

Received:
16-12-2022

Continuous Wave of Condensation Improves the Filling of Curved Canals: a Micro-CT Study

Accepted:
24-1-2023

Published Online:
1-2-2023

La condensación de onda continua mejora el selle de canales curvos: un estudio de micro-CT

Jader Camilo Pinto DDS, PhD¹; Mariana Mena Barreto Pivoto-João²; Juliane Maria Guerreiro-Tanomaru DDS, PhD³; Jessie Fabiola Reyes-Carmona DDS, MSD, PhD⁴; Mario Tanomaru-Filho DDS, PhD⁵

1. Department of Restorative Dentistry, Sao Paulo State University (UNESP), School of Dentistry, Araraquara, SP, Brazil. <https://orcid.org/0000-0003-2023-1589>
2. Department of Restorative Dentistry, Sao Paulo State University (UNESP), School of Dentistry, Araraquara, SP, Brazil. <https://orcid.org/0000-0002-1788-3351>
3. Department of Restorative Dentistry, Sao Paulo State University (UNESP), School of Dentistry, Araraquara, SP, Brazil. <https://orcid.org/0000-0003-0446-2037>
4. Department of Endodontics, Faculty of Dentistry, LICIFO, University of Costa Rica, San José, Costa Rica. <https://orcid.org/0000-0003-2872-6623>
5. Department of Restorative Dentistry, Sao Paulo State University (UNESP), School of Dentistry, Araraquara, SP, Brazil. <https://orcid.org/0000-0002-2574-4706>

Correspondence to: PhD. Mario Tanomaru-Filho - tanomaru@uol.com.br

ABSTRACT: The aim of this study was to compare the filling capacity in curved root canal using a new continuous wave of condensation technique (Termo Pack II, Easy Dental Equipments, Brazil) or lateral compaction. The percentage of voids in the filling of mesial root canals of mandibular molars was assessed by micro-computed tomography (micro-CT). Mesial root canals (n=24) of mandibular molars with a degree of curvature between 20° and 40° were prepared using rotary system (ProDesign Logic, Easy, Brazil) up to #35, .05 taper. The root canals were filled by using the continuous wave of condensation system or lateral compaction and AH Plus sealer (n=12). Scanning at 9 µm was performed after preparation and after filling by using micro-CT SkyScan 1176. The volumetric percentage of filling material and voids (total length and in each root canal third) were calculated. Data were analyzed using ANOVA/Tukey and Student's t tests ($\alpha=0.05$). Before the filling techniques, the root canals volume after preparation was similar ($p>0.05$). The root canals filled by the continuous wave of condensation technique presented the lowest percentage of voids, and the greatest percentage of filling material in total length and thirds (cervical, middle and

apical) ($p < 0.05$). Both techniques were not able of completely filling the root canals. The continuous wave of condensation technique Termo Pack II promoted better root canal filling in curved root canals, when compared with lateral compaction.

KEYWORDS: Endodontics; Dentin; Root canal; Root canal filling materials; Dental pulp cavity; X-ray microtomography.

RESUMEN: El objetivo de este estudio fue comparar la capacidad de obturación en conductos radiculares curvos utilizando una nueva técnica de condensación de onda continua (Termo Pack II, Easy Dental Equipments, Brasil) vs compactación lateral. El porcentaje de brechas en la obturación de los conductos radiculares mesiales de los molares mandibulares se evaluó mediante microtomografía computarizada (micro-CT). Se prepararon conductos radiculares mesiales ($n=24$) de molares mandibulares con un grado de curvatura entre 20° y 40° utilizando un sistema rotatorio (ProDesign Logic, Easy, Brasil) al #35, conicidad 0,05. Los conductos radiculares se obturaron utilizando un sistema de condensación de onda continua o compactación lateral y cemento AH Plus ($n=12$). Se realizó un escaneo de $9 \mu\text{m}$ después de la preparación y después de la obturación usando el micro-CT SkyScan 1176. Se calculó el porcentaje volumétrico de material de obturación y vacíos (longitud total y en cada tercio del conducto radicular). Los datos se analizaron utilizando las pruebas ANOVA/Tukey y t de Student ($\alpha=0,05$). Antes de las técnicas de obturación, el volumen de los conductos radiculares después de la preparación fue similar ($p > 0,05$). Los conductos radiculares obturados con la técnica de condensación por onda continua presentaron el menor porcentaje de vacíos y el mayor porcentaje de material de obturación en longitud total y en tercios (cervical, medio y apical) ($p < 0,05$). Ambas técnicas no fueron capaces de llenar completamente los conductos radiculares. La técnica de condensación de onda continua Termo Pack II promovió un mejor relleno del conducto radicular en conductos radiculares curvos en comparación con la compactación lateral.

PALABRAS CLAVE: Dentina; Canal raíz; Materiales de obturación del conducto radicular; Cavidad de la pulpa dental; Microtomografía de rayos X.

INTRODUCTION

The success of endodontic treatment depends on the control of endodontic infection of the root canal system (1). The ideal filling technique should fill the root canal three-dimensionally, including areas with irregularities and isthmus (2), in order to favor the prognosis (3). However, incomplete obturation is observed in endodontic treatments (4), increasing the chance of persis-

tence of apical periodontitis (5). No root canal obturation technique is capable of completely filling the root canal system (2,6-8).

Lateral compaction is considered a simple, low-cost filling method and promotes sealing (9), with less overextension of root canal filling material (3). However, cold gutta-percha may not allow adaptation to the irregularities of root canals, allowing the presence of voids between the gutta-

percha cones and root canal (10,11). To overcome these disadvantages, thermoplastic root canal obturation methods are proposed (1,12,13).

Thermoplastic obturation techniques, with vertical compaction of heated gutta-percha and subsequent injection of thermoplastic gutta-percha, promote a homogeneous mass of obturation material capable of filling irregularities (2,13,14). This technique has been used in different devices, such as: System B (2), Obtura II (9), and others (13-16). However, thermoplastic filling technique used in curved canals depends on the enlargement of the root canal and apical penetration of the plugger (2). Thermo Pack II system (Easy Dental Equipment, Brazil) has a thermoplastic plugger with a diameter #50 which performs heating and compaction of the apical gutta-percha. The Thermo Pack II system has a thermal injector with gutta-percha in the alpha phase that is injected with a flexible needle.

Micro-computed tomography (micro-CT) is used to analyze root canal filling techniques (9,17,18). However, most micro-CT studies for comparisons between obturation techniques used straight root canals (2,7,9). Although some studies have evaluated mesial roots of mandibular molars, most studies performed 20 μ m average resolution scans (13-15).

The aim of this study was to compare the percentage of filling and voids in mesial canals of mandibular molars filled by a continuous wave of condensation system or lateral compaction, using micro-CT analysis with the resolution of 9 μ m. The null hypothesis was that there would be no significant difference in the percentage of voids and filling using continuous wave of condensation system or lateral compaction.

MATERIALS AND METHODS

After approval from the Institutional Ethics Committee (Registration number 6473611.40000.5416), mesio-buccal and mesio-lingual root canals from mandibular molars were selected. Digital radiography system (Kodak RVG 6100, Kodak Dental Systems, NY, USA) and micro-computed tomography were used to confirm the inclusion criteria and to perform a homogeneous distribution of the samples. The initial scanning was performed at 35 μ m, using SkyScan 1176 (Skyscan 1176, Bruker-MicroCT, Kontich, Belgium) with the following parameters: copper and aluminum filter, exposure time of 87ms, frame average 3, rotation of 180°, 80kV, and 300uA.

Total of 12 first and second human mandibular molars with two mesial root canals, presenting type IV configuration according to the classification of Vertucci (19) were selected. Complete apical formation, absence of root fractures, angle of curvature between 20° and 40° and radius of curvature smaller than 10mm, were observed in accordance with Schneider method (20). The size of the teeth was standardized at 18mm with a tolerance of \pm 2mm of discrepancy. The root canals selected were stored in a 0.1% Thymol solution at 5°C.

ROOT CANAL PREPARATION

After the specimens were washed in water for 48 hours, access to the canals was obtained with a high speed bur (n.2, KG Sorensen, São Paulo, Brazil), and the root canals were irrigated with 2.5% sodium hypochlorite, a size 10 K-file (Dentsply Sirona, Ballaigues, Switzerland) was used to explore the mesial root canals until its tip was visible through the apical foramen. The

working length (WL) was established 1mm short of the apical foramen. The roots were embedded in condensation silicone (Oranwash, Zhermack SpA, Badia Polesine, Italy) to simulate the periodontal ligament. Afterwards, a single, experienced operator performed the root canal preparations.

ROOT CANAL PREPARATION

The ProDesign Logic (PDL) instruments, size 25, .01 taper, were activated by an electric motor (VDW.SILVER, VDW GmbH, Munich, Germany) in rotary motion at 350rpm and 1 N cm⁻¹ of torque in accordance with the manufacturer's instructions, with in-and-out movements up to the WL. Then, a PDL instrument, size 25, .06 taper, was used at 600 rpm and 3 N cm⁻¹ of torque (manufacturer's instructions for curved root canals), with movements in the apical direction up to the WL. The root canals were enlarged with using ProDesign Logic instrument size 35, .01 taper, and ProDesign Logic instrument size 35, .05 taper as described above. Each root canal was irrigated with 10ml of 2.5% sodium hypochlorite. Final irrigation was performed with 2.5ml EDTA under agitation for 3 minutes, and afterwards, irrigation with 5ml of 0.5% sodium hypochlorite.

FILLING BY THE CONTINUOUS WAVE OF CONDENSATION TECHNIQUE

Gutta-percha cones size 35, .05 taper (Tanari industry Ltda., São Paulo, Brazil) were used. The gutta-percha cones were selected according to the tip size and taper measured in the profilometer (Profile Projector Nikon Model 6C-2). After radiographic evaluation of adaptation of the gutta-percha cone selected, the AH Plus sealer (Dentsply DeTrey GmbH, Konstanz, Germany) was placed into the root canal by using a Lentulo size 35 instrument (Dentsply Maillefer, Ballaigues, Switzerland) and manual K-file size 35 pre-curved (Dentsply

Maillefer, Ballaigues, Switzerland). After this, the gutta-percha cone covered by endodontic sealer was placed in the root canal. The thermoplastic plugger from the Termo Pack II System (Easy Dental Equipments, Brazil) was used for plasticization, cutting and compaction of the gutta percha within the apical root canal (Downpack) up to 3mm of the working length. After this, the thermal injector of the system was used to inject the warmed gutta-percha that was compacted. Compaction was performed with Nickel and Titanium condensers (Easy Dental Equipments, Brazil). A radiograph was taken to verify the quality of the obturation.

FILLING BY THE LATERAL COMPACTION TECHNIQUE

Gutta-percha cones size 35, .02 taper (Tanari Indústria Ltda., São Paulo, Brazil), were also selected after being measured in a Profilometer (Profile Projector Nikon Model 6C-2). The filling sealer AH Plus (Dentsply, DeTrey GmbH, Konstanz, Germany) was placed to the root canal by using a Lentulo size 35 (Dentsply Maillefer, Ballaigues, Switzerland) instrument and pre-curved manual K-file size 35 (Dentsply Maillefer, Ballaigues, Switzerland). After this, the gutta-percha cone covered by endodontic sealer was placed in the root canal. The finger spreader B (Dentsply Maillefer, Ballaigues, Switzerland) was used for inserting the auxiliary XF cones (Tanari industry Ltda., São Paulo, Brazil) into the apical third. Afterwards, the finger spreader C (Dentsply Maillefer, Ballaigues, Switzerland) was used for inserting the auxiliary FF gutta-percha cones (Tanari industry Ltda., São Paulo, Brazil) into the middle and coronal thirds. Lateral compaction was performed on a precision balance to control the force applied, which did not exceed 1.5kg. A radiograph was taken to verify the quality of the obturation.

After filling the root canals, coronal sealing was performed with restorative material Coltisol

(Vigodent, Rio de Janeiro, Brazil), and the roots were kept in an oven at a temperature of 37°C, in 95% humidity, for three days, for sealer setting.

MICRO-CT ANALYSIS

The roots were scanned using micro-CT (SkyScan 1176; Bruker microCT, Kontich, Belgium) after preparation, and after the filling of the root canals. The roots were positioned in a standardization device, allowing the specimens to remain in the same position at all times during scanning procedures. The scanning parameters were: copper and aluminum filter, 90kV power, 278mA energy, evolution cycle 0,5, rotation 180° and frame average 3 with 9µm voxel size. The post-preparation and post-obturation images obtained were reconstructed using the NRecon software (NRecon v.1.6.10.4, Bruker Micro-CT), Volumetric analysis was performed in all canals after the preparation, through the software CTAn (CTAn v.1.14.4, Bruker Micro-CT) with the use of specific task lists.

The reconstructed images, obtained before and after obturation, were superimposed by means of geometric alignment in the Data Viewer software (Data Viewer v.1.5.1, Bruker Micro-CT). Quantitative analyses were then made using the CTAn software by applying task lists, and arithmetic and logic operations between the superimposed sections. Were quantified root canal volume, filling material volume (gutta-percha and sealer), and voids volume. The gray scale range required to recognize each object under study was determined in a density histogram by using an adaptive threshold method. The percentages of filling material were taken as a basis on the post-preparation volume of the canal and on the filling volume: [percentage of filling = (volume of filling x 100) / volume of canal]. The volume of voids was calculated by subtracting the filling material volume from

the post-obturation root canal volume: [volume of voids = volume of canal – volume of filling]. The percentage volume of voids was calculated by using the following formula: [Percentage of voids = (volume of voids X 100)/volume of canal]. Representative images were performed by means of models obtained by using CTVol software (CTVol v. 2.0, Bruker Micro-CT).

Evaluation was performed at all root canal extension and by thirds (Coronal, Middle and Apical). The value of approximately 9mm was determined for the total length analysis and approximately 3mm for each third. In the software (CTAn), the value of bottom was corresponding to the working length, and to this value was added 9mm, as the value of top, corresponding to the furcation level.

STATISTICAL ANALYSIS

The Graph Pad Prism 7.00 (GraphPad Software, Inc., California, USA) software was used for data analysis. Data obtained for canal volume values after preparation, percentage of filling material and percentage of voids between the groups were submitted to Student's t-test. ANOVA/Tukey tests were used for comparison of filling material and voids between thirds. The significance level was set at 5%.

RESULTS

The volume of the root canals prepared was similar for the two obturation techniques ($p>0.05$) (Table 1). Canals obturated by the lateral compaction technique presented a higher percentage of voids than the canals obturated by continuous wave ($p<0.05$) (Table 2 and Figure 1). A higher percentage of filling material was obtained for the canals filled by the continuous wave of condensation technique ($p<0.05$) (Table 2).

Table 1. Mean percentage (\pm standard deviation) of volume (mm^3) - total and by thirds of canals after preparation.

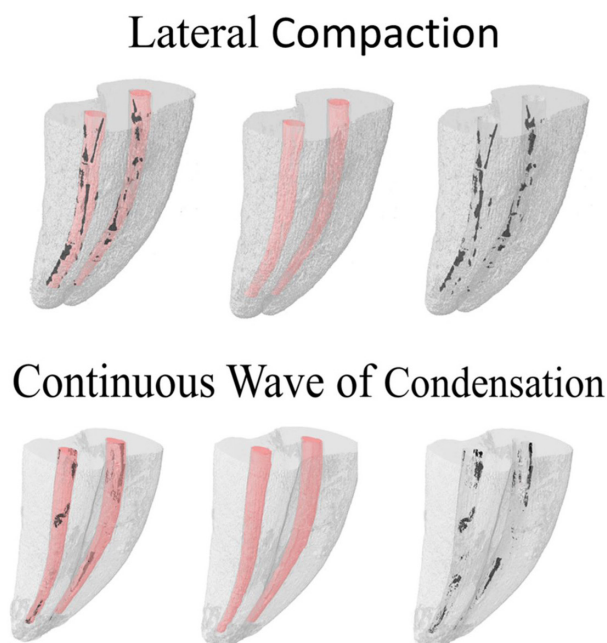
	Continuous wave of condensation	Lateral compaction
Total	3.858 \pm 0.562	3.573 \pm 0.501
Coronal	2.086 \pm 0.306	1.951 \pm 0.256
Middle	1.121 \pm 0.195	1.079 \pm 0.148
Apical	0.596 \pm 0.105	0.544 \pm 0.089

*There was no statistical difference between the groups ($p > 0.05$).

Table 2. Mean percentage (\pm standard deviation) of voids and filling material in the filling after use of lateral compaction and continuous wave of condensation.

		Continuous Wave of Condensation	Lateral Compaction
% voids	Total	7.77 \pm 2.23 ^b	18.21 \pm 4.49 ^a
	Coronal	10.06 \pm 4.09 ^{bA}	17.07 \pm 4.43 ^{aA}
	Middle	5.87 \pm 2.60 ^{bB}	20.60 \pm 7.77 ^{aA}
	Apical	2.92 \pm 1.12 ^{bC}	18.43 \pm 4.43 ^{aA}
% filling material	Total	92.22 \pm 2.32 ^b	81.79 \pm 4.49 ^a
	Coronal	89.94 \pm 4.09 ^{bA}	82.93 \pm 4.43 ^{aA}
	Middle	94.12 \pm 2.60 ^{bB}	74.84 \pm 7.77 ^{aA}
	Apical	96.27 \pm 1.12 ^{bC}	81.57 \pm 4.43 ^{aA}

*Different superscript lowercase letters in same line indicate statistical difference between the groups ($p < 0.05$). Superscript uppercase letters in the same column indicate statistical difference among the thirds ($p < 0.05$).

**Figure 1.** Representative three-dimensional reconstruction of mesial root canals of mandibular molars obturated by lateral compaction and continuous wave of condensation. Filling material and voids are depicted in pink and black, respectively.

DISCUSSION

Our results showed that no obturation technique was able to completely fill the root canals, in agreement with previous studies (7,8,12,15,18,21,22). A higher percentage of filling material was observed for the continuous wave of condensation Terno Pack II System, in comparison with lateral compaction. Therefore, the null hypothesis was rejected. The micro-CT images showed gutta-percha cones covered by sealer in

the root canals filled by lateral compaction, and a uniform mass of filling material for Terno Pack II (Figure 2), as observed by Ho *et al.* (14). Cold gutta percha has been shown to be incapable of filling artificial irregularities in mandibular incisors (10). A previous study (14) comparing three techniques of lateral compaction (manual, mechanical, and ultrasonic), presented that all the methods caused void areas in the root filling. The authors attributed the voids to the spreader, that creates a larger space than required for the accessory cones.

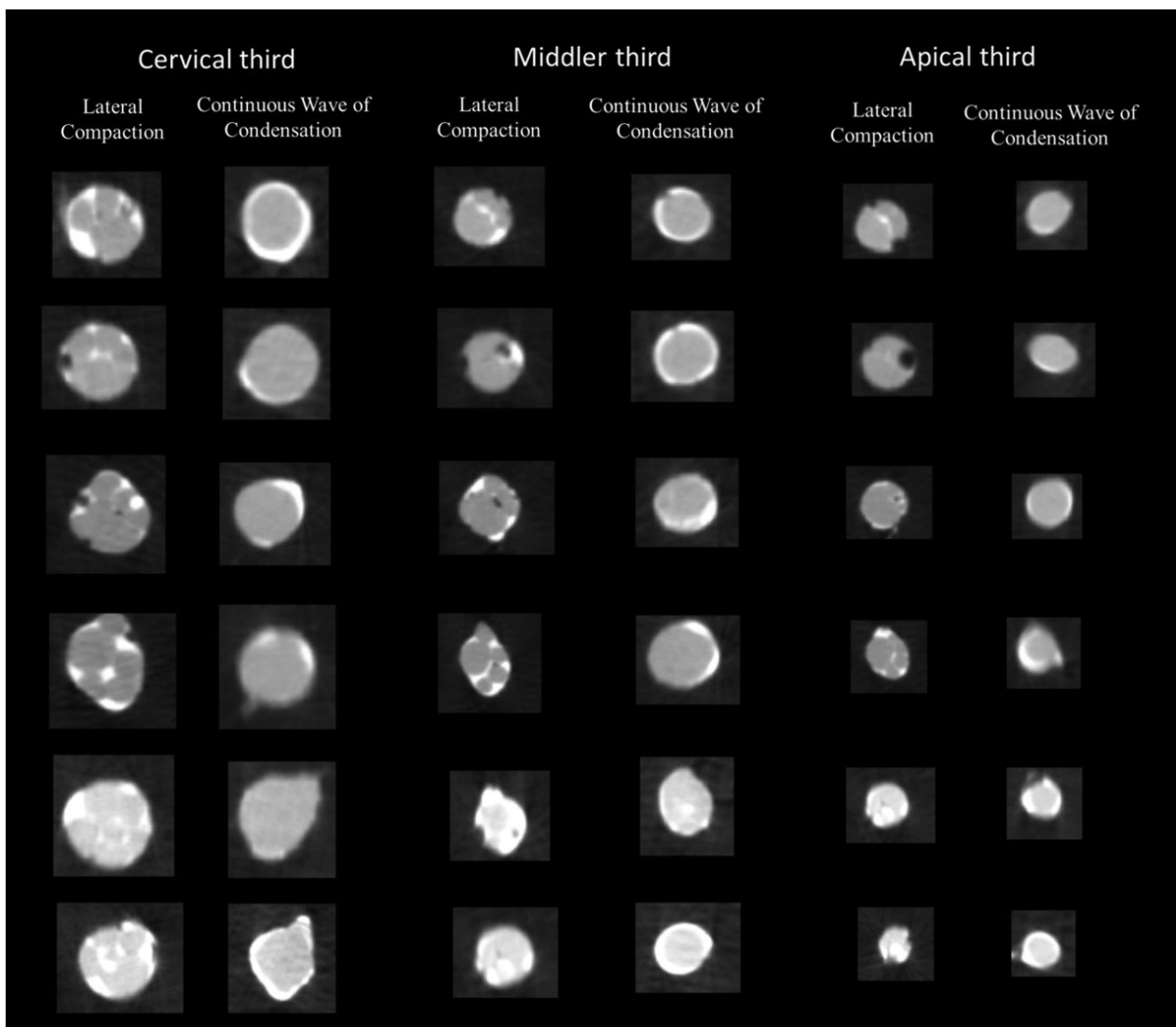


Figure 2. Representative micro-CT cross-sections from the coronal, middle and apical thirds of six different mesial root canals of mandibular molars filled by continuous wave of condensation and six different mesial root canals of mandibular molars filled by lateral compaction, showing the presence of voids (black spots within the filling materials), sealer (in white) and gutta-percha (in grey).

Endodontic sealers must fill irregularities and areas that are difficult to access (23). AH Plus has sealing capacity (18) and promotes adaptation in the root canal walls (24), and is compatible with thermal compaction techniques (25). Proper filling was observed for continuous wave of condensation evaluated by micro-CT in mesial root canals from mandibular molars (13,14) and mandibular premolars (7,9,10). However, the comparison by micro-CT of the filling volume in oval canals (mandibular premolars) after lateral compaction techniques has demonstrated that the finger spreaders may leave spaces in the gutta-percha, which are occupied by sealer (AH Plus), or remain empty (7). The continuous wave of condensation technique allows plasticization of the gutta percha throughout the entire extension of the canal promoting a homogeneous mass capable of filling irregularities of the root canal (7,15), consequently decreasing the layer of sealer and formation of voids. Considering that gutta-percha is a dimensionally stable material (7,26) and sealers are subject to solubilization, a higher proportion of gutta percha in the apical region in relation to sealer, may favor the prognosis in the long term (11,27).

The apical third is considered critical for endodontic treatment success (28) and control of re-infection (29). Our results showed that the root canals obturated with the Thermo Pack II System obtained a lower percentage of voids in the apical region, than the root canals obturated by the lateral compaction technique. These results corroborated previous results that compared the quality of filling in the apical regions in mesial roots of mandibular molars, prepared up to the ProTaper Next X4 instrument, and obturated by continuous wave of condensation or lateral compaction (13).

Moreover, the continuous wave of condensation Easy Thermo-Pack II presented a lower percentage of voids in the apical third than in the other thirds. Other studies that have evaluated conti-

nuous wave of condensation systems obtained better results in the coronal third (7,15). According to Iglecias *et al.* (15), this occurred because in the continuous wave of condensation technique the coronal third received the force of compaction more directly. However, this study used mesial root canals of mandibular molars prepared with Reciproc R25 and observed a percentage of 4.93 ± 1.9 of voids in the apical third. In the present study, the root canals were prepared up to ProDesign Logic 35/.05, with a lower percentage of voids in the apical third (2.923 ± 1.124). Considering that the quality of endodontic obturations may be influenced by the enlargement of root canals (7), the greatest enlargement may have contributed for inserted up to 3mm of the working length in the continuous wave of condensation technique. Besides that, the gutta-percha used for thermocompaction may affect the results (30). The warmed gutta-percha may undergo volumetric changes with heating (3,21). Thus, different compositions of gutta-percha and temperatures of thermoplastic techniques may influence filling.

The homogeneous filling of the root canal system is just one of the many factors that contribute to the success of an endodontic treatment. Overall, within the limitations of the current study, this is the first research to evaluate the Thermo Pack II as a continuous condensation wave technique. Moreover, a high resolution was performed in order to allow the detection of small voids in the filling root canals. Further studies are needed to investigate this system.

CONCLUSION

In conclusion, none of the techniques used was able of completely filling the root canals. The continuous wave of condensation Thermo Pack II System produced a higher percentage of filling material and lower incidence of voids when compared with the lateral compaction technique.

AUTHOR CONTRIBUTION STATEMENT

Conceptualization and design: J.C.P and M.T-F.

Literature review: J.C.P

Methodology and validation: J.C.P, M. M. B. P-J., J.M.G-T and M.T-F.

Formal analysis: J.C.P and M.T-F.

Investigation and data collection: J.C.P and M.T-F.

Resources: J.C.P and M.T-F.

Data analysis and interpretation: J.C.P, M.M.B. P-J., J.M.G-T and M.T-F.

Writing-original draft preparation: J.C.P, J.F.R-C and M.T-F.

Writing-review & editing: J.C.P, M.M.B. P-J., J.M.G-T, J.F.R-C., and M.T-F. Supervision: M.T-F.

Project administration and funding acquisition: M.T-F.

ACKNOWLEDGEMENTS

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001, and São Paulo Research Foundation - FAPESP (2015/03437-6, 2017/19049-0).

REFERENCES

1. Meire M.A., Bronzato J.D., Bomfim R.A., Gomes B.P.F.A. Effectiveness of adjunct therapy for the treatment of apical periodontitis: A systematic review and meta-analysis. *Int Endod J.* 2022 Sep 26. doi: 10.1111/iej.13838. Epub ahead of print. PMID: 36156804.
2. Somma F., Cretella G., Carotenuto M., Pecci R., Bedini R., De Biasi M., Angerame D. Quality of thermoplasticized and single point root fillings assessed by micro-computed tomography. *Int Endod J.* 2011 Apr; 44 (4): 362-9.
3. Peng L., Ye L., Tan H., Zhou X. Outcome of root canal obturation by warm gutta-percha versus cold lateral condensation: a meta-analysis. *J Endod.* 2007 Feb; 33 (2): 106-9.
4. Saatchi M., Mohammadi G., Vali Sichani A., Moshkforoush S. Technical Quality of Root Canal Treatment Performed by Undergraduate Clinical Students of Isfahan Dental School. *Iran Endod J.* 2018 Winter; 13 (1): 88-93.
5. Nur B.G., Ok E., Altunsoy M., Ağlarci O.S., Çolak M., Güngör E. Evaluation of technical quality and periapical health of root-filled teeth by using cone-beam CT. *J Appl Oral Sci.* 2014 Nov-Dec; 22 (6): 502-8.
6. Marciano M.A., Bramante C.M., Duarte M.A., Delgado R.J., Ordinola-Zapata R., Garcia R.B. Evaluation of single root canals filled using the lateral compaction, tagger's hybrid, microseal and guttaflow techniques. *Braz Dent J.* 2010; 21 (5): 411-5.
7. Keleş A., Alcin H., Kamalak A., Versiani M.A. Micro-CT evaluation of root filling quality in oval-shaped canals. *Int Endod J.* 2014 Dec; 47 (12): 1177-84.
8. Naseri M., Kangarlou A., Khavid A., Goodini M. Evaluation of the quality of four root canal obturation techniques using micro-computed tomography. *Iran Endod J.* 2013 Summer; 8 (3): 89-93.
9. Kierklo A., Tabor Z., Pawińska M., Jaworska M. A microcomputed tomography-based comparison of root canal filling quality following different instrumentation and obturation techniques. *Med Princ Pract.* 2015; 24 (1): 84-91.
10. Collins J., Walker M.P., Kulild J., Lee C. A comparison of three gutta-percha obturation techniques to replicate canal irregularities. *J Endod.* 2006 Aug; 32 (8): 762-5.
11. Silva R.V., Silveira F.F., Horta M.C., Duarte M.A., Cavenago B.C., Morais I.G., Nunes E. Filling Effectiveness and Dentinal Penetration of Endodontic Sealers: A Stereo and Confocal Laser Scanning Microscopy Study. *Braz Dent J.* 2015 Oct; 26 (5): 541-6.
12. Celikten B., F. Uzuntas C., I. Orhan A., Tufenkci P., Misirli M., O. Demiralp K.,

- Orhan K. Micro-CT assessment of the sealing ability of three root canal filling techniques. *J Oral Sci.* 2015; 57 (4): 361-6.
13. Oh S., Perinpanayagam H., Kum D.J.W., Lim S.M., Yoo Y.J., Chang S.W., Lee W., Baek S.H., Zhu Q., Kum K.Y. Evaluation of three obturation techniques in the apical third of mandibular first molar mesial root canals using micro-computed tomography. *J Dent Sci.* 2016 Mar; 11 (1): 95-102.
 14. Ho E.S., Chang J.W., Cheung G.S. Quality of root canal fillings using three gutta-percha obturation techniques. *Restor Dent Endod.* 2016 Feb; 41 (1): 22-8.
 15. Iglecias E.F., Freire L.G., de Miranda Candeiro G.T., Dos Santos M., Antoniazzi J.H., Gavini G. Presence of Voids after Continuous Wave of Condensation and Single-cone Obturation in Mandibular Molars: A Micro-computed Tomography Analysis. *J Endod.* 2017 Apr; 43 (4): 638-642.
 16. Ahmed H., Ratnayake J., Cathro P., Chandler N. The effect of an additional application of sealer prior to backfilling in the Continuous Wave of Condensation technique. *Aust Endod J.* 2022 Jul 14. doi: 10.1111/aej.12658. Epub ahead of print. PMID: 35834235.
 17. Araújo V.L., Souza-Gabriel A.E., Cruz Filho A.M., Pécora J.D., Silva R.G. Volume of sealer in the apical region of teeth filled by different techniques: a micro-CT analysis. *Braz Oral Res.* 2016; 30: S1806-83242016000100234. doi:10.1590/1807-3107BOR-2016.vol30.0027. Epub 2016 Mar 28.
 18. Santos-Junior A.O., Tanomaru-Filho M., Pinto J.C., Tavares K.I.M.C., Torres F.F.E., Guerreiro-Tanomaru J.M. Effect of obturation technique using a new bioceramic sealer on the presence of voids in flattened root canals. *Braz Oral Res.* 2021 Feb 12; 35: e028.
 19. Vertucci FJ. Root canal anatomy of the human permanent teeth. *Oral Surg Oral Med Oral Pathol.* 1984 Nov; 58 (5): 589-99.
 20. Schneider SW. A comparison of canal preparations in straight and curved root canals. *Oral Surg Oral Med Oral Pathol.* 1971 Aug; 32 (2): 271-5.
 21. Moeller L., Wenzel A., Wegge-Larsen A.M., Ding M., Kirkevang L.L. Quality of root fillings performed with two root filling techniques. An in vitro study using micro-CT. *Acta Odontol Scand.* 2013 May-Jul; 71 (3-4): 689-96.
 22. Freire L.G., Iglecias E.F., Cunha R.S., Dos Santos M., Gavini G. Micro-Computed Tomographic Evaluation of Hard Tissue Debris Removal after Different Irrigation Methods and Its Influence on the Filling of Curved Canals. *J Endod.* 2015 Oct; 41 (10): 1660-6.
 23. Sant'Anna-Junior A., Guerreiro-Tanomaru J.M., Martelo R.B., Silva G.F., Tanomaru Filho M. Filling of simulated lateral canals with gutta-percha or thermoplastic polymer by warm vertical compaction. *Braz Oral Res.* 2015; 29: 56.
 24. Macedo L.M.D., Silva-Sousa Y., Silva S.R.C.D., Baratto S.S.P., Baratto-Filho F., Abi Rached-Júnior F.J. Influence of Root Canal Filling Techniques on Sealer Penetration and Bond Strength to Dentin. *Braz Dent J.* 2017 May-Jun; 28 (3): 380-384.
 25. Qu W., Bai W., Liang Y.H., Gao X.J. Influence of Warm Vertical Compaction Technique on Physical Properties of Root Canal Sealers. *J Endod.* 2016 Dec; 42 (12): 1829-1833.
 26. Lea C.S., Apicella M.J., Mines P., Yancich P.P., Parker M.H. Comparison of the obturation density of cold lateral compaction versus warm vertical compaction using the conti-

- nuous wave of condensation technique. *J Endod.* 2005 Jan; 31 (1): 37-9.
27. Wu M., van der Sluis L.W., Wesselink P.R. A preliminary study of the percentage of gutta-percha-filled area in the apical canal filled with vertically compacted warm gutta-percha. *Int Endod J.* 2002 Jun; 35 (6): 527-35.
28. Saunders W.P., Saunders E.M., Herd D., Stephens E. The use of glass ionomer as a root canal sealer--a pilot study. *Int Endod J.* 1992 Sep; 25 (5): 238-44.
29. De-Deus G., Gurgel-Filho E.D., Magalhães K.M., Coutinho-Filho T. A laboratory analysis of gutta-percha-filled area obtained using Thermafil, System B and lateral condensation. *Int Endod J.* 2006 May; 39 (5): 378-83.
30. Moon H.J., Lee J.H., Ahn J.H., Song H.J., Park Y.J. Temperature-dependent rheological property changes of thermoplastic gutta-percha root filling materials. *Int Endod J.* 2015 Jun; 48 (6): 556-63.

