated. After the removal filling material and reinstrumentation of the root canals, they were refilled with AH Plus with 0.1% fluorescein. The specimens were sectioned crosswise into 2 mm slices to be analyzed by a confocal laser scanning microscope (CLSM) at 1, 3 and 5 mm from the apex, where the volume of material was evaluated through *LAS X 3D and 2D* software. The time of preparation, removal filling material and reinstrumentation of the root canals between the different systems was measured by a digital timer. The evaluation of canal volumetric increase and preparation time between Mtwo and ProDesign Logic systems were conducted using Student t-test analysis. Non-parametric Wilcoxon test was used to the intragroup comparison at the 2, 4, 6, 8 and 10 mm levels and non-parametric Mann-Whitney test was used to the comparison between groups in the root canal transportation in all sections of the root canal. The intra-group comparison regarding

the presence or absence of root canal deviation after removal of root canal filling material and re-instrumentation was submitted to the parametric T-paired statistical test, since it had a normal distribution. The working time with the different alloys used to removal filling material an reinstrumentation was analyzed through parametric ANOVA e Tukey statistical test. The analysis of the remaining material present in the root canals was performed with nonparametric Kruskal-Wallis and Dunn tests. For the intra-group comparison between the different slices (1, 3 and 5 mm), the data were submitted to nonparametric Friedman and Dunn tests. The level of significance was established at 5% in all analysis. After the initial preparation of the root canals, the ProDesign Logic system proved to be faster than Mtwo system, with statistical difference between them ($P < 0.05$). There was no statistical difference in root canal deviation after initial preparation and after retreatment ($P > 0.05$). In addition, the groups did not present a significant statistical difference to the volume increase of the root canals after the initial preparation or to the volume of filling material remaining after the retreatment ($P > 0.05$). The Reciproc system proved to be the fastest system for the removal filling material and reinstrumentation of the root canals ($P < 0.05$). The present study demonstrated that the Prodesign Logic and Mtwo systems presented similar capacity of preparation of mesial root canals. The Reciproc, Hyflex and ProDesign Duo Hybrid systems are similar in the removal of filling material, preserving the original root canal shape in endodontic retreatment. However, Reciproc was the fastest compared to the other groups.

Keywords: Confocal, X-Ray Microtomography, Reciprocating, Retreatment, Rotary.

RESUMO

Análise dos sistemas rotatório e reciprocante com diferentes ligas na desobturação em retratamentos endodônticos

O presente trabalho teve como objetivo avaliar os efeitos decorrentes do preparo inicial, desobturação, reinstrumentação e reobturação de canais radiculares com diferentes ligas de Ni-Ti em casos de retratamento endodôntico. Primeiramente, foi realizado a seleção e o pareamento da anatomia de canais mesiais de primeiros molares inferiores (n=45) através de micro-tomografia computadorizada (micro-CT). Após o pareamento dos espécimes, os mesmos foram divididos em três grupos (n =15), instrumentados com os sistemas Mtwo® (até a lima 25.06), ProDesign Logic (25.06) e ProDesign R (25.06) sendo escaneados novamente para análise de desvio do canal radicular a 2, 4, 6, 8 e 10 mm, além do aumento de volume desses canais, avaliados através do CTan. Em seguida, os canais radiculares foram obturados com o cimento Endofill® acrescido de 0,1% de rodamina B e escaneados em micro-CT mais uma vez. Para o retratamento dos espécimes, foram estabelecidos 3 grupos, de acordo com o sistema utilizado (Reciproc®, Hyflex® e ProDesign Duo Híbrido®). Durante o retratamento, os espécimes foram escaneados em micro-CT em mais duas etapas, após a desobturação e a após a reinstrumentação dos canais. Todas as imagens obtidas referentes ao pré e pós retratamento foram confrontadas com o intuito de avaliar a capacidade de remoção de material obturador de cada sistema através do volume de material remanescente nos 3 mm apicais, além de avaliar possíveis desvios dos canais a 2, 4, 6, 8 e 10 mm do ápice. Foram avaliados também, o tempo efetivo de preparo, desobturação e de reinstrumentação desses instrumentos. Após a desobturação e reinstrumentação dos canais, os mesmos foram reobturados com cimento AH Plus acrescido de 0,1% de fluoresceína. Os espécimes foram seccionados transversalmente em fatias de 2 mm para serem analisados em microscópio confocal de varredura a laser (MCVL) a 1, 3 e 5 mm do ápice, onde foi avaliado, através do *software LAS X 3D e 2D*, o volume de material obturador antigo. O tempo de preparo, desobturação e reinstrumentação dos canais entre os diferentes sistemas foi marcado através de um cronômetro digital. A análise do aumento volumétrico e tempo de preparo entre os sistemas Mtwo e ProDesign Logic foi feita através do teste estatístico Student t. Para a análise do desvio do canal radicular após

o preparo inicial, o teste não-paramétrico Wilcoxon foi utilizado para a comparação intra-grupos nos níveis a 2, 4, 6, 8 e 10 mm do ápice, enquanto o teste não-paramétrico Mann-Whitney foi utilizado para comparação entre os grupos nos mesmos níveis. Para a análise do desvio do canal radicular após a desobturação e reinstrumentação dos canais, os dados foram submetidos ao teste paramétrico T-pareado. O tempo de desobturação e reinstrumentação com os diferentes sistemas foi analisado através do teste ANOVA e Tukey. Os dados referentes ao remanescente de material obturador foram analisados através dos testes não-paramétrico Kruskal-Wallis e Dunn. Para a comparação intra-grupos entre os diferentes níveis (1, 3 e 5 mm) foram utilizados os testes não-paramétricos Friedman e Dunn. O nível de significância foi estabelecido a 5% em todas as análises. Após o preparo inicial dos canais, o sistema ProDesign Logic demonstrou ser mais rápido que o sistema Mtwo, havendo diferença estatística entre eles ($P < 0.05$). Não houve diferença estatística quanto ao desvio do canal radicular tanto após o preparo inicial quanto após o retratamento ($P > 0.05$). Além disso, os grupos também não apresentaram diferença estatística significante quanto ao aumento do volume dos canais após o preparo inicial, nem em relação ao volume de remanescente de material obturador após o retratamento ($P > 0.05$). O sistema Reciproc demonstrou ser o mais rápido dentre os sistemas quanto à desobturação e reinstrumentação dos canais ($P < 0.05$). O presente trabalho demonstrou que os sistemas Prodesign Logic and Mtwo apresentaram capacidade similar de preparo dos canais mesiais de molares inferiores. Os sistemas Reciproc, Hyflex e ProDesign Duo Híbrido são parecidos quanto à remoção de material obturador, preservando o formato original do canal em casos de retratamentos entodônticos. Entretanto, Reciproc foi o mais rápido comparado aos outros grupos.

Palavras-chave: Microscopia confocal, Microtomografia por Raio-X, Reciprocante, Retratamento endodôntico, Rotação

LISTA DE ABREVIATURA E SIGLAS

%	percentagem
+	mais
x	vezes
<	menor
>	maior
#	número
=	igual
º	grau
2D	duas dimensões
3D	três dimensões
cm	centímetro
EDTA	ácido etelino diaminotetracético
KV	quilovolts
MCVL	Microscopia confocal de varredura a laser
micro-CT	microtomografia computadorizada
mL	mililitro
mm	milímetro
mm^3	milímetro cubico
n	número
N	Newton
NaOCl	hipoclorito de sódio
Ni-Ti	Níquel Titânio
nm	nanômetro
P	significância estatística
rpm	rotações por minuto
s	segundos
µm	micrômetro
µA	microampère

SUMMARY

1 Introduction

1 INTRODUCTION

One of the main objectives of root canal preparation is cleaning and shaping of the root canal system, while retaining the original shape of the canal without creating iatrogenic events, such as instrument fracture, apical transportation, ledge or perforation (CAPAR et al. 2014, DA SILVA LIMOEIRO et al. 2016).

Failure in an endodontic treatment may occur due to persistence of bacteria in the root canal system as a consequence of inadequate obturation, insufficient cleaning/disinfection of the root canal system, unfilled root canals, underextended root fillings, overextended root fillings advancing beyond the apical limit, and defective coronal restoration (SCHILDER 1974; HULSMANN; STOTZ 1997, ZAMIN et al. 2012, RODIG et al. 2014, SILVA et al. 2015). Non-surgical root canal retreatment is the first choice to re-establish the healthy periapical tissues. The procedure requires complete removal of the filling material from the canal system to allow effective cleaning, shaping and re-filling (ABOU-RASS, FRANK, GLICK 1980).

During shaping and cleaning of curved canals, occurrence of iatrogenic errors such as ledges, zips, perforations, and root canal transportation is common (WEINE et al. 1975).

Canal transportation is the removal of canal wall structure on the outside curve in the apical half of the canal due to the tendency of files to restore themselves to their original linear shape during canal preparation'' (AMERICAN ASSOCIATION OF ENDODONTISTS 2012). The common factors responsible for canal transportation are: insufficiently designed access cavities, inflexible canal preparation instruments, instrumentation technique like crown down preparation using hand instruments, degree and radius of a canal curvature, unseen canal curvatures in two dimensional radiographs and experience of the operator (WEINE et al 1975).

To improve performance and prevent accidents, in the recent decades, new systems with different motions and techniques have been introduced in Endodontics for the preparation of the root canal system. The need to enlarge curved canals, while at the same time preserve dental anatomy, will always involve the challenge of selecting appropriate endodontic instruments (FREIRE et al. 2011). It was further claimed that this thermomechanical processing serves to raise the flexibility and the fracture resistance of the file (KIM et al. 2010). Also, several rotary nickel-titanium (Ni-Ti) instruments with different designs and shapes have been developed to favor a major safety in the root canal instrumentation and reducing the operating time, including the development of Ni-Ti single-file systems (HAAPASALO; SHEN 2013, GRANDE et al. 2015).

The conventional Ni-Ti alloy has an austenite structure, but recently it was developed M-wire Ni-Ti, which suffers a thermal treatment, promoting a mixture of nearly equal amounts of R-phase and austenite (ALAPATI et al. 2009, RODRIGUES et al. 2016). M-wire Ni-Ti contains substantial amounts of martensite that does not undergo phase transformation resulting in a metallurgical microstructure that exhibits alloy strengthening (ALAPATI et al. 2009). Besides this M-wire technology, another innovative approach is the use of a controlled memory alloy (CM-wire) to produce rotary Ni-Ti instruments, the Hyflex CM files (Coltene/Whaledent, Altstätten, Switzerland) (GUTMANN; GAO 2012) and ProDesign Logic (Easy Equipamentos Odontológicos, Belo Horizonte, MG, Brazil).

Nickel-titanium (Ni-Ti) rotary systems have been also used in endodontic retreatments due to their safety, efficiency, and ability to remove filling material faster than hand files (BETTI et al. 2009, COLACO; PAI 2015, ZUOLO et al. 2013). The reciprocating instruments kinematics has emerged as a result of the evolution of mechanized systems. With a general concern of simplifying endodontic procedures while maintaining safety and effectiveness, these systems have their use indicated for both root canal preparation and removal of filling material for retreatment purposes, and are mainly used in single instrument techniques (BERNARDES et al. 2016, FRUCHI et al. 2014, RIOS et al. 2014, RODIG et al. 2013, SILVA et al. 2015, YURUKER et al. 2016, ZUOLO et al. 2013). Furthermore, new rotary nickel-titanium systems that were specially designed for retreatment procedures have been introduced to the field of endodontics (GU et al. 2008, TASDEMIR et al. 2008, TAKAHASHI et al. 2009).

A single endodontic file (RECIPROC, VDW, Munich, Germany) has been extensively used to instrument root canals in a faster manner and in a reciprocation motion. Reciproc is made of M-Wire Ni-Ti-alloy and its working motion consists of a counter-clockwise (cutting direction) and a clockwise motion (release of the instrument), while the angle of the counterclockwise cutting direction is greater than the angle of the reverse direction (BURKLEIN et al., 2012). Studies have shown that the Reciproc system removes more tooth structure than rotary instruments due to its increased cutting ability (BUSQUIM et al., 2015).

ProDesign Logic (Easy Equipamentos Odontológicos, Belo Horizonte, MG, Brazil), is a new automated single-file rotary system. According to the manufacturer, these file presents a different hybrid design, modified S-shaped cross-section with two or three cutting blades, an inactive tip and Ni-Ti alloy with CM heat treatment, offering several mechanical and biological advantages, such as the decreased instrument fatigue associated with the use of one instrument for the root canal preparation (YARED 2008).

Hyflex®CM (Coltene Whaledent, Cuyahoga, Falls, OH, USA) is a rotary instrumentation system of Ni-Ti files, which have a triangular cross-section with no radial blade. These instruments are produced with CM-Wire alloy by a single process not revealed by the manufacturer. The CM-Wire alloy shows variations in its composition, presenting a lower percentage of nickel (52% by weight) than the most used alloys (54.5-57% by weight) (TESTARELLI et al. 2011). Thus, according to the manufacturer, these files have greater flexibility than other instruments in the same line, demonstrating 300% more fatigue resistance, besides being able to recover their original shape after sterilization.

In order to add to the advantages of the rotating and reciprocating systems, the ProDesign Duo Híbrido system (Easy, Belo Horizonte, Brazil) has been presented recently, recommending a hybridization of the kinematics in the prepare of root canal systems. The rotational motion is used in until establishment of patency and the pre-enlargement, while the refinement is realized in the reciprocating motion.

In laboratorial studies, several methods of analysis, in addition to radiography, have been used to assess remaining filling material, such as clearing techniques (TASDEMIR et al. 2008), scanning electron microscopy (PIRANI et al. 2009, FENOUL et al. 2010, XU et al. 2012), computed tomography (BARLETTA et al. 2007), computed microtomography (ROGGENDORF et al. 2010, RODIG et al. 2012) and analysis by optical microscopy (TAKAHASHI et al. 2009, DUARTE et al. 2010).

A nondestructive analysis through three-dimensional images can provide more precise results via volumetric evaluation of dental tissues as well as the root canal filling materials (SOLOMONOV et al. 2012). Micro-computed tomography (micro-CT) allows a quantitative evaluation of residual filling material (HAMMAD et al. 2008, MA et al. 2012, RODIG et al. 2012, ROGGENDORF et al. 2010, SOLOMONOV et al. 2012). This technique also facilitates the measurement of dentine removal during retreatment (RODIG et al. 2012), which is an important factor as excessive removal of dentine should be avoided, thus reducing the risk of vertical root fracture or perforation (HULSMANN et al. 2011).

Another alternative to the analysis of remaining material filling is confocal laser scanning microscopy (CLSM), which can assess filling material in root canals and dentinal tubules with no need for special processing, thus decreasing the potential to produce technical artefacts (GHARIB et al. 2007, ORDINOLA-ZAPATA et al. 2009, Marciano et al. 2011, De-Deus et al. 2012).

Therefore, the purpose of this study was to compare the performance of two rotary systems (Mtwo and ProDesign Logic) in preparation of mesial canals of mandibular molars by assessing volumetric increase and root canal transportation. Besides, this study also evaluated the canal transportation and remaining filling material volume between the groups (Reciproc, Hyflex and ProDesign Duo Híbrido) by micro-CT and confocal laser scanning microscope (CLSM) analysis after endodontic retreatment. The instrumentation and removal filling material time were also evaluated.

2 Articles

2 ARTICLES

2.1 Article 1 - Comparison of the shaping ability using Mtwo and ProDesign rotary systems

The article presented in this Thesis was written according to the Journal of Endodontics instructions and guidelines for article submission

ABSTRACT

Introduction: The aim of this ex vivo study was to compare the shaping ability of two rotary systems, Mtwo and ProDesign Logic in terms of the time dispended to instrumentation, volume increase and canal transportation at distances of 2, 4, 6, 8 and 10mm from the apex.

Methods: Thirty mandibular molars were divided into 2 groups according to instrumentation procedures: Mtwo in full sequence (10.04, 15.05, 20.06, 25.06) and “single-file” ProDesign Logic (25/.06). Micro-computed tomography scans were performed before and after each instrumentation procedure to evaluate the volume and canal transportation. The instrumentation time was measured with a 1/100 second chronometer from the moment files entered the canals until they got out. The data were compared statistically using a significant level of 5%.

Results: No statistical significant differences in the volume increase and canal transportation between the groups in all portions analyzed (2, 4, 6, 8 or 10 mm) were found ($P>0.05$). However, the difference in the instrumentation time was significant ($P<0.05$).

Conclusions: The Prodesign Logic using on file prepared the mesial root canals faster than the MTwo System and with the similar volume and root canal transportation.

Keywords: Micro-computed tomography. Root canal preparation. Rotary systems. Transportation

INTRODUCTION

The principal purposes of the root canal preparations is the complete cleaning and shaping of the root canal system, maintaining the original canal shape as much as possible without causing iatrogenic events (1, 2).

Deviation from the original canal path and occurrence of apical transportation are some of the most common errors during the root canal preparation. Stainless steel hand instruments present great ability in causing these mishaps, due to the stiffness of the file and intense lateral pressure on the walls of the canal (3).

In the recent decades, new systems with different movements and techniques have been introduced in Endodontics for the preparation of the root canal system. Also, several rotary nickel-titanium (Ni-Ti) instruments with different designs and shapes have been developed to favor a major safety in the root canal instrumentation and reducing the operating time, including the development of Ni-Ti single-file systems (4, 5).

Mtwo is a rotary Ni-Ti system (VDW, Munich, Germany) composed by four different basic sizes: 10.05, 15.05, 20.06 and 25.06, also offering accessory files for wider root canals (30.06, 35.06, 40.05 and 25.07). These files have a S-shaped cross-sectional design, a noncutting safety tip, positive rake angle with two cutting edges, increasing pitch length from the tip to the shaft and manufacture with conventional Ni-Ti alloy. This design prevents the screwing effect in continuous rotation and reduces the extrusion ensuring good control of the instrument's progress (6–8).

There are also the Ni-Ti endodontic instruments that undergo a thermomechanical treatment, which offers significant benefits in terms of effectiveness and safety (9). Several thermal treatments of Ni-Ti alloys, such as M-wire and CM-wire, have been used to optimize the microstructure of Ni-Ti alloys favoring a greater influence on the reliability and mechanical properties of Ni-Ti files (9–12). The CM-wire instruments have been manufactured by means of a special thermomechanical process that controls the memory of the material in the martensite phase. This makes the files extremely flexible and resistant to cyclic fatigue and reduces procedural errors such as ledges and instrument fracture in curved canals (9, 13).

A new automated single-file rotary system was introduced on the market recently. The Easy ProDesign Logic (Easy Equipamentos Odontológicos, Belo Horizonte, MG, Brazil), is available in four different sizes for the patency: 25/.01, 30/.01, 35/.01 and 40/.01 and four shaping file: 25/.06, 30/.05, 35/.05 and 40/.05, besides the accessories 15/.05, 25/.04, 45/.01 and 50.01 files (14). According to the manufacturer, these file presents a different hybrid design, modified S-shaped cross-section with two or three cutting blades, an inactive tip and Ni-Ti alloy with CM heat treatment, offering several mechanical and biological advantages, such as the decreased instrument fatigue associated with the use of one instrument for the root canal preparation (15).

Various techniques have been used to evaluate the performance of files inside the root canal, including longitudinal and transverse sectioning and use of radiographs (16, 17). By means of images with excellent resolution, the Computed Micro-tomography (micro-CT) allows a three-dimensional quantitative evaluation of the root canal system (18, 19), as well as the volume of the canal and dentin, surface area, proportion of the root canal prepared or obturated (19, 20). In addition, the analysis through micro-CT is a non-destructive technique, allowing an evolutionary analysis of the specimen, evaluating the effects of each instrument among the different systems present in the current market.

Thus, this study evaluated through computed micro-tomography the performance of the Mtwo and ProDesing Logic systems, in the preparation of mesial canals of mandibular first permanent molars by assessing volumetric increase and root canal transportation. Preparation time and instrument fracture frequency were also observed. The null hypothesis tested was that there is no differences between the two systems.

MATERIALS AND METHODS

Teeth selection

After ethics committee approval (protocol 1.334.911), thirty first and second mandibular human molars with fully formed apices were selected. The inclusion criteria consisted of only molars with a moderately curved mesial root (10º-20º) according to Schneider’s method (21), with 2 independent root canals and foramina, and with 19–22 mm in length. A total of 30 mesial roots of mandibular molars, totaling 30 root canals were used.

Micro-CT scanning procedures

The teeth were placed in silicone molds to allow the sample to be scanned in the same position before and after instrumentation.

Pre- and post-instrumentation images were acquired by a Skyscan 1174 micro-computed tomography (Bruker-microCT, Kontich, Belgium) in the same parameters (50kV, 800 μA and 360º rotation with a 0.7º rotation step, resulting in an image with a 19.7 μm voxel. Next, the images were reconstructed with NRecon v.1.6.4.8 software (Bruker microCT). After binarization, the region of interest was determined as the circumferential area of the root canal. In the CTan v.1.12 software (Bruker microCT) was performed the measures of volume manually, and the end of the root apex was used as the landmark to determine the root canal areas analyzed.

Root canal preparation

The coronal access was performed by using diamond burs. The working length was established with a size 10 K-file (Dentsply Maillefer, Ballaigues, Switzerland) using 2.5% sodium hypochlorite (NaOCl) as the irrigant. Under a dental operative microscope set at 8x magnification, and the working length was determined when the tip of the instrument could be seen through the foramen, it was withdrawn 1 mm. All specimens were prepared by the same operator. The teeth were divided into 2 groups, each with similar characteristics, to ensure homogeneity.

Mtwo group (n = 15). The instrumentation sequence was performed using the following parameters: 10.04, 15.05, 20.05 and 25.06 files at the full working length, with the respective Mtwo program of the VDW Silver electric motor (VDW, Munich, Germany) with a rotational speed of 280 rpm and the torque was adjusted to 1.2 N/cm.

ProDesign Logic group (n = 15). The instrumentation sequence was performed using the following parameters: 25.06 “single-file” at the full working length, with the respective Logic program of the Easy Endo SI electric motor (Easy Equipamentos Odontológicos, Belo Horizonte, MG, Brasil) with a rotational speed of 950 rpm and the torque was adjusted to 4.0 N/cm, configuration pre-set by the engine system. Between each preparation step, the instrument was cleaned, and irrigation was performed with 1 mL 1.0% NaOCl in disposable syringes and 30-G NaviTip needles (Ultradent, South Jordan, UT). A final rinse with 5 mL 17% EDTA was delivered for 3 minutes followed by saline solution and the root canals were dried with absorbent paper points (Dentsply Maillefer, Ballaigues, Switzerland).

Analysis method

The pre- and post-instrumentation images were aligned by using the 3D registration function of the DataViewer v.1.5.1.2 software (Bruker microCT). The recorded images were processed using CTAn v.1.12 software (Bruker microCT) to construct visual 3D models and calculate quantitative parameters. The measures of volume were performed manually and after the binarization the region of interest was determined. The total volume consisted of furcation region to the apex of the mesial root, integrating regions of interest in all the cross sections. The volume of the apical third was calculated at 1, 2, and 3 mm from de apex, dividing slice by three. The volume of the root canals was calculated by subtracting the values for the treated canals from those recorded for the untreated counterparts.

The instrumentation time was measured with a 1/100 second chronometer from the moment files entered the canals until they got out.

For root canal transportation analysis, the first 1 mm from the apex was discarded. Axial sections corresponding to distances of 2, 4, 6, 8 and 10 mm from the apex were selected. Canal transportation was calculated in millimeters using the formula ([X1-X2]-[Y1-Y2]) as described by Gambill et al (22), where X1 is the shortest distance between the mesial portions of the root and uninstrumented canal, X2 is the shortest distance between the mesial portions of the root and instrumented canal, Y1 is the shortest distance between the distal portions of the root and uninstrumented canal, and Y2 is the shortest distance between the distal portions of the root and instrumented canal. Pre- and postoperative measurements were compared to reveal the presence or absence of deviations in canal anatomy and to identify the most affected region (Figure 1). According to this formula, a result of 0 indicated no canal transportation. A negative result indicated transportation away from the furcation region, and a positive result indicated transportation toward the furcation region.

Statistical Analysis

The normality of the variable distribution in each group was verified using Shapiro-Wilks test.

The evaluation of canal volumetric increase and preparation time were conducted using Student t-test analysis.

Non-parametric Wilcoxon test was used to the intragroup comparison at the 2, 4, 6, 8 and 10 mm levels and non-parametric Mann-Whitney test was used to the comparison between groups in the root canal transportation in all sections of the root canal.

All analyses were calculated using the GaphPad Prism 7 (La Jolla, CA, USA), and the level of significance was established at 5%.

RESULTS

During the preparation of the curved canals, no instrument fractured and no deformation of an instrument was noted.

The initial root canal volume was similar for both groups ($p>0.05$).

The table 1 presents the effective time required in root canals instrumentation for both systems. The Prodesign Logic system dispended significantly less time than MTwo system ($p<0.05$).

Table 2 refers to the volumetric increase in the different thirds (1, 2 and 3 mm) of the apical root canal and the volumetric increase along the entire canal length. There was not observed statistical significant differences between the groups in the volume ($p>0.05$).

Table 3 presents the canal transportation in the two groups (Mtwo and ProDesign Logic) at five different sections of the canals (2, 4, 6, 8 and 10 mm from the apex). There were no statistical significant differences ($p>0.05$) between different levels in both groups, even in the comparison between the groups.

DISCUSSION

The null hypothesis tested was partially rejected once the Prodesign Logic favored a faster time in the root canal preparation.

The success of root canal preparation is directly related to the removal of contaminated dentin to eliminate bacteria and their toxins (23-25).

The aim of this study was to compare the shaping ability of two rotary systems, Mtwo (full sequence) and ProDesign Logic (single-file), in root canals of extracted human mandibular molars teeth that have two separate canals which provide an excellent model of side-by-side comparison for two different shaping systems (26, 27).

Dentin removal increases root canal volume, which is essential to a successful preparation. In the present study, although the Mtwo group presented the greatest increase in total volume of the root canal when compared with the ProDesign Logic, the difference was not significant. This finding may be explained by the same final taper (0.06 mm) of both systems used in this study.

The volumetric increase in the different sections of apical third was slightly larger in Mtwo group than in ProDesign Logic group, but with no statistically significant difference (Table 2). The apical volumetric increase was relatively small and may be justified by the fact that there may be accumulation of debris in this region. Studies show that the projection of dentin debris in the apical portion is due to the pressure resulting from the use of the instruments. In addition, single instrument systems that are not used progressively, there is a greater pressure applied to the apical portion to achieve the working length (28), which may lead to a greater accumulation of debris in that region.

While the Mtwo system used in this investigation consisted of four instruments to prepare the root canal to a size of 25, only one instrument was used for ProDesign Logic. This difference in the number of instruments used in the preparation clearly explains why ProDesign Logic, required significantly less time than Mtwo system in the root canal preparation ($P<0.05$), which corroborates previous findings (29). This difference in preparation time may be also associated with the instrument’s preparation performance speed and torque. Instruments such as the ProDesign Logic system act on the canal with greater speed and torque (950 rpm, 4 N/cm), reducing the preparation time and incidence of interruptions at the maximum torque, especially if compared with the Mtwo system, which operates with a 1.2 N/cm torque. The higher speed and torque as necessary to increase the efficiency of cut dentin, because the instruments with CM-Wire which are more flexible and present less cut ability. However, the high flexibility increase the security in curvature due to the high fatigue resistance (11).

In the present study, there were no significant differences in canal transportation in the different levels between Mtwo and ProDesign Logic systems, which might be attributed to structural properties of these files. Both files present S-shaped cross-sectional design with cutting almost perpendicular edges. This configuration results in an increase in file flexibility and its centering ability (30, 31).

Several factors influence the amount and direction of apical transportation in addition to the metallurgic properties (10, 32) and cross-sectional design of the file. Dimension of the file, operator technique and canal system anatomy can directly influence on transportation during preparation (33).

Micro-CT analysis was chosen because it is an excellent, noninvasive, and nondestructive method for quantitatively and qualitatively evaluating root canals (34). The high-resolution and fully quantifiable data obtained through this imaging modality coupled with the ability to match and compare precisely the same pre- and post-instrumentation slice yields a highly accurate approach to the assessment of apical transportation (35).

Considering ProDesing Logic files are new, to completely assess the shaping potential, further studies are required to focus on other criteria for canal preparation.

Based on the results obtained following the described ex vivo methodical approach, The Prodesign Logic and Mtwo system presented the similar ability preparation of mesial canal and mandibular molars. The Prodesign Logic dispended less time than MTwo system during the root canal preparation of mesial canals of mandibular molars.

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FIGURE LEGENDS

Figure 1. Representative cross sections of root canals before (A) and after (B) instrumentation. X1 and X2 correspond to the distances between the mesial portions of the root canals in the uninstrumented and instrumented root canals, respectively. Y1 and Y2 represent the distances between the distal portions of the root in the uninstrumented and instrumented canal, respectively.

Table 1. Mean time required (s) and standard deviation (SD) after root canal instrumentation.

	n	Preparation time (s)
Mtwo	15	125.8 ± 10.97[a]
Logic	15	45.7 ± 3.01[b]

Different superscript lower case letters in each row indicate statistically significant difference between the groups (P<0.05).

Table 2. Mean volume increase (mm^3) and standard deviation (SD) after instrumentation.

	Volume increase (%)			
	1mm	2mm	3mm	Total root canal
Mtwo	$0.05 \pm 0.08^{a, A}$	$0.07 \pm 0.09^{a, A}$	$0.08 \pm 0.11^{a, A}$	1.10 ± 0.08^{1}
Logic	$0.05 \pm 0.09^{a, A}$	$0.06 \pm 0.09^{a, A}$	$0.07 \pm 0.10^{a, A}$	1.07 ± 0.04^{1}

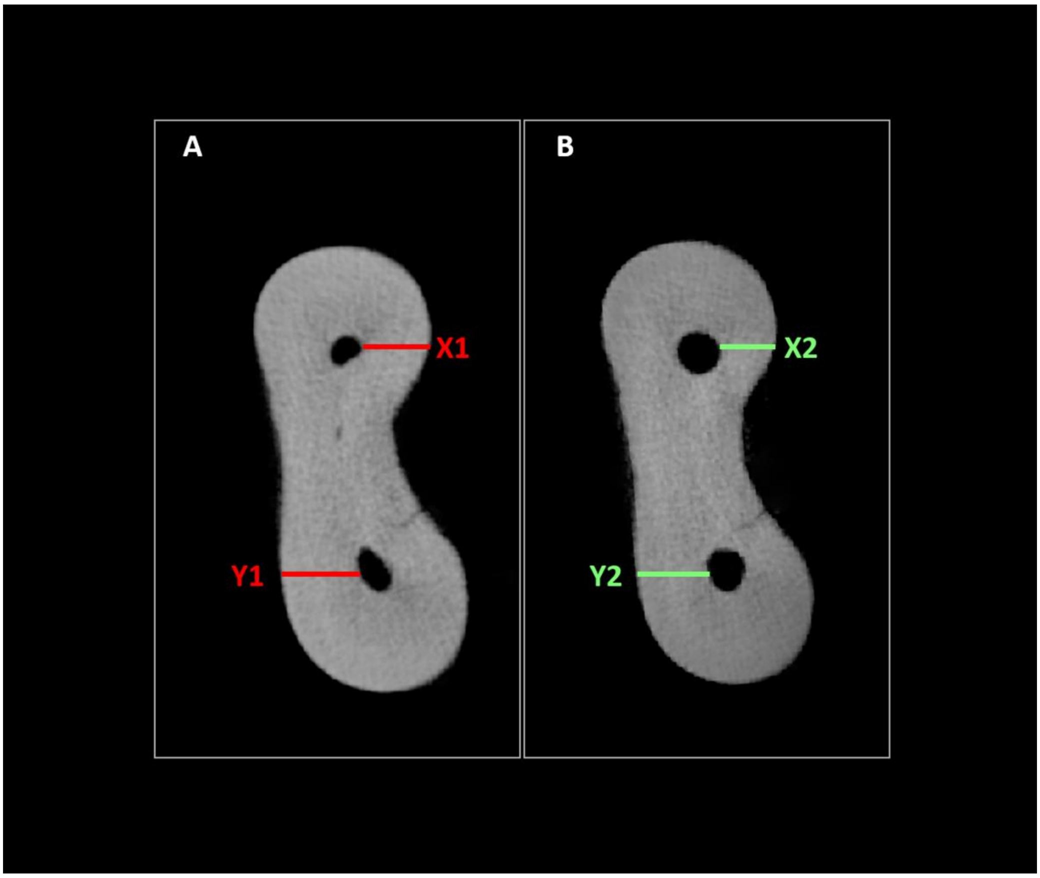
Same superscript lower case letters in each column indicate no statistically significant difference in the different sections (P>0.05). Same superscript upper case letters in each row indicate no statistically significant difference between the groups (P>0.05). Same superscript number in each row indicate no statistically significant difference in the different total root canal between the groups (P>0.05).

Table 3. Mean, minimum and maximum canal transportation (mm) after instrumentation in different slices.

	Canal transportation (mm)				
	2mm	4mm	6mm	8mm	10mm
Mtwo	-0.01 (-0.04 / 0.02)$^{a, A}$	0.01 (-0.01 / 0.03)$^{a, A}$	0.02 (-0.02 / 0.08)$^{a, A}$	0.03 (-0.01 / 0.07)$^{a, A}$	0.03 (-0.02 / 0.06)$^{a, A}$
Logic	-0.01 (-0.01 / 0.04)$^{a, A}$	0.01 (-0.01 / 0.05)$^{a, A}$	0.02 (-0.02 / 0.06)$^{a, A}$	0.04 (-0.02 / 0.06)$^{a, A}$	0.02 (-0.01 / 0.07)$^{a, A}$

Same superscript lower case letters in each column indicate no statistically significant difference in the different sections (P>0.05). Same superscript upper case letters in each row indicate no statistically significant difference between the groups (P>0.05).
Negative result indicates transportation away from the furcation region. A positive result indicates transportation toward the furcation region.

Figure 1



2.2 Article 2 - Efficacy of CM-Wire and M-Wire Nickel-Titanium Instruments for Removing Filling Material from Curved Root Canals

The article presented in this Thesis was written according to the International Endodontic Journal instructions and guidelines for article submission

ABSTRACT

Introduction: The aim of this ex vivo study was to evaluate the removal of filling material after using nickel-titanium and CM-wire instruments in both reciprocating and rotary motions in curved canals, evaluating root canal transportation at distances of 2, 4, 6, 8 and 10mm from the apex, volume of endodontic filling remaining at 1, 3 and 5 mm from the apex and the time dispended to material removal and canal reinstrumentation.

Methodology: Forty-five mandibular molars were prepared and divided into 3 groups according to retreatment procedures: Reciproc R25 followed by R40; Hyflex 25.04 followed by 40.04; ProDesign Duo Híbrido 25.06 followed by 40.05. Micro–computed tomography scans were performed each step procedure to evaluate root canal transportation and canal filling removal. An additional analysis was made by confocal laser scanning microscope to evaluate volume of remaining filling material. The retreatment time dispended was measured with a 1/100 second chronometer during the procedure of removal filling and then, in the moment that files entered the canals until they got out on reinstrumentation step. Statistical analysis was performed with t-paired, ANOVA, Kruskal-Wallis and Friedman tests ($P < 0.05$).

Results: No significant differences in canal transportation and filling material removal were found in the 3 groups. The Reciproc group presented significantly less time for filling material removal as well as for reinstrumentation.

Conclusions: None of the retreatment techniques removed the root fillings completely. The results suggest that no difference exists between the groups when considering apical transportation in curved canals. The Reciproc system featured a significantly shorter preparation time than the others.

Keywords: Confocal microscopy, Micro-computed tomography. Reciprocating systems. Root canal retreatment. Rotary systems.

INTRODUCTION

Failure in an endodontic treatment may occur due to persistence of bacteria in the root canal system as a consequence of inadequate obturation, insufficient cleaning/disinfection of the root canal system, unfilled root canals, underextended root fillings, overextended root fillings advancing beyond the apical limit, and defective coronal restoration (Hulsmann & Stotz 1997, Zamin *et al.* 2012, Rodig *et al.* 2014, Silva *et al.* 2015).

Retreatment is intended to completely remove the filling material to recommended root canal disinfection and allow periradicular healing through cleaning, disinfection, and reinstrumentation of canals prior to refilling (Paik *et al.* 2004, Cavenago *et al.* 2014, Nudera 2015).

Several techniques have been used for removing root-filling materials, including stainless steel hand files (Imura *et al.* 2000, Schirrmeister *et al.* 2006), burs and rotary instruments (Takahashi *et al.* 2009, Bramante *et al.* 2010, Rodig *et al.* 2012, Zuolo *et al.* 2013, Cavenago *et al.* 2014, Fruchi *et al.* 2014, Rios *et al. 2014*, Bernardes *et al.* 2016, Zuolo *et al.* 2016). Nickel-titanium (Ni-Ti) rotary systems have been used in endodontic retreatments due of their efficiency, safety and ability to remove filling material faster than hand files (Zuolo *et al.* 2013, Colaco & Pai 2015). Reciprocating instruments have also shown good results in retreatment procedures when used to remove filling material (Zuolo *et al.* 2013, Yuruker *et al.* 2016).

The conventional Ni-Ti alloy has an austenite structure, but recently it was developed M-wire Ni-Ti, which suffers a thermal treatment, promoting a mixture of nearly equal amounts of R-phase and austenite (Alapati *et al.* 2009, Rodrigues *et al.* 2016). M-wire Ni-Ti contains substantial amounts of martensite that does not undergo phase transformation resulting in a metallurgical microstructure that exhibits alloy strengthening (Alapati *et al.* 2009). Besides this M-wire technology, another innovative approach is the use of a controlled memory alloy (CM-wire) to produce rotary Ni-Ti instruments, the Hyflex CM files (Coltene/Whaledent, Altstätten, Switzerland) (Gutmann & Gao 2012) and ProDesign Logic (Easy Equipamentos Odontológicos, Belo Horizonte, MG, Brazil).

Studies show that rotational systems are widely used to remove filling material efficiently and safely with less operator fatigue and high success rates (Barletta *et al.* 2007, Marques da Silva *et al.* 2012, Silva *et al.* 2015). Recently, the reciprocating kinematics emerged as a result of an evolution of the mechanized systems, indicated for instrumentation of the root canals and for the removal of filling material in endodontic retreatments, mainly used in single instrument techniques. (Zuolo *et al.* 2013, Fruchi *et al.* 2014, Rodig *et al.* 2014, Silva *et al.* 2014).

Therefore, the purpose of this study was to compare remaining filling material between the groups by micro-CT and confocal laser scanning microscope the purpose of this study was to compare remaining filling material between the groups by micro-CT and confocal laser scanning microscope (CLSM) analysis after retreatment of mandibular molars with curved canals with Reciproc, Hyflex and ProDesign Duo Híbrido. Besides, time of removal filling material and canal transportation was also evaluated. The null hypothesis tested was that there is no differences between the systems.

MATERIALS AND METHODS

Teeth selection

After ethics committee approval (protocol 1.334.911), forty-five first and second mandibular human molars with fully formed apices were selected. The inclusion criteria consisted of only molars with a moderately curved mesial root (10º - 20º) according to Schneider's method (21), with 2 independent root canals and foramina, and with 19–22 mm in length.

Root canal preparation and filling

The coronal access was performed by using diamond burs. The working length was established with a size 10 K-file (Dentsply Maillefer, Ballaigues, Switzerland) using 1% sodium hypochlorite (NaOCl) as the irrigant. Under a dental operative microscope set at 8x magnification, and the working length was determined when the tip of the instrument could be seen through the foramen, it was withdrawn 1 mm. The same operator prepared all specimens.

The teeth were divided in three groups (n=15) and the root canals were prepared by using Mtwo instruments (VDW, Munich, Germany) up to instrument 25.06 using VDW Silver electric motor (VDW, Munich, Germany) with a rotational speed of

280 rpm and the torque was adjusted to 1.2 N/cm, ProDesig Logic (Easy Equipamentos Odontológicos, Belo Horizonte, MG, Brazil) with 25.06 single-file by using Easy Endo SI electric motor (Easy Equipamentos Odontológicos, Belo Horizonte, MG, Brazil) with a rotational speed of 950 rpm and the torque was adjusted to 4.0 N/cm and ProDesign R with 25.06 single-file using VDW Silver electric motor in reciprocating mode. The canals were irrigated with 1 mL 1% sodium hypochlorite, and a final rinse was performed with 5mL 17% EDTA for 3 minutes. The canals were flushed with saline solution, dried with paper points, filled by the single-cone technique and zinc oxide and eugenol–based sealer (Endofill; Dentsply Ind Com Ltda, Petrópolis, RJ, Brazil) with Rhodamine B (Sigma-Aldrich, St Louis, MO) for fluorescence. Rhodamine B was mixed with sealer at a 1:100 ratio by weight. Coronal accesses were sealed with temporary filling material (Coltosol, Coltene-Whaledent, Cuyahoga Falls, OH, USA), and the teeth were stored at 37ºC and 100% humidity for 7 days to allow complete setting of the sealer. Then, the samples were scanned by using the micro-CT system (SkyScan 1174v2; Bruker-microCT, Kontich, Belgium) with 50 kV, 800 mA, 0.7º step size rotation, and 19.7 mm voxel resolution. The data were elaborated by reconstruction software (NRecon v.1.6.3; Bruker-microCT), and the CTan 1.14.4.1 software (Bruker-microCT) was used for measuring the volume (mm^3) of the root canal.

Retreatment

The same operator prepared all specimens. The teeth were again subdivided to ensure homogeneity between the groups. For this, 5 specimens prepared with Mtwo, 5 specimens prepared with ProDesing Logic and 5 specimens prepared with ProDesing R were distributed for each group, maintaining a value of *n* equal to 15.

An aliquot of 0.5 mL xylene solvent (Merck KGaA, Darmstadt, Germany) was put into the pulp chamber for 30 seconds to soften the gutta-percha at the cervical level before beginning with root-filling removal.

In the Reciproc group (n = 15 teeth), root fillings were removed by using R25 Reciproc files (size 25 with a taper of 0.08) (VDW, Munich, Germany) with the respective Reciproc program of the VDW Silver electric motor until working length was reached followed by apical enlargement with a R40 file (size 40 with a taper of 0.06) over the first apical millimeters.

In the Hyflex group (n = 15 teeth), root fillings were removed by using file size 25 with a taper of 0.06 with a VDW Silver electric motor, in rotary mode, until working length was reached followed by apical enlargement with a file size 40 with a taper of 0.04 over the first apical millimeters, with 500 rpm and a torque of 2 N/cm with minimal apical pressure.

In the ProDesign Duo Híbrido group (n = 15 teeth), root fillings were removed by using file size 25 with a taper of 0.06 with an Easy Endo SI® motor, in rotary mode, until working length was reached followed by reciprocating mode (500 rpm and a torque of 2 N/cm) with the same file for refining of re-preparation also until working length. Then, the apical enlargement was made by a file size 40 with a taper of 0.05 over the first apical millimeters, with 500 rpm and a torque of 2 N/cm.

In all groups, irrigation was performed with 2 mL 1% NaOCl every time after the use of an instrument. Ni-Ti instruments were discarded after four uses or if a visible deformation occurred. Time to reach working length (T1) as well as time needed for complete gutta-percha removal and preparation to size 40 (T2) were recorded. Time for instrument changes and irrigation was not accounted. Total working time was calculated by adding T1 and T2. Removal was considered complete when no residual filling material was observed in the instrument flutes or in the irrigation solution.

Instrument fractures were recorded and as a fracture occurred, the tooth was discarded. Final irrigation was performed with 5 mL 17% EDTA and 5 mL 1% NaOCl, and root canals were dried with paper points.

The canals were refilled by the single-cone technique and AH Plus sealer (Dentsply Maillefer, Ballaigues, Switzerland) with fluorescein dye (Sigma-Aldrich, St Louis, MO). Fluorescein was mixed with sealer at a 1:100 ratio by weight. Coronal accesses were sealed with temporary filling and the teeth were stored at 37ºC and 100% humidity for 7 days to allow complete setting of the sealer. Then, the samples were analyzed by using the CLSM.

Micro-CT scanning procedures

Altogether, each tooth was scanned 4 times: pre- and post-preparation, after the root canal filling and after the removal of root canal filling.

The teeth were placed in silicone molds to allow the sample to be scanned in the same position before, during and after retreatment. The same scanning parameters were used for all specimens. For reconstructions, the parameters used were the same for each tooth after each scanning procedure. After binarization, the region of interest was determined as the circumferential area of the root canal. In the CTan v.1.12 software was performed the measures of volume manually, and the end of the root apex was used as the landmark to determine the root canal areas analyzed.

Confocal Microscopy analysis

After the micro-CT analysis, the specimens were sectioned in to slices of 2 mm thickness with a cutting machine (Isomet, Buehler, Lake Bluff, Illinois, USA) under water cooling, discarding the first apical millimeter. The volume of filling material was calculated at 3 levels: between 1.0 and 3.0 mm from de apex, between 3.0 and 5.0 mm, between 5.0 and 7.0 mm.

The slices of each root canal were evaluated using a confocal inverted microscope Leica TCS-SPE (Leica Microsystems GmbH, Mannheim, Germany) and a method of epifluorescence with wavelengths of absorption and emission to rhodamine B of 540/590 nm and to fluorescein of 536/617 nm. The samples were analyzed 10 μm below the surface sample with 10x of magnification.

To evaluate remaining of filling material that was not removed during retreatment, the LAS x 3D and 2D analysis V1.46r (Leica Microsystems GmbH, Mannheim, Germany) software was used. The scale offered by CLSM images (100μm) was set in the program and used to measure the total length of old material. Once these measurements were obtained, the percentages were calculated for all sections. The volumes were recorded, and the percentage of remnant filling material after each procedure was expressed in terms of percentage of the initial root-filling material volume.

Statistical analysis

For the analysis, GraphPad Prism 7 (La Jolla, CA, USA) was used. Preliminary analysis of data normality was performed with the Shapiro-Wilk test.

The intra-group comparison regarding the presence or absence of root canal deviation after removal of root canal filling material and re-instrumentation was submitted to the parametric T-paired statistical test, since it had a normal distribution.

The working time with the different alloys used in this study was analyzed through parametric ANOVA e Tukey statistical test.

The analysis of the remaining material present in the root canals was performed with nonparametric Kruskal-Wallis and Dunn tests. For the intra-group comparison between the different slices (2, 4 and 6 mm), the data were submitted to nonparametric Friedman and Dunn tests. The significance level of 5% ($P < 0.05$) was considered.

Results

During the removal of root canal filling, two instruments of group II (Hyflex) fractured and the specimens were discarded.

In all groups, the thirds of 4, 6, 8 and 10 mm were transported to the danger zone (towards the furcation). However, the apical third (2 mm) was transported in opposite direction to the furcation as shown in Table 1, but with no statistically significant difference between them ($P > 0.05$)).

The mean time to perform endodontic retreatment with the different instruments is shown in Table 2. The time required to removal filling material (T1) from the root canals was higher in Hyflex group, presenting statistical significant difference between them. The Reciproc group presented significantly less time for apical enlargement (T2) and total time (T1 + T2) for root canals retreatment ($P < 0.05$).

Remaining filling material was observed in all specimens. Mean percentages of residual material are shown in Table 3 in different levels. All retreatment techniques left 5.56–8.97% (confocal analysis) and 5.92–8.52% (micro-CT analysis) of the filling material in the root canal. The Prodesign Duo Híbrido group had a lower percentage of filling material in all levels when compared to other groups, with no statistic between them ($P > 0.05$).

Discussion

Retreatment is intended to completely remove the filling material to permit thorough cleaning, disinfection, and reinstrumentation of canals prior to refilling (Saad *et al.* 2007, Marques da Silva *et al.*2012).

Recently, it has been suggested that the combination of techniques might result in more efficient removal of material from the root canal system (Hammad *et al.* 2008).

An evaluation of whether a file used in reciprocation or rotary motion, or even in a hybridization of both kinematics is able to removal all material filling, keep the original position of the canal and facilitate even enlargement in all directions is an important consideration to take into account. (Junaid *et al.* 2014).

Mandibular molars that have 2 separate canals ending in 2 separate foramina in the mesial root were selected as the study model due the complicated canal morphology and significant curvatures often make these canals challenging to treat and allow for a realistic evaluation of a file system's true capabilities and performance level (Junaid *et al.* 2014).

One of the most important aims of root canal treatment and retreatment is to produce the most conical canal shape as possible from the apical to the coronal area, preserving the original general shape of the canal (Thompson *et al.* 2000). This is difficult to achieve in curved root canals and some errors might occur during the process, including canal transportation, ledge formation and/or canal perforation (Abou-Rass *et al.* 1980, Alves *et al.* 2013).

Retreatment is much more difficult and time-consuming than the initial root canal treatment. The use of Ni-Ti files makes the retreatment procedure easier (Duncan & Chong 2008). In order to overcome the endodontic retreatment difficulty, rotary and reciprocating instruments have been widely used for maintaining the original shape of the root canal (Fruchi *et al.*, 2014), which is in agreement with this study, as no significant difference was observed between the instruments used for root canal deviation.

Some studies show that micro-CT has been used to evaluate the remaining filling material (Rodig *et al.* 2012, Cavenago *et al.* 2014, Fruchi *et al.* 2014, Rodig et al. 2014, Zuolo *et al.* 2016, Alves *et al.* 2016). Micro-CT imaging was chosen due it is excellent nondestructive high-resolution imaging method, which provides a highly accurate quantitative 3D analysis of filling material volume in mm^3 before and after use of each instrument (Fruchi *et al.* 2014, Crozeta *et al.* 2016) allowing for calculating the percentage of filling material left in the canals after retreatment. CLSM can be also used as an alternative to other method of evaluation of endodontic filling remaining.

In this study, the authors used different retreatment procedures, including rotary files, reciprocating instruments and a hybridization between the two motions. Although the instruments were efficient in removing a large amount of gutta-percha, none of the techniques was able to completely remove the filling material from the root canal walls, which is in agreement with the literature (Betti *et al.* 2009, Bramante *et al.* 2010, Cavenago *et al.* 2014, Bernardes *et al.* 2016, Rodrigues *et al.* 2016). The presence of filling remnants in all groups could be attributed to the oval shape of the canals. It has been demonstrated that the root canal anatomy, especially the oval shape can impair the removal of filling material (Ma *et al.* 2012, Rechenberg & Paque 2013) because of the untouched regions in the flattened areas of the canal (Keles *et al.* 2014).

The ProDesign Duo Hibrido group presented a lower amount of filling material remaining in the root canals. This fact occurs probably due to the association of two different movements (rotational and reciprocating) during endodontic retreatment, promoting a longer time of the file in movement, facilitating the removal filling material from the canal.

This study showed no significant differences in canal transportation between the groups in the different levels. It might be attributed to structural properties of these files. Indeed, the cross-sectional in S-shaped with two cutting almost perpendicular edges in Reciproc file and the thermomechanical treatment in the Hyflex and ProDesign Duo Híbrido files result in an increase of flexibility and centering ability (Bonaccorso *et al.* 2009, Moradi *et al*. 2009). In all groups, the thirds of 4, 6, 8 and 10 mm were transported to the danger zone (towards the furcation), while the apical third (2 mm) was transported in opposite direction to the furcation. None of the transportation values measured in this study has an impact result. The number of factors influence the amount and direction of canal transportation in addition to the metallurgic properties (Shen *et al.* 2011, Gutmann & Gao 2012) and cross-sectional design of the file (Zhao *et al.* 2013). Operator technique, canal system anatomy, canal curvature and dimension of the file also may influence transportation during preparation (Zhao *et al.* 2013).

The goal for a short instrumentation time is important in the endodontic retreatment because in addition to facilitating the treatment, makes it less tiring for both, professional and the patient.

The results revealed that Reciproc was faster in removal endodontic filling than the other groups, as shown in the recent studies (Zuolo *et al*. 2013, Dincer *et al.* 2015). The Hyflex group was slower than the others, even using a “single-file”, probably to the thermomechanical treatment that it undergoes, making it more flexible, reducing its cutting ability (Zhou *et al.* 2012).

There is a literature scarcity as much as the use of Easy files, as for the hybridization of motions in endodontic retreatment. Therefore, more studies involving this material and methodology should be developed to ensure the results of this research.

CONCLUSION

Based on the results obtained, no significant differences in measures of apical transportation in curved canals were observed between the three systems. In all groups, transportation toward the danger zone was observed in the cervical and middle thirds, while the transportation in apical third was transported in opposite direction.

None of the retreatment techniques removed the root fillings completely. The combination of reciprocating and rotary files in the retreatment of curved canals was as efficient as rotary and reciprocating motion separately. Preparation with the Reciproc system was faster than the other groups.

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FIGURE LEGENDS

Figure 1. CLSM illustration: a. presence of Endofill in dentinal tubules (red) around the entire circumference of the root canal and gutta-percha cones (black colour); b. discrete quantity of AH Plus (green); c. overlay of the images.

Table 1 – Mean, minimum and maximum canal transportation (mm) in different slices after endodontic retreatment.

	Canal transportation (mm)				
	2mm	**4mm**	**6mm**	**8mm**	**10mm**
Reciproc	-0.01 (-0.04 / 0.02)$^{a, A}$	0.01 (-0.01 / 0.03)$^{a, A}$	0.02 (-0.02 / 0.08)$^{a, A}$	0.03 (-0.01 / 0.07)$^{a, A}$	0.03 (-0.02 / 0.06)$^{a, A}$
Hyflex	-0.01 (-0.01 / 0.04)$^{a, A}$	0.01 (-0.01 / 0.05)$^{a, A}$	0.02 (-0.02 / 0.06)$^{a, A}$	0.04 (-0.02 / 0.06)$^{a, A}$	0.02 (-0.01 / 0.07)$^{a, A}$
ProDesign Duo Híbrido	-0.03 (-0.02 / 0.05)$^{a, A}$	-0.01 (-0.01 / 003) $^{a, A}$	0.03 (-0.01 / 0.05) $^{a, A}$	0.04 (-0.01 / 0.04)$^{a, A}$	0.03 (-0.02 / 0.05)$^{a, A}$

Same superscript lower case letters in each column indicate no statistically significant difference in the different sections (P>0.05). Same superscript upper case letters in each row indicate no statistically significant difference between the groups (P>0.05).

Table 2 – Mean time (± standard deviation – SD) required (s) for removal filling endodontic material (T1), reinstrumentation (T2) and total time of the treatment (T1 + T2).

	Retreatment time		
	T1 (s)	**T2 (s)**	**TOTAL (T1 + T2)**
Reciproc	70.46 ±13.11[a]	22.32 ± 4.60[b]	92.78 ± 15.58[c]
Hyflex	117.9 ± 27.01[b]	32.98 ± 14.69[a]	150.9 ± 26.96[b]
ProDesign Duo Híbrido	86.98 ±17.8[a]	34.42 ± 4.56[a]	121.4 ± 16.75[a]

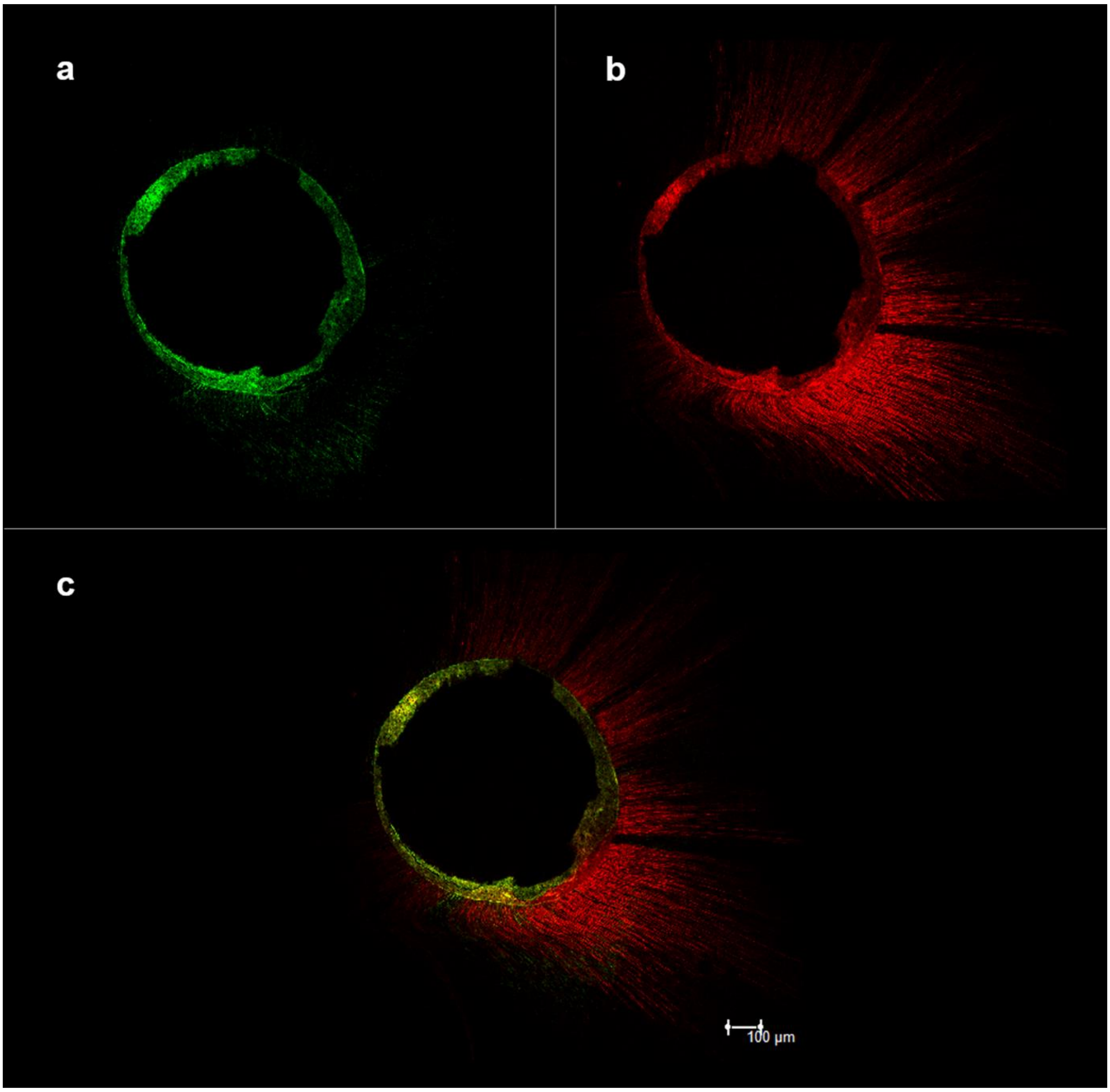
Different superscript lower case letters in each column indicate statistically significant difference in the different sections (P < 0.05).

Table 3. Mean volume (mm^3) and standard deviation (SD) of remaining filling material in different root canal slices.

	Volume (%)					
	CLSM analysis			Micro-CT analysis		
	1 – 3mm	**3 – 5mm**	**5 – 7mm**	**1 – 3mm**	**3 – 5mm**	**5 – 7mm**
Reciproc	8.21 ± 12.06$^{a, A}$	7.68 ± 6.02$^{a, A}$	7.33 ± 5.15$^{a, A}$	8.03 ± 5.12$^{a, A}$	7.99 ± 5.10$^{a, A}$	6.47 ± 4.80$^{a, A}$
Hyflex	8.97 ± 6.73$^{a, A}$	8.87 ± 6.00$^{a, A}$	7.38 ± 5.89$^{a, A}$	8.19 ± 5.47$^{a, A}$	8.52 ± 5.89$^{a, A}$	8.11 ± 5.25$^{a, A}$
ProDesign Duo Híbrido	6.37 ± 4.11$^{a, A}$	5.74 ± 4.29$^{a, A}$	5.56 ± 3.97$^{a, A}$	7.86 ± 5.20$^{a, A}$	7.00 ± 6.70$^{a, A}$	5.91 ± 4.43$^{a, A}$

Same superscript lower case letters in each column indicate no statistically significant difference in the different sections (P>0.05). Same superscript upper case letters in each row indicate no statistically significant difference between the groups (P>0.05).

Figure 1



3 Discussion

3 DISCUSSION

With increasing mechanization in endodontics, the use of Ni-Ti rotary instrument is widespread. Kandaswamy et al. (2013) have reported less canal deviation of Ni-Ti instruments as compared to stainless steel. Therefore, most reports on preserving original canal curvature have focused on Ni-Ti instrument composition and design. Mtwo and ProDesign Logic are different in their geometric design and manufacturing method. Hence, the first part of this study focused to compare the effect of these Ni-Ti rotary instruments on canal transportation and volume increase using micro-CT scanning.

Instrument design influences cutting ability to some degree and it was this parameter that these two endodontic systems (Mtwo and ProDesign Logic) were tested in the present study. ProDesign Logic is manufactured with a thermomechanical treatment, wich confers more flexibility and has a triple helix cross section. The objectives of this geometry are to reduce mechanical stress on the instrument, facilitate canal penetration by a snake-like movement and enable the upward removal of debris (HAMMAD et al. 2008). In a previous study, which tested the effect of asymmetry on the behavior of instruments with a triple helix cross section, the authors concluded that file behavior was modified, particularly causing a decrease in axial stress (DIEMER et al. 2013). Mtwo instruments have a double cutting-edge geometry with a smaller S-shaped cross-sectional area and an S-shaped cross-sectional design. The objectives of this design are to increase flexibility and give a higher torsional strength and a resistance to torsional breakage (YANG et al. 2011).

Root canal anatomy preservation is very important for three-dimensional obturation and for the success of the endodontic treatment. In the present study, there was no significant difference in canal transportation and in the volume increase between Mtwo and ProDesign Logic. As the root canals were instrumented until 25.06 file, may have contributed to this result, since the flexibility of the instruments depends on complex interrelationships among different parameters, such as the cross-sectional design, core diameter, pitch, metallurgical properties, and surface treatment of the instruments (MCSPADDEN et al. 2007). The most common way to increase file flexibility is to decrease the metal mass of the file by increasing the number of spirals or flutes per unit length; increasing the depth of the flutes; and decreasing the taper, size, and/or core diameter of the file (MCSPADDEN et al. 2007). Thus, an increased taper is related directly to the increased cross-sectional area and decreased flexibility (JAVAHERI et al. 2007). Given that an increase in the taper reduces instrument flexibility, the size of the taper is a key factor in root apical transportation (MCSPADDEN et al. 2007, SCHAFER et al. 2003). To conclude, the present study showed that the Mtwo and ProDesign Logic rotary files performed similarly in an extracted tooth model.

The results showed that there was no difference between the only one rotary file and the conventional methods of canal preparation for preservation of initial canal curvature. But the time of canal preparation was significantly shorter in only one rotary file technique (ProDesign Logic) compared to the multifile method (Mtwo).

The second result of this study shows that although the instruments were efficient in removing a large amount of gutta-percha, none of the techniques were able to completely remove the filling material from the root canal walls, which is in agreement with the literature (CAVENAGO et al. 2014, ZUOLO et al. 2013, FRUCHI et al. 2014, BERNARDES et al. 2016, BETTI et al. 2014, YURUKER et al. 2016). It was used different retreatment procedures: rotary files and reciprocating instruments.

The present study indicated no significant difference between the use of reciprocating compared with rotary files in canal transportation and filling material removal, corroborating the findings of previous studies (DALL'AGNOL et al. 2008, TAKAHASHI et al. 2009). The hypothesis of the same efficacy of instruments with different CM-wire and M wire was confirmed. In this study, Reciproc, which is made from M-wire, had a similar performance in removing filling material compared with Hyflex and ProDesign Duo Híbrido, both CM-wire files. The ProDesign Duo Híbrido group showed slightly less remnant filling material compared with the Reciproc and Hyflex groups, but with no statistical difference. It occurred probably because ProDesign Duo Híbrido used two different kinematics, contributing for longer instrument action time within the root canal.

A major advantage of using Micro-CT technology in this analysis was that the same specimen could be evaluated at different stages of the root canal treatment and served as its own control (DE-DEUS et al. 2016).

CLSM was used like another alternative to analysis of remaining material filling to complement with the results obtained in micro-CT, thus decreasing the potential to produce technical artefacts (GHARIB et al. 2007, ORDINOLA-ZAPATA et al. 2009, Marciano et al. 2011, De-Deus et al. 2012).

During the filling material removal procedures, two Hyflex files fractured. It occurred probably due to its great flexibility resulting from the CM-wire alloy in its composition. It is known that this system is excellent for root canals instrumentation (SABER et al. 2015, PIRANI et al. 2016, VENINO et al. 2017), showing great results. Although it presented similar results to the other groups in endodontic retreatment, it presented a difficulty in being used due to the resistance of the obturator material.

The combination of reciprocating and rotary files in the retreatment of curved canals, irrespective of the type of alloy of the instruments, was efficient but did not remove root canal filling completely. The Reciproc group was faster in filling material removal and reinstrumentation procedures. The ProDesign Duo Híbrido file is a new system in the market, that is why few works are found in the literature. Therefore, more studies are needed to provide better knowledge and safety in its use.

4 Conclusions

4 CONCLUSIONS

- Prodesign Logic and Mtwo system presented a similar ability preparation of mesial canals in mandibular molars, but Mtwo dispended more time for root canal instrumentation.

- No significant differences in measures of apical transportation in mandibular molars were observed between the single-file Prodesign Logic system and the multifile Mtwo system.

- The Reciproc, Hyflex and ProDesign Duo Híbrido systems presented similar morphological parameters after endodontic retreatment except for the time of treatment, where Reciproc was faster than the others.

- The combination of reciprocating and rotary files in the retreatment of curved canals did not remove root canal filling completely. None of the techniques caused complete removal of material.

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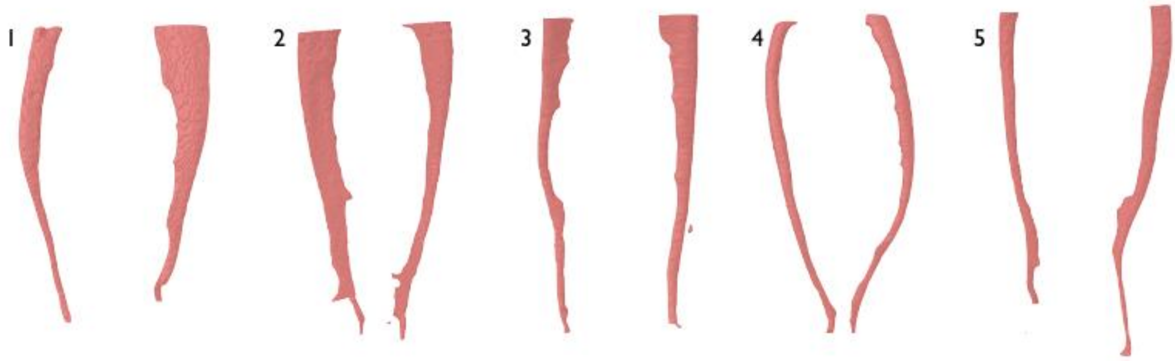
Appendix

APENDIX A – Representative 2D images of Vertucci Type IV of mesial canals (totally separated)



Annexes

ANNEX A – Ethics committee approval

1 de 3

FACULDADE DE ODONTOLOGIA DE BAURU-USP

PARECER CONSUBSTANCIADO DO CEP

DADOS DO PROJETO DE PESQUISA

Título da Pesquisa: Análise dos sistemas rotatório e reciprocante com diferentes ligas na desobturação em retratamentos endodônticos

Pesquisador: AMANDA GARCIA ALVES MALIZA

Área Temática:

Versão: 2

CAAE: 49810715.1.0000.5417

Instituição Proponente: Faculdade de Odontologia de Bauru

Patrocinador Principal: Financiamento Próprio

DADOS DO PARECER

Número do Parecer: 1.334.911

Apresentação do Projeto:

Idem ao parecer 1.298.458.

Objetivo da Pesquisa:

Idem ao parecer 1.298.458.

Avaliação dos Riscos e Benefícios:

Idem ao parecer 1.298.458.

Comentários e Considerações sobre a Pesquisa:

Idem ao parecer 1.298.458.

Considerações sobre os Termos de apresentação obrigatória:

Idem ao parecer 1.298.458.

Recomendações:

Conclusões ou Pendências e Lista de Inadequações:

1)O termo de aquiescência do Centro Integrado de Pesquisa, onde parte da pesquisa será realizada, no caso, o uso do MCVL, não foi anexado;

PENDÊNCIA ATENDIDA.

Endereço: DOUTOR OCTAVIO PINHEIRO BRISOLLA 75 QUADRA 9
Bairro: VILA NOVA CIDADE UNIVERSITARIA **CEP:** 17.012-901
UF: SP **Município:** BAURU
Telefone: (14)3235-8356 **Fax:** (14)3235-8356 **E-mail:** cep@fob.usp.br

FACULDADE DE ODONTOLOGIA DE BAURU-USP

Continuação do Parecer: 1.334.911

2)O cronograma deve ser readequado. No projeto anexado, o envio do projeto ao CEP consta de março/abril de 2015. A pesquisa só deverá ser iniciada após aprovação do projeto por este CEP.
PENDÊNCIA ATENDIDA.

Considerações Finais a critério do CEP:

Esse projeto foi considerado APROVADO na reunião ordinária do CEP de 18.11.2015, com base nas normas éticas da Resolução CNS 466/12. Ao término da pesquisa o CEP-FOB/USP exige a apresentação de relatório final. Os relatórios parciais deverão estar de acordo com o cronograma e/ou parecer emitido pelo CEP. Alterações na metodologia, título, inclusão ou exclusão de autores, cronograma e quaisquer outras mudanças que sejam significativas deverão ser previamente comunicadas a este CEP sob risco de não aprovação do relatório final. Quando da apresentação deste, deverão ser incluídos todos os TCLEs e/ou termos de doação assinados e rubricados, se pertinentes.

Este parecer foi elaborado baseado nos documentos abaixo relacionados:

Tipo Documento	Arquivo	Postagem	Autor	Situação
Informações Básicas do Projeto	PB_INFORMAÇÕES_BÁSICAS_DO_PROJETO_551082.pdf	29/10/2015 10:52:34		Aceito
Projeto Detalhado / Brochura Investigador	Projeto_doutorado_cronograma_modificado.pdf	29/10/2015 10:51:52	AMANDA GARCIA ALVES MALIZA	Aceito
Outros	Termo_aquiescencia_CIP.pdf	29/10/2015 10:49:40	AMANDA GARCIA ALVES MALIZA	Aceito
Outros	Carta_resposta_as_pendencias.pdf	29/10/2015 10:46:04	AMANDA GARCIA ALVES MALIZA	Aceito
Outros	Questionario_Tecnico.pdf	01/10/2015 16:23:34	AMANDA GARCIA ALVES MALIZA	Aceito
Outros	Declaracao_de_compromisso.pdf	01/10/2015 16:16:59	AMANDA GARCIA ALVES MALIZA	Aceito
Outros	Termo_aquiescencia.pdf	01/10/2015 16:15:21	AMANDA GARCIA ALVES MALIZA	Aceito
Projeto Detalhado / Brochura Investigador	Projeto_Doutorado.pdf	01/10/2015 16:12:59	AMANDA GARCIA ALVES MALIZA	Aceito
Outros	Termo_cessao_de_dentes.pdf	01/10/2015 16:07:59	AMANDA GARCIA ALVES MALIZA	Aceito
Folha de Rosto	Folha_de_rosto.pdf	29/09/2015 23:01:38	AMANDA GARCIA ALVES MALIZA	Aceito

FACULDADE DE ODONTOLOGIA DE BAURU-USP

Plataforma Brasil

Continuação do Parecer: 1.334.911

Situação do Parecer:
Aprovado

Necessita Apreciação da CONEP:
Não

BAURU, 24 de Novembro de 2015

Assinado por:
Izabel Regina Fischer Rubira Bullen
(Coordenador)

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