Homogeneity of root canal fillings performed by undergraduate students with warm vertical and cold lateral techniques

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Objectives. The aim of this study was to determine radiographic and microscopic appearances of root canal fillings performed by undergraduate students using vertical and lateral compaction techniques.
Study design. Thirty dental students were instructed how to fill curved simulated canals with gutta-percha and sealer using lateral and vertical compaction. Digital radiographs were taken in buccolingual and mesio-distal projections; radiographs were evaluated for homogeneity and root canal wall contact. Plastic blocks with simulated canals were sectioned and cross sections were assessed under a light microscope for voids. Probabilities were expressed as odds ratios (OR) with 95% confidence intervals (CI).
Results. Radiographs showed that the chances of obtaining a homogeneous root canal filling by using a vertical compaction technique were 3 times higher in the coronal canal third (OR 3.2; CI: 1.9, 5.3), the same in the middle third, and 2 times higher in the apical third (CI: 1.1, 2.4) than when using lateral compaction. Microscopic evaluation of the same canals revealed that the chances of obtaining a homogeneous root canal filling by vertical compaction were 3 times higher in the coronal canal third (CI: 1.6, 5.8), almost 3 times higher in the middle canal third (CI: 1.6, 4.7), and about 10 times higher in the apical canal third (OR 9.8; CI: 2.2, 43.4) than by lateral compaction. The chances of transporting filling material beyond the apex were almost 5 times higher (OR 4.6; CI: 2.8, 7.6) when using vertical rather than lateral compaction.
Conclusion. Inexperienced students obtained more homogeneous root canal fillings with the vertical compaction method; however, the probability of overextruding filling material with this method was high. **(Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2010;110:e41-e49)**

The aim of a root canal filling is to prevent leakage of fluids and microorganisms into and out of the entire canal system by complete obturation of the root canal space, as mentioned in the most recent quality guidelines of the European Society of Endodontology.[1] The importance of a coronal and apical seal appears to be universally accepted.[2,3]

Root fillings of high quality are often regarded as technically demanding and difficult. This may be one of the many reasons for the high number of existing root-filling techniques and the frequency of new techniques being developed.[4] To date, the cold lateral compaction method is probably the most often taught and practiced filling technique; this is likely because of its safety, cost-effectiveness, and possibly historical reasons.[5-8] It still represents the standard to which other methods are compared.[3]

Oval cross sections of a canal can be sealed by lateral compaction.[9] However, this technique reaches its limits if the canal lumen suddenly increases within a tapering root canal system. Warm vertical compaction, however, permits sealing of canals of irregular anatomy with gutta-percha and other thermoplastic filling materials. Apart from a higher technical complexity, such as the need to plasticize gutta-percha, this method is also considered less "user-friendly."[3] Moreover, vertical pressure may result in pushing filling material beyond the apex; the likelihood of this appears to be higher with vertical compared with lateral compaction.[3,10] Such overfilled material, depending on its composition, may cause various inflammatory reactions in the periradicular area.[11]

Besides intimate adaptation between filling material and canal wall, the density of filling materials is important to promote a fluid-tight seal: root fillings with a homogeneous appearance, showing no voids in the material, correlate with a reduced risk of apical periodontitis.[12-14] Typically, ex vivo examinations of the density of root canal fillings have been carried out in fluid-penetration models,[15-17] with assessment of bacterial percolation[18] or air penetration.[19] However, in

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vivo the density of root filling material can usually only be estimated from periapical radiographs.

In previous studies, root canals obturated by students using lateral compaction were assessed by different examiners to evaluate the radiographic density of the filling material: 53.2% to 90.0% of the fillings appeared to be satisfactory.[20-22] To the best of our knowledge, no direct comparisons between root canal filling with lateral and vertical compaction techniques performed by inexperienced clinicians have been published.

Therefore, this study aims to examine the radiographic and microscopic homogeneity of root canal fillings accomplished by dental students using a lateral and a vertical compaction method. We were specifically interested in how students with limited experience but a standardized introduction would be performing these tasks.

The following hypotheses were tested in this study:

1. By using the lateral compaction method, even novices are able to obtain (1) radiographically and (2) microscopically homogeneous root canal fillings.
2. The risk of extruding filling material through the apex is significantly higher with warm vertical compaction than with lateral compaction.

MATERIALS AND METHODS

Thirty dental students without any prior experience with either lateral or vertical obturation techniques participated in this study. They were asked to fill a total of 420 simulated root canals with gutta-percha using cold lateral and warm vertical obturation.

Standardized root canals in heat-resistant plastic blocks (Sybron Endo, Orange, CA) were used. The canals had a uniform geometry with a length of 18 mm, a radius of curvature of 16 mm and an angle of 37°, determined with Schneider's[23] method. Patency and apical foramen size of the simulated canals was standardized by inserting a size #15 C-file (VDW, Munich, Germany) so that the tip of the file was just visible beyond the apical foramen; canals that were not patent with this instrument were discarded. The plastic blocks had been manufactured so that the simulated canals had an .04 taper and a size #40 1 mm short of the foramen; the latter was verified by inserting a size #40 K-file (VDW) to that length.

The plastic blocks were numbered and put into a computer-generated random order (www.random.org). According to the sequence of random numbers, the blocks were then divided into 30 groups of 14 ascending numbers, each group being allocated to 1 of the 30 participating students. The distribution was recorded and number-coded, making it possible to identify canal number, individual student, and obturation method. The students were given a random serial number and divided into 2 groups as follows. The students who were allocated the first 15 code numbers were assigned to group A; the rest was assigned to group B. Group A started with the cold and group B with the warm compaction method.

Table I. Procedures in groups A and B

	Group A (15 participants)	*Group B (15 participants)*
1.	Practice session (cold GP-technique) 1 straight & 1 curved canal	Practice session (warm GP-technique) 1 straight & 1 curved canal
2.	Filling of 7 canals with cold GP root canal filling technique with NiTi spreader	Filling of 7 canals with warm GP-technique
3.	Practice session (warm GP-technique) 1 straight & 1 curved canal	Practice session (cold GP-technique) 1 straight & 1 curved canal
4.	Filling of 7 canals with warm GP-technique	Filling of 7 canals with cold GP root canal filling technique with NiTi spreader

GP, gutta-percha.

Care was taken to calibrate participating students with exercises and lectures designed for this study. In addition to lectures on endodontic therapy during their curriculum, both groups had a 2-hour lecture on obturation methods and the instruments to be used before starting on practical tests Students practiced each method on straight human lower incisors and on plastic blocks. Before filling the experimental root canals, participating students filled a lower incisor root canal instrumented to size #35 and a taper of 0.06 and 1 simulated root canal. These projects were assessed and when found defective, the respective student clinician was counseled on correct technique.

After completion of these exercises, the students received their first number-coded plastic block. After each root canal obturation, a new block was handed out to the students. After completion of 7 root canal fillings with the allocated technique, all students filled the remaining canals each with the respective other method (Table I).

Obturation of root canals

Lateral compaction. For each root canal, a gutta-percha cone size #35, taper 0.02 (Roeko, Langenau, Germany) was cut to a size #40 with the aid of a measuring gauge (Dentsply Maillefer, Ballaigues, Switzerland). Gutta-percha protruding past the metal insert for size 40 was removed with a scalpel. This master cone was cut back in increments from the tip to fit the canal 1 mm short of the apex, thus obtaining an apical tug-back sensation. To verify tug-back, the gutta-percha cone was required to show a slight resistance against pulling forces.

AH plus sealer (Dentsply, Konstanz, Germany) was mixed manually and the master cone dipped into the paste once to coat it on all sides with a thin film. The master cone was then slowly inserted to working length using slight pumping movements.

Lateral compaction of the master cone was then carried out with a size #15 NiTi finger spreader (VDW). The aim was to compact the gutta-percha by inserting the spreader to 1 to 2 mm short of the working length. Size #15 accessory cones were then inserted into the space created by the spreader. Gutta-percha cones were inserted until the spreader could not be placed beyond 3 mm apical of the canal orifice. Excess gutta-percha protruding coronally was removed with a System B heat carrier (Sybron Endo). As a final step, the root canal filling was compacted vertically with a hand plugger (Dentsply Maillefer).

Vertical compaction. Size fine-medium gutta-percha cones (Analytic Endodontics, Glendora, CA) were cut back to a size #40 and adjusted until apical tug-back was obtained. System-B endodontic heat carriers (Sybron Endo) were then selected so that they could be inserted into the canal as close to the apical end point as possible without binding, 3 to 5 mm from the canal apex. The length determined was marked on the heat carrier with a rubber stop. The prepared gutta-percha cone was coated with a thin layer of AH Plus sealer and introduced into the canal with pumping motions.

Using a modified Schilder technique, coronal gutta-percha was gradually removed with a preselected System-B heat carrier with the temperature set at 200°C. The cooling gutta-percha was compacted apically with the aid of appropriately sized hand pluggers. The hand pluggers were selected to permit insertion of the smallest plugger into the canal to 4 to 5 mm short of the apex.[24] The material removal and compaction procedure was repeated until a depth of 3 to 5 mm to the apex was reached.

The coronal root canal space was then filled by injection of heat-softened gutta-percha with an Obtura II device (Obtura Spartan, Earth City, OH). This backfill was carried out in 2 increments and the gutta-percha was compacted following each injection. Injectable gutta-percha is typically placed in increments of 3 to 5 mm, with increments of up to 10 mm being permissible.[25] In the coronal third, the root canal filling terminated 1 to 2 mm below the canal orifice.

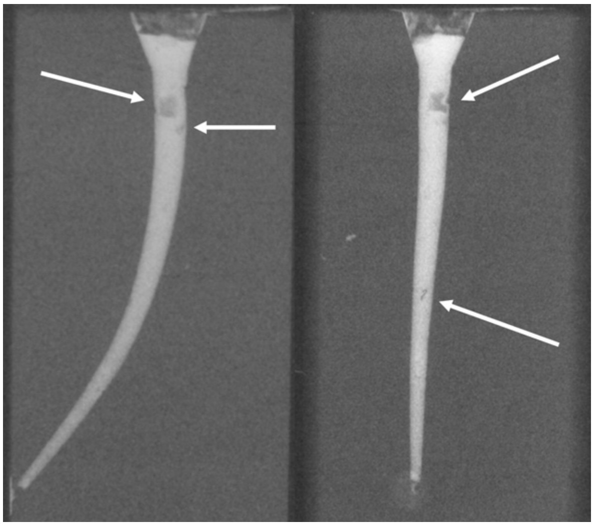

Fig. 1. Clinical view (*left*) and mesio-distal projection (*right*) of a root canal after vertical compaction. Voids denoted by arrows.

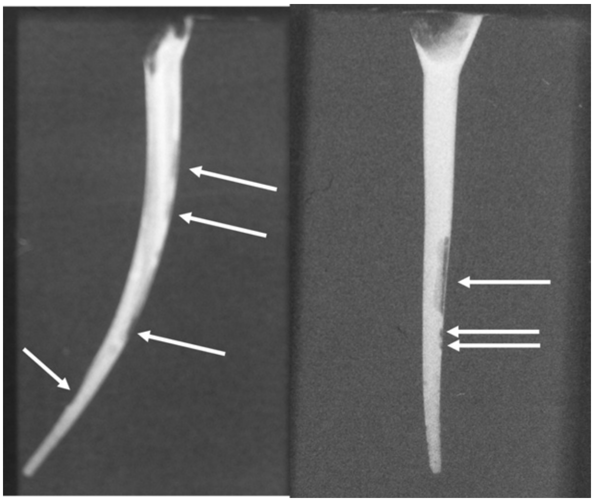

Fig. 2. Clinical view (*left*) and mesio-distal projection (*right*) of a root canal filling with lateral compaction. Lack of wall contact denoted by arrow.

Evaluation of root canal fillings

Radiographic evaluation. To evaluate the radiographic homogeneity of the root filling, digital radiographic images of all canals were obtained on phosphor imaging plates (Digora Gendex, Hamburg, Germany) with an exposure time of 0.6 seconds, and a voltage of 65 kV. Resolution and pixel size of this system are 40 μm and 12.5 lp/mm, respectively. Radiographs were taken in 2 planes perpendicularly to each other (Figs. 1 and 2). The radiographs were labeled and saved in TIFF format. Assessments included (1) the adaptation to the canal wall, i.e., the continuously homogeneous contact between canal wall and root filling material and (2) the number and size of voids within the root filling.

The adaptation of the root canal filling to the canal walls was assessed by continuous visual tracking of both inner and outer canal curvature at a magnification of ×20 on a 19-inch screen with 1536 × 2560 pixel matrix and a resolution of 2.4 lp/mm (Belinea, Marl, Germany), which is approved for radiographic evaluation. Coronal, middle, and apical canal thirds were evaluated separately and labeled as having contact to the canal walls or no contact to canal walls. If a filling showed no continuity in one section of a canal third, the entire canal third was categorized as no homogeneous contact.

The size and number of voids within the root filling were evaluated at the same magnification. Sizes of unfilled areas visible in 2-dimensional, calibrated images were measured with the Digora software (Figs. 1 and 2).

The evaluation of canal wall contact and radiographic density of the root filling was carried out separately for the apical, middle, and coronal canal thirds. Radiographic appearance was classified according to the following categories:

I. 0 to 0.25 mm (homogeneous filling)
II. 0.26 to 1.00 mm (slight voids)
III. 1.01 to 2.00 mm (medium voids)
IV. > 2.01 mm (distinct voids)

Microscopic evaluation. Extensive pilot studies had indicated that in the model used in this study, measuring void area was a valid strategy to simplify the evaluation method. Specifically, void area measurements had very high correlation at various sectioning levels (−0.969; −0.998) to gutta-percha–filled area, a measure that was recently used in assessing filling quality in extracted teeth.[26] Microscopic evaluation was accomplished at ×32 magnification using an inverted light microscope (Zeiss, Oberkochen, Germany). Assessments included (1) the type of filling material protruding through the canal terminus and (2) the number and size of voids within the obturated canal space. Filling material was categorized as:

I. no overfilled material
II. overfilled sealer only
III. overfilled gutta-percha and sealer
IV. overfilled gutta-percha only

After visual examination of the extruded material at ×20 magnification, the apical, middle, and the coronal thirds were cut into 4 cross sections each, totaling 12 cross sections per canal. Per filling method, 2520 cross sections were evaluated; this was a total of 5040 cross sections for both techniques studied.

Plastic blocks were sectioned under constant water-cooling with the first section placed 1 mm from the canal terminus. The diamond band saw (Exakt Apparatebau, Norderstedt, Germany) was set to an axial movement of 1.2 mm with a load of 25 g; with a material loss attributable to the blade thickness of 0.4 mm, sections of 0.8 mm were available for evaluation. Section surfaces were further processed with an Exakt 400 CS automatic grinding system in a stepwise fashion up to 2000 grit. Pilot experiments with canals filled with a single gutta-percha cone had ensured that the selected parameters resulted in a true representation of existing voids. Double measurements of detected voids demonstrated very high intraobserver reliability (Cohen's kappa 0.89-0.92). Moreover, sectioning plastic blocks with filled simulated canals failed to create any extraneous voids when canals were filled with a perfectly matched single cone.

Block cross sections were subsequently placed onto microscope slides in chronological order and evaluated at ×32 magnification. The size of each void was determined as the longest straight line that could be inscribed into the void circumference. A reticle in the microscope's eyepiece permitted a measurement of the voids to the next 1 μm at the selected magnification. The results for void size were divided into the following categories:

I. 0 to 0.002 mm homogeneous root filling
II. 0.003 to 0.01 mm slight porosities
III. 0.11to 0.2 mm medium porosities
IV. > 0.21 mm distinct porosities

The largest void detected was used for scoring a given cross section. For subsequent statistical analysis, 4 cross sections were used to score each canal third. The largest void detected in these 4 cross sections determined the score of the coronal, middle, and apical canal thirds of a tooth (Figs. 3 and 4).

Statistical evaluation

The observers for both radiographic and microscopic appearance of filled canals were blinded with regard to the filling technique used. Characteristics of the examined root canal fillings, such as contact to the canal wall, overfilling, and homogeneity based on radiographic and microscopic examinations are presented as percentages. Root canal fillings performed with lateral and vertical compaction were compared based on their ratings using chi-square tests. Probabilities were expressed by odds ratios (OR) with 95% confidence intervals (CI). McNemar tests were used to assess differences in filling homogeneity in coronal, middle, and apical canal thirds as well as adaptation between root canal filling and canal wall as detected by radiograph and microscope. Because of multiple testing, a Bonferroni-Holm adjustment was necessary and only adjusted P values are reported. Results with α less than 0.05

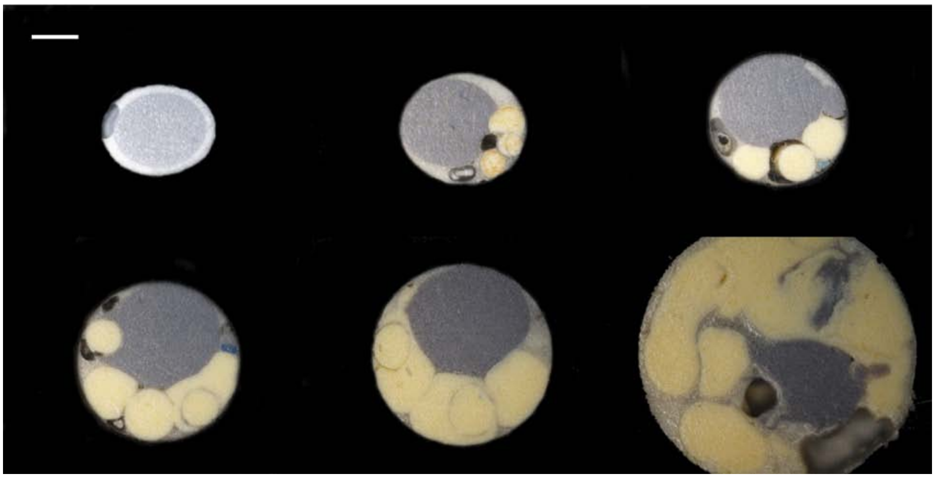

Fig. 3. Cross sections of simulated canals filled with the lateral compaction technique at 2-, 4-, 6-, 8-, 10-, and 12-mm distance from the apex. Voids and insufficiently sealed areas are visible. Bar length is 200 μm.

Fig. 4. Cross sections of simulated canals filled with the vertical compaction technique at 2-, 4-, 6-, 8-, 10-, and 12-mm distance from the apex. The root filling appears homogeneous and in close contact with the canal wall. Bar length is 200 μm.

were considered significant. Statistical evaluation of the data was carried out using SPSS 14.0 software (SPSS, Chicago, IL).

RESULTS

Radiographic evaluation

Density of root canal fillings. Vertically compacted root canal fillings showed significantly denser fills in coronal canal thirds than in apical one-thirds (McNemar test, $P < .0005$), this difference was not observed with lateral compaction ($P = .066$). When comparing middle and apical thirds of filled canals, both compaction methods produced a significantly higher homogeneity in the middle third than in the apical canal third ($P < .0005$). No significant differences in homogeneity were found comparing coronal and middle root canal thirds ($P > .05$).

A significant difference in root canal filling density in the coronal third existed between obturation methods (chi-square test, $P < .0005$). Here, chances of obtaining a homogeneous root filling were about 3 times higher using vertical compaction rather than using lateral compaction (OR: 3.2; 95% CI: 1.9, 5.3). In the middle canal third no significant differences could be detected between the 2 obturation techniques ($P = .055$). In the apical canal third, no significant differences were found between the 2 obturation methods ($P = .084$). However, the chances of obtaining a homogeneous void-free

Table II. Radiographic assessment of porosities in root fillings

Canal third	*Void size*	*Lateral compaction, %*	*Vertical compaction, %*	*P value (chi-square test)*
Coronal 1/3	0-0.25 mm	70.0	88.2	<.0001
	0.26-1.00 mm	18.6	9.9	
	1.01-2.00 mm	9.5	1.9	
	> 2.01 mm	1.9	0.0	
Middle 1/3	0-0.25 mm	77.6	84.9	.055
	0.26-1.00 mm	14.8	12.3	
	1.01-2.00 mm	4.3	1.9	
	> 2.01 mm	3.3	0.9	
Apical 1/3	0-0.25 mm	59.0	69.8	.055
	0.26-1.00 mm	20.5	25.9	
	1.01-2.00 mm	15.2	2.8	
	> 2.01 mm	5.2	1.4	

Voids were classified by size; *P* values correspond to overall comparison.

Table III. Radiographic evaluation of adaptation of root fillings to canal walls

Canal third	*Lateral compaction, %*	*Vertical compaction, %*	*P value (chi-square test)*
Coronal 1/3	35.7	55.7	<.001
Middle 1/3	52.4	70.8	<.001
Apical 1/3	16.7	17.0	>.05

root filling with vertical compaction are almost 2 times higher than with lateral compaction (OR: 1.6; 95% CI: 1.1, 2.4, Table II).

Canal wall contact. In the coronal and middle canal third, twice as many root fillings with close adaptation to the canal wall were achieved with vertical compaction (OR: 2.3; 95% CI: 2.0; 3.0) than with lateral compaction (OR 2.2; 95% CI: 1.8; 2.8). No significant differences were found in the apical third comparing the 2 obturation methods with regard to contact between canal wall and root filling.

With both compaction methods, the adaptation between root filling and canal wall was significantly less close in the coronal third than in the middle third (McNemar test, $P = .001$ lateral; $P < .0005$ vertical) or apical canal third ($P < .0005$). Both filling techniques produced significantly better-adapted root canal fillings in the middle canal third ($P < .0005$) than in the apical canal third (Table III).

Microscopic evaluation

Vertical compaction caused overfilling of the root filling material in 40.4% of canals, whereas the incidence of overfilled material was 12.7% in the case of lateral compaction. This difference between the 2 obturation methods was significant (chi-square test: $P <$ .0001). The risk of transporting root filling material beyond the apex during vertical compaction was therefore almost 5 times higher than during lateral compaction (OR: 4.6; 95% CI 2.8, 7.6, Tables IV and V).

Table IV. Presence of apically extruded root canal filling materials, determined with direct observation at ×20 magnification

Material	*Lateral compaction, %*	*Vertical compaction, %*
Sealer	7.5	15.0
GP + sealer	3.3	19.2
GP	1.9	6.1
Total	12.7	40.4

GP, gutta-percha.

None of the obturation methods showed significant differences with regard to microscopically visible porosities of the root canal filling (McNemar test, $P >$ .05) in the coronal (cross sections 9-12) and the middle canal third (cross sections 5-8). Both compaction methods showed a significantly denser fill in the coronal third (cross sections 9-12, $P < .0001$) or middle thirds (cross sections 5-8) compared with the apical third (cross sections 1-4, $P < .001$).

Significant differences were found comparing the 2 filling techniques for the incidence of filling porosities (chi-square test: $P < .0005$).

Root canal fillings without porosities in the coronal third (cross sections 9-12) were about 3 times more frequent with the vertical compaction method than with the lateral compaction method (OR: 3.1; 95% CI: 1.6, 5.8). Root canal fillings without porosities in the middle canal section (cross sections 5-8) were almost 3 times more frequent with vertical compaction than with lateral compaction (OR: 2.7; 95% CI: 1.6, 4.7). Root fillings without porosities in the apical canal third (cross sections 1-4) were almost 10 times more frequent with vertical compaction than with lateral compaction (OR: 9.8; 95% CI: 2.2, 43.5).

DISCUSSION

This article describes radiographic and microscopic appearances of root canal fillings performed by inexperienced dental students with the warm vertical and cold lateral techniques. Both examination techniques demonstrated denser root canal fillings with significantly fewer voids using vertical compaction than with lateral compaction. Under microscopic examination, both compaction methods obtained a significantly higher degree of homogeneity in the coronal third than in the middle and apical thirds of the canal. However, the chances of transporting root filling material beyond the root apex during vertical compaction were about 5 times higher than with lateral compaction.

Table V. Microscopic assessment of porosities in root fillings

	Size of nonhomogeneity	*Lateral compaction, %*	*Vertical compaction, %*	*P value (chi-square test)*
Coronal canal third *cross sections:* 9-12	0-0.02 mm	11.2	25.4	<.0001
	0.03-0.10 mm	23.5	36.1	
	0.11-0.20 mm	36.8	22.8	
	>0.21 mm	28.6	15.7	
Middle canal third *cross sections*: 5-8	0-0.02 mm	7.6	20.3	<.001
	0.03-0.10 mm	36.0	39.6	
	0.11-0.20 mm	35.5	27.4	
	>0.21 mm	20.8	12.7	
Apical canal third *cross sections*: 1-4	0-0.02 mm	1.0	9.1	<.021
	0.03-0.10 mm	5.6	24.9	
	0.11-0.20 mm	26.4	31.0	
	>0.21 mm	68.0	35.0	

Voids were classified by size; *P* values correspond to overall comparison.

It needs to be emphasized that the present study aimed to evaluate the outcomes achieved by inexperienced operators. Therefore, care needs to be taken to extrapolate findings, for example regarding overfills, to more experienced clinicians. However, the goal of the present study was to assess whether warm vertical techniques may be suitable for teaching at an undergraduate level. Lateral condensation is a frequently taught root canal filling technique that has certain advantages over warm gutta-percha filling methods.[3] For example, it does not require expensive devices or equipment and is thus comparatively inexpensive. Length control is believed to be easier with cold lateral compared with warm vertical compaction, which leads to less overfilling into periradicular tissues.[5-8] Clinical outcomes were often reported to be similar with both filling methods.[12,14] Disadvantages of cold lateral compaction include incomplete filling of certain canal areas and a more time-consuming procedure than with warm gutta-percha filling regimens.[3]

Warm vertical compaction is superior to lateral condensation in the ability to fill irregular root canal spaces, i.e., lateral canals or isthmus areas,[3,10] which has recently been linked to better clinical outcomes.[27] Perceived disadvantages are greater potential for clinical complications owing to extrusion of filling materials beyond the confines of the root[11] and potential heat damage of periodontal tissues.[28]

In the present study, root canal filling quality was not influenced by differences in taper, curvature, or canal diameter. Artificial canals guaranteed standardized conditions without having to resort to split tooth models. Standardized artificial canals have been used in several earlier investigations to examine the quality of root canal obturation.[4,29] Plastic blocks with simulated canals may be readily cut using a diamond band saw at low speeds and water cooling with little danger of obscuring or creating voids in root canal fillings, as indicated by extensive pilot studies (data not shown). Moreover, it seems likely that all groups would have been uniformly affected by any artifacts during the sectioning process.

However, a disadvantage of using simulated canals in plastic blocks or plastic teeth, however, is that the contact area between plastic material and gutta-percha does not closely resemble the clinical situation. For this reason, an examination of filling density, using penetration by bacteria, fluids, or air, cannot be simulated in plastic blocks. Moreover, it is conceivable that the use of a hot instrument may cause deformations in the artificial canals.[30] However, plastic blocks with a simulated canal specifically manufactured for warm vertical compaction were used in this study; therefore, any deformation risk appears to be low. In fact, visible discoloration of the plastic material changes in canal shape was not found during the examination. Another factor to be considered is canal taper (4% in the present case). An increased taper may lead to improved spreader penetration and hence improved filling quality. However, this has been shown only when comparing standardized canal shapes (i.e., 2% taper) and canals that were prepared with a 1-mm step-back (i.e., 5% taper).[31] In the present study, simulated canals with an apical diameter of size #40 were used, which permitted penetration of the selected size #15 spreaders to 1 to 2 mm from working length and hence permitted favorable conditions for lateral compaction. Similar to other studies,[4,29] simulated canals used in the present experiment had a length of 18 mm, which may be longer than canals in molars. However, canals in incisors and canines are often longer than 18 mm.

In this context it needs to be emphasized that this study does not attempt to extrapolate its findings into clinical factors, such as potential for leakage or quality of the seal. Other parameters such as the percentage of gutta-percha to voids in cross sections have been reported for that purpose.[26] Rather, the study aimed at comparing, in a highly standardized model, students' ability to perform 2 root canal filling methods that are commonly perceived as being less (lateral compaction) and more (vertical compaction) technique-sensitive. The degree of standardization permitted a simplified evaluation of more than 5000 sections measuring voids rather than gutta-percha filled area, as indicated by extensive pilot studies (data not shown).

Interestingly, lateral compaction seems to result in significantly less consistent root canal fillings even though this technique is considered to be a less sensitive and easier procedure to use than vertical compaction. To obtain the best lateral compaction results, NiTi spreaders, which have a significantly higher penetration depth than stainless steel spreaders with identical pressure,[32] were used in this study. Nevertheless, variations among the root canal sections assessed regarding voids may be, at least in part, a result of variations in spreader penetration. Another portion of variability is introduced with cone fit; however, these are common issues in the clinic and hence to be expected to occur with inexperienced student dentists.

A comparison with the existing body of literature shows that similar results regarding lateral compaction were found by other authors. In a retrospective radiographic examination, at a Turkish university, only 53.2% of all root fillings carried out with lateral compaction were of adequate radiographic density.[21] In a another report, however, single-rooted teeth had an acceptable level of density of 70% after lateral compaction.[22] Eleftheriadis and Lambrianidis[33] found that 82.6% of root canals filled by students using lateral compaction were tightly sealed on the radiograph. In yet another investigation, 72.6% of all teeth examined radiographically showed an acceptable filling without visible porosities or missing canal wall contact after lateral compaction.[20]

No clinically significant differences in treatment success were detected in the 450 root canal fillings made by students either by warm vertical or cold lateral compaction.[34] In addition, the presence of overfilled obturation material in the apical area or filling voids detected by radiographs was not associated with altered clinical outcomes. On the other hand, phase II, a later examination of the same patient group, indicated that the compaction method had a significant influence on clinical success: healing was significantly more frequent with warm vertical compaction ($P = .049$) than with cold lateral compaction.[27] In phase III of the studies, all results from phases I to III were summarized and evaluated for increased statistical power This evaluation revealed that the vertical compaction method was significantly ($P = .008$) superior to the lateral compaction technique. However, neither sealer extrusion nor radiographic deficiencies had any significant influence.[35] Similarly, a recently published meta analysis found no difference between the 2 compaction methods regarding clinical success rate, postoperative complications, or quality of obturation.[36]

In the present investigation, root canal filling material was extruded through the apex in 40.4% of the canals filled by vertical compaction and in 12.7% of the canals filled by lateral compaction. It might have been possible to reduce the incidence of sealer overfill if, for example, Kerr Pulp Canal Sealer had been used, a sealer with a reduced flow rate specifically recommended for vertical compaction, instead of AH plus sealer.[37] Sealer in the periapical region leads to inflammation, the extent of which varies according to the chemical composition of the material; this may cause pain and discomfort for patients.[11] Introduced by Schilder in 1967,[38] warm vertical compaction has been discussed heatedly by supporters and opponents with regard to advantages and disadvantages of this technique.[39] Nevertheless, it seems desirable that students have the opportunity to get acquainted with both filling techniques. As can be gathered from the undergraduate curriculum guidelines of the European Society for Endodontology,[1] students should "have an in-depth knowledge of the principles and practice of non-surgical root canal treatment."

CONCLUSIONS

In this study, inexperienced practitioners were able to obtain homogeneous root fillings using a warm vertical gutta-percha technique after minimal training. The results of this investigation motivate both to continue the use of warm gutta-percha filling methods in preclinical education and to further examine this obturation technique on extracted human teeth so as to develop the best possible strategy of employment. The increased risk of overfilled root filling material during vertical compaction and possible consequences for patients should be considered in clinical education of students.

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