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Comparative analysis of warm vertical compaction and single-cone obturation techniques

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Abstract:
Effective root canal obturation is essential for minimizing microleakage and achieving long-term endodontic success. Therefore, it is of interest to evaluate the warm vertical compaction and single-cone obturation in 70 human single-rooted permanent teeth, randomly divided into two groups (n=35 each), using micro-computed tomography to assess void volume, gutta-percha and sealer volume, canal wall adaptation and overall filling volume. Warm vertical compaction produced significantly fewer voids, greater gutta-percha-filled volume and better canal wall adaptation than the single-cone technique ($p<0.001$). The single-cone technique required significantly less time for obturation while providing clinically acceptable filling. These findings advance knowledge by supporting warm vertical compaction for superior three-dimensional obturation while recognizing single-cone obturation as a faster alternative.

Keywords: Root canal filling, bioceramic sealer, Single cone obturation, micro-computed tomography (micro-CT), warm vertical compaction (WVC)

Background:
Cleaning, disinfection and completion of the 3D filling of the root canal system is important to successful endodontic treatment. The efficiency of obturation is an important factor in the success of the treatment since it creates a hermetic seal, prevents the bacterial leakage and reduces the potential for reinfection of the root canal system **[1]**. Ideal obturation technique should result in complete adaptation to walls and irregularities of the canal and thickness of the sealer should be minimized while voids are minimized **[2].** The single cone (SC) and warm vertical compaction (WVC) methods are the two most popular obturation techniques. The single cone technique is easily done, less technique sensitive and also acceptable to modern bioceramic sealers, while a warm vertical compaction relies on thermoplasticized gutta-percha in order to enhance adaptation to the complex canal anatomy. Both techniques are well accepted, but their effectiveness compared to each other is still a topic of debate **[3].** The advantage of calcium silicate-based bioceramic sealers is their excellent biocompatibility, dimensional stability and bioactive properties, which has improved the performance of the single-cone technique **[4]**. In parallel, micro-computed tomography (micro-CT) is the method of choice for evaluating obturation quality because it allows a nondestructive 3D evaluation of voids, filling volume and adaptation to canal walls. The results from recent studies on compaction showed a reduction in the number of voids and adaptation with warm vertical compaction, while the advantages of the single cone are shorter operatory time and satisfactory clinical results **[5].** Both techniques have shown effectiveness in recent systematic review and randomized clinical trials, however filling homogeneity and sealing quality is often found to be higher in warm vertical compaction **[6, 7]**. Therefore, it is of interest to compare the quality of root canal obturation obtained using warm vertical compaction (WVC) and single cone (SC) obturation technique.

Materials and Methodology:
Study design and setting:
This was an *in vitro*, comparative experimental study, which took 12 months, conducted in the Department of Conservative Dentistry and Endodontics and in collaboration with a micro-computed tomography (micro-CT) imaging laboratory.

Sample size:
The total numbers of the extracted human permanent single-rooted teeth were 70 and they were divided randomly into two groups:
[1] Group I (n=35): Warm Vertical Compaction (WVC)
[2] Group II (n = 35): Single Cone (SC) Obturation

Sample selection:
Selected studies included extracted single rooted mature permanent teeth with curved apices, straight canals, perfect root morphology and curvature of the canal < 20°. Only teeth that had previously had endodontic treatment and teeth that had canals that were calcified, resorbed, had an open apex, multiple canals or fractures in the root were excluded.

Specimen preparation:
Soft tissue, calculus was removed and the specimens were disinfected with 0.1% thymol solution. Standardized access orifices were developed and #10 K-file was used to determine working length 1 mm short of the apical foramen. Nickel–titanium rotary files of size 25/.06 were used to instrument root canals. It was irrigated using 3% sodium hypochlorite solution and 17% EDTA solution followed by distilled water.

Obturation procedure:
Group I canals were obturated using the warm vertical compaction method, thermoplasticized gutta-percha and bioceramic sealer. Canals were obliterated in Group II with the single cone technique with the same bioceramic sealer. All specimens were kept at 37°C with 100% humidity after obturation for 7 days.

Outcome assessment:
Evaluation of the obturation quality was done by micro-computed tomography (micro-CT). The parameters measured were total void volume, gutta-percha-filled volume, sealer-filled volume, total void percent and adaptation of filling material to walls of the canals. All measurements were done by two blinded examiners.

Statistical analysis:
Data were analysed in SPSS statistics version 26.0. Data for quantitative variables presented in the form of Mean ± SD and frequency and percentage for categorical variables. Independent Student's t test or Mann–Whitney U test was used for conducting intergroup comparisons and intraclass coefficient (ICC) for interobserver comparisons. Statistically significant p-values were regarded as being < 0.05.

Results:
A total of 70 extracted human permanent single-rooted teeth were included in the study. The specimens were randomly allocated to warm vertical compaction (WVC; Group I, n = 35) or single-cone obturation (SCO; Group II, n = 35). Micro-computed tomography (micro-CT) was used to assess void volume, percentage of voids, gutta-percha-filled volume, sealer-filled volume, apical adaptation and internal and external void distribution. As shown in **Table 1**, WVC had significantly lower total void volume (0.19 ± 0.07 vs 0.41 ± 0.12 mm^3) and percentage of voids (1.48 ± 0.56% vs 3.82 ± 1.09%) than SCO (both $p < 0.001$). Gutta-percha-filled volume was significantly higher with WVC (94.86 ± 2.31% vs 90.42 ± 3.18%), whereas sealer-filled volume was lower (3.66 ± 1.12% vs 5.76 ± 1.43%; both $p < 0.001$). **Table 2** shows significantly smaller gaps with WVC at the apical (42.8 ± 10.4 vs 67.5 ± 14.2 µm), coronal (36.7 ± 9.5 vs 55.8 ± 12.1 µm) and middle thirds (39.4 ± 8.7 vs 58.2 ± 11.6 µm; all $p < 0.001$). However, obturation time was significantly longer with WVC than with SCO (8.54 ± 1.12 vs 4.37 ± 0.83 minutes; $p < 0.001$). Regarding overall obturation quality **(Table 3)**, excellent quality was observed in 28 WVC specimens (80.0%) and 14 SCO specimens (40.0%). Good quality was recorded in 6 (17.1%) and 13 (37.1%) specimens, respectively. Acceptable quality was observed in 1 WVC specimen (2.9%) and 6 SCO specimens (17.1%), while poor quality occurred in 2 SCO specimens (5.7%) and none in the WVC group. As shown in **Table 4**, WVC had significantly lower internal void volume (0.08 ± 0.03 vs 0.19 ± 0.07 mm^3) and external void volume (0.11 ± 0.05 vs 0.22 ± 0.08 mm^3) than SCO (both $p < 0.001$). WVC also had a higher canal wall adaptation score (4.76 ± 0.41 vs 3.89 ± 0.58) and overall filling homogeneity score (4.71 ± 0.36 vs 3.94 ± 0.52; both $p < 0.001$).

Table 1: Comparison of obturation quality between the study groups

Parameter	Warm Vertical Compaction (n=35) Mean ± SD	Single-Cone (n=35) Mean ± SD	t-value	p-value
Total void volume (mm^3)	0.19 ± 0.07	0.41 ± 0.12	9.45	<0.001*
Percentage of voids (%)	1.48 ± 0.56	3.82 ± 1.09	11.26	<0.001*
Gutta-percha-filled volume (%)	94.86 ± 2.31	90.42 ± 3.18	6.81	<0.001*
Sealer-filled volume (%)	3.66 ± 1.12	5.76 ± 1.43	6.87	<0.001*

Table 2: Comparison of apical adaptation and obturation time

Parameter	Warm Vertical Compaction (n=35) Mean ± SD	Single-Cone (n=35) Mean ± SD	t-value	p-value
Apical gap (µm)	42.8 ± 10.4	67.5 ± 14.2	8.33	<0.001*
Coronal gap (µm)	36.7 ± 9.5	55.8 ± 12.1	7.38	<0.001*
Middle third gap (µm)	39.4 ± 8.7	58.2 ± 11.6	7.74	<0.001*
Obturation time (minutes)	8.54 ± 1.12	4.37 ± 0.83	17.63	<0.001*

Table 3: Distribution of specimens according to overall obturation quality

Overall obturation quality	Warm Vertical Compaction (n=35)	Single-Cone (n=35)	χ^2	p-value
Excellent (<2% voids)	28 (80.0%)	14 (40.0%)		
Good (2–4% voids)	6 (17.1%)	13 (37.1%)		
Acceptable (>4–6% voids)	1 (2.9%)	6 (17.1%)		
Poor (>6% voids)	0 (0%)	2 (5.7%)	12.96	0.005*

Table 4: Comparison of internal and external void distribution

Parameter	Warm Vertical Compaction (n=35) Mean ± SD	Single-Cone (n=35) Mean ± SD	t-value	p-value
Internal void volume (mm^3)	0.08 ± 0.03	0.19 ± 0.07	8.71	<0.001*
External void volume (mm^3)	0.11 ± 0.05	0.22 ± 0.08	7.08	<0.001*
Canal wall adaptation score	4.76 ± 0.41	3.89 ± 0.58	7.25	<0.001*
Overall filling homogeneity score	4.71 ± 0.36	3.94 ± 0.52	7.17	<0.001*

Discussion:

The present study compared the quality of obturation of warm vertical compaction and single cone techniques using the micro-computed tomography. The warm vertical compaction showed significantly less void space, better adaptation to canal walls and a greater percentage of gutta percha volume than the one-cone technique. The present results showed that thermoplasticized gutta-percha has the best adaptation in the 3-dimensional aspect of the prepared root canal system. The present results confirm those of Zare *et al.*, which showed that single-cone obturation technique with modern bioceramic sealers yielded acceptable fillings, but the presence of voids inside the obturation mass, especially around areas of irregularity in canals was found **[8].** Similarly, Karam *et al.* showed that the applications of controlled heat did not negatively impact the physicochemical properties of modern endodontic sealers, thus maintaining the use of warm vertical compaction with calcium silicate-based sealers **[9].** The increased resistance to fracture (reported by Al-hiyasat *et al.*) with the thermoplasticized obturation could be related to the good adaptation and the more uniform distribution of filling material obtained with the warm compaction technique, as good adaptation with the present canal wall technique was also observed **[10].** However, Lichaa *et al.* found no statistically significant difference in the fracture resistance of mandibular incisors obturated using single-cone or warm vertical compaction techniques with a calcium silicate-based sealer. This suggests that improved filling adaptation should not automatically be interpreted as evidence of superior fracture resistance **[11].** Also, Zhang *et al.* showed that the warm Zfy technique was more successful in the reduction of voids in the isthmus of a canal compared to all other techniques, which corroborates the better performance of thermoplasticized gutta-percha in physiologically complex canals **[12].** Various studies by Alfayate *et al.* and da Silva *et al.* revealed acceptable sealing capacity of bioceramic sealers when used with different obturation techniques, with however much homogenous filling in the warm techniques, likely due to the reduced thickness of the sealers **[13, 14].** Eid *et al.* found that warm vertical compaction enhanced the dentinal tubule penetration of calcium silicate-based sealers compared with the single-cone technique at both 1 and 5 mm from the apex, providing additional evidence of the potential advantages of thermoplasticized obturation **[15].** Other similar findings have been reported by Holmes *et al.* **[16],** Keleş and Keskin **[17],** Iglecias **[18],** Kim *et al.* **[19],** all of which saw reduced voids and improved filling homogeneity with the use of warm vertical compaction technique using the micro-CT technique **[16-19].** Elzanaty *et al.* reported that canals obturated using the single-cone technique had a greater percentage of residual debris after retreatment than those obturated using warm vertical compaction, although retreatment took longer in the WVC group. These findings suggest that the implications of obturation technique may extend beyond initial filling quality to subsequent retreatment procedures **[20]**. These observations are backed by more recent evidence. Mushtaq *et al.*, performed a systematic review and meta-analysis, the results showed that the warm obturation method resulted in better filling performance in general, whereas it was equally able to produce good clinical outcomes due to the use of present day, modern bioceramic sealers **[21].** Similar results were found with thermoplasticized obturation techniques by Kumari *et al.* **[22]** with thermoplastic materials and single-cone seating by Zhang *et al.* **[23].** Results indicated good 3D obturation quality for thermoplastic methods (and good sealing for the single-cone method), suggesting that the right sealer may somewhat compensate for the various obturation techniques **[22, 23]**. Swathi *et al.* **[24],** in a retrospective analysis of obturation techniques used in mandibular molars, discussed the potential advantages of the single-cone technique, including reduced apical stress and a lower risk of sealer extrusion. This highlights the importance of considering procedural and anatomical factors alongside three-dimensional filling quality when selecting an obturation technique.

Conclusion:

Warm vertical compaction showed superior obturation quality, with fewer voids, greater gutta-percha filling and better adaptation to canal walls than the single-cone technique. The single-cone technique required longer operating time while providing satisfactory filling quality. Warm vertical compaction may be preferred when optimal three-dimensional sealing of the root canal system is desired.

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