ORIGINAL RESEARCH

Comparison of Fracture Resistance between Single-cone and Warm Vertical Compaction Technique Using Bio-C Sealer® in Mandibular Incisors: An *In Vitro* Study

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Abstract

Aim: The aim of the study was to compare the fracture resistance of the single-cone technique with the warm vertical compaction technique (WVCT) in mandibular incisors using Bio-C sealer®, by applying a compressive force using a universal testing machine (UTM) (Instron 5943; Instron, Norwood, Massachusetts, USA).

Materials and methods: Twenty-two mandibular incisors were selected and divided into two groups after applying the same shaping protocol. To assess the influence of the wave vertical compaction technique on the fracture resistance, the first group was obturated by a single-cone obturation technique (SCOT) ($n = 12$), and the second group was obturated with a WVCT ($n = 10$). Bio-C sealer® (Angelus, Hague Netherlands) was used in the two obturation techniques. Wax-coated roots were put in an acrylic mold and loaded to compressive strength fracture in a mechanical material testing machine (UTM) (Instron 5943; Instron, Norwood, Massachusetts, USA), with Bluehill 3 software (version 3.15.1343) recording the maximum load at fracture. Fracture loads were compared statistically, and data were examined with the Mann–Whitney *U* test with a level of significance set at $p \leq 0.05$.

Results: No statistically significant difference was registered between the SCOT (264.97 ± 83.975 N) and WVCT (313.35 ± 89.149 N) concerning the endodontically treated mandibular incisors' fracture resistance ($p = 0.159$).

Conclusion: Warm vertical compaction technique (WVCT) did not affect the fracture resistance of endodontically treated mandibular incisors when compared to SCOT canal preparation.

Clinical significance: General practitioners and endodontists face challenges during root canal treatment such as cracks and root fractures. This article aims to guide experts in choosing between the single-cone and the continuous WVCT aiming for higher long-term quality of root canal filling.

Keywords: Compressive strength, Fracture resistance, Mandibular incisors, Single-cone technique, Warm vertical condensation.

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Introduction

The ultimate goal of root canal therapy is to prevent microorganisms and intracanal toxins from causing periapical diseases.[1] This goal is established by an optimal debridement and disinfection of the canal system.[2] This procedure aims to remove dentinal structures that could cause a lower fracture resistance.[3]

To ensure the sustainability of the work obtained, three-dimensional obturation of the canal system is required. This obturation must ensure a hermetic seal to achieve long-term endodontic success.[1] Several obturation techniques are used for the filling of root canals such as continuous wave vertical compaction and single-cone that were compared in this study. The WVCT consists of heating the obturation material and allowing a better distribution of this material in the pulpal complex.[4] The devices that permit this technique are combined with special tips that function by warming up the obturation material up to 150–200°C. However, this technique can induce root fractures due to the apical compaction forces, and results in root canal enlargement, in order to allow the use of a tapered plugger.[1] The SCOT was developed, in 1960, in order to simplify the stages of endodontic treatment.[5] It consists of the insertion of a single-cone gutta-percha, at room temperature, accompanied by a layer of intracanal sealer. It takes less armamentarium, is simple to manage, and is thus gaining appeal among many dentists.[1] With hydraulic calcium silicate sealers, the single-cone obturation procedure has been suggested.[6]

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Grossman listed the properties of the ideal sealer: Easy handling, relatively slow hardening, establishing a hermetic seal, stability over time, and low absorption.[1] In addition, they must be insoluble in tissue fluids, antiseptic, bacteriostatic, tolerated by periapical tissues, and radiopaque to be visualized on an X-ray. They should not stain the tooth structure and should not exhibit shrinkage when setting as well as good adhesion to the root canal walls. Their surface tension and fluidity should allow the plugging of tubules and accessory canals. They must be soluble in a common solvent if it is necessary to remove the root canal filling.[1,7] Over the last years, calcium silicate-based sealer (CSS), a new class of endodontic sealers was introduced to modern dentistry to overcome the disadvantages of conventional sealers. With the water absorption of CSS, minor expansion can occur. This is why these CSS sealers have excellent sealing ability and biocompatibility that ensure better obturation over time.[8] Biomineralization is another characteristic of CSS. At the calcium silicate/dentin interface, it forms a tag-like structure. Since calcium silicate-based sealers attach micro mechanically to dentin, they improve dislocation resistance and reduce the gap at the interface.[9] Bio-C sealer® (Angelus, Hague Netherlands), a type of calcium silicate-based sealer, has been used in this study.

According to the European Society of Endodontology, root fracture is one of the most common reasons for extraction of an endodontically treated tooth.[10] Root fractures can be divided into two major groups: Transverse horizontal fractures caused by severe trauma, and vertical fractures caused by an iatrogenic origin.[11] The challenging part of diagnosing the vertical root fracture is determining what could have been the iatrogenic cause.

Nowadays, with the techniques of obturation evolving, what could be interesting is to determine if there is any correlation between the technique of obturation and the fracture resistance of the treated tooth.

The aim of the study is to compare the fracture resistance of SCOT and continuous WVCT on mandibular incisors, using a tricalcium silicate sealer (Bio-C sealer®); by applying a compressive force with the help of the UTM (Instron 5943; Instron, Norwood, Massachusetts, USA).

The null hypothesis states that the fracture resistance of teeth treated with the SCOT and teeth treated with the WVCT.

Materials and Methods

Sample Selection

After the approval of the independent ethics committee (USJ-2020-220), one hundred human mandibular incisors were collected randomly from a collection of extracted teeth due to periodontal problems. Radiographs (DBSWIN®) version 5.15.1. were taken in the buccolingual and mesiodistal directions to select teeth with one root. Then, the incisors were evaluated by axial radiological sections at 3, 6 and 9 mm from the apex using a cone-beam computed tomography (CBCT) (Newton VGI, NNT viewer). Mandibular incisors were selected with Vertucci's canal configuration type I, type II, and type III. Mandibular incisors with an old restoration, decay, calcified canals, type IV and V Vertucci classification, and roots with an open apex were excluded from the study. Twenty-two mandibular incisors were included and stored in thymol solution.

Root Canal Preparation

All the access cavities were realized in a conservative way. It was done using an 802,012 diamond bur. All the roots were prepared with E3 AZURE (25; 6%) (Endostar, Poland) and were operated with E-connect motor Pro (Eighteeth, Changzhou, China) following the manufacturer's instruction. K10 file was used for measuring the working length, followed directly by E3 AZURE (25; 6%) for shaping the root canal system till the working length. After each insertion, irrigation with 1 mL 5.25% sodium hypochlorite (NaOCl) was applied with a 3 mL syringe and a bevel-end needle that was inserted 2 mm from the working length. All the specimens were shaped to apical size 25/100, taper 6%. Final irrigation was applied with 3 mL of 17% EDTA, followed by 3 mL of 5.25% NaOCl as a final rinse.

All specimens were randomly divided into two groups, the first group was obturated by a SCOT ($n = 12$), and the second group was obturated with WVCT ($n = 10$).

Filling Procedure

The experimental groups were filled using the following methods.

Group I: Bio-C sealer® + Gutta-Percha (G-P) (Single-cone) (n = 12)

Each canal was fitted with an FM G-P cone. Bio-C sealer® (Angelus, Hague, Netherlands) was injected through the intracanal tip to fill the apical part of the canal, until the complete filling of the canal. The FM G-P (META BIOMED, South Korea) was introduced into the canal up to working length. Excess material was sheared off and condensed with a plugger 1 mm below the canal opening.

Group II: Bio-C Sealer® + Gutta-Percha-Continuous Wave Vertical Compaction (n = 10)

Each canal was fitted with an FM G-P cone. Bio-C sealer® (Angelus, Hague Netherlands) was injected through the intracanal tip to fill the apical part of the canal, until the complete filling of the canal. The FM G-P (from META BIOMED, South Korea) was introduced into the canal 0.5 mm from the working length. After that, continuous vertical compaction was completed with EQV from META BIOMED SYSTEMS. A #0.06 tapered stainless steel plugger was pre-fitted to fit within 5 mm of the canal length. Placing the plugger deeper into the canal may enhance the flow of gutta-percha. In touch mode, the meta-system unit was set at 230°C. To remove excess coronal material, the plugger was put into the canal orifice and activated. With the meta-system unit, firm pressure was applied and the heat was activated. For 1–2 seconds, the plugger was rapidly moved. The heat was turned off by applying firm pressure to the plugger for 5 seconds. The plugger is then separated from the gutta-percha with a 1-second application of heat. The thermoplastic injection technique was used to fill the area left by the plugger (Gutta gun from EQV-meta-system).

All teeth were restored coronally with the same composite (Filtek Z250, 3M ESPE, St Paul, Minnesota, USA) that closes the class I cavity produced during endodontic treatment. All specimens were stored in a 100% humid environment at room temperature until analysis.

Simulated Periodontal Ligament and Alveolar Bone

To replicate the function of the periodontal ligament, a small layer of wax was applied to the root surfaces. After that, the wax-covered roots were individually mounted in plastic cubes and inserted in an acrylic mold up to 2 mm below the cement enamel junction (CEJ). After resin polymerization, the excess wax and resin were removed.[12,13]

Fracture Resistance Test

The teeth embedded in resin were placed on the compressive discs. The specimens were then subjected to loading with a UTM (Instron 5943; Instron, Norwood, Massachusetts, USA) (Fig. 1). The specimen was compressed at a rate of 1 mm min^{-1} until a fracture of the tooth was detected (Figs 2 and 3). Prior to starting the test, a 5 mm metallic spherical fixture[8] was placed in the middle of the incisal board along the vertical axis of the tooth, contacting the flat root face on both mesial and distal sides to evenly distribute the load on the root surface, as an antagonistic tooth (Fig. 4).[8] Where the incisor board was too sharp, a file was used to minimally flatten

Fig. 1: The UTM (Instron 5943; Instron, Norwood, Massachusetts, USA) used to compare the fracture resistance

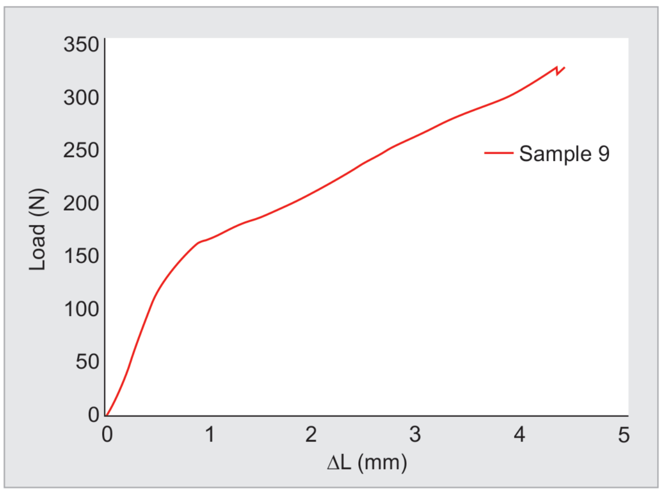


Fig. 2: Showing the compressive load at a crosshead speed of 1 mm min^{-1} of sample 9 in the SCOT group

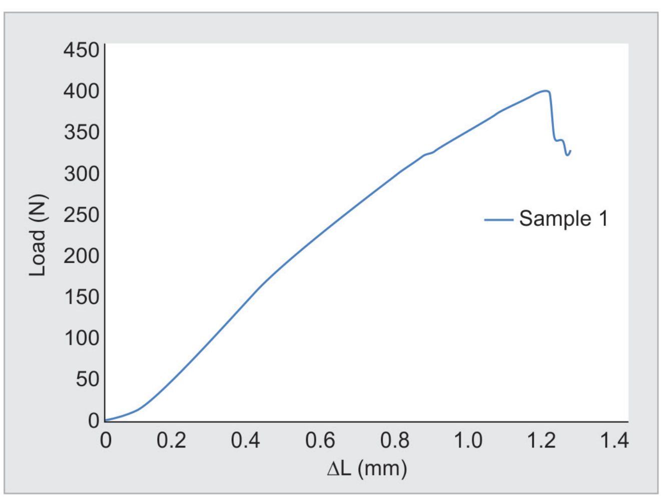


Fig. 3: Illustrating the compressive load at a crosshead speed of 1 mm min^{-1} of sample 1 in the WVCT group

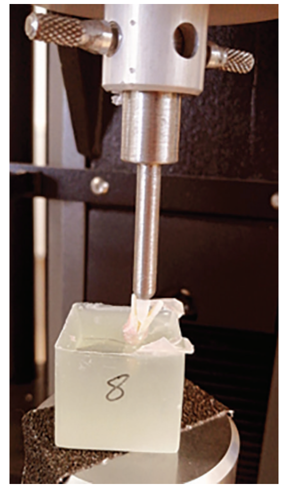


Fig. 4: Fractured crown after load

Table 1: The maximum load in the two groups: SCOT and WVCT

	Maximum load (N)	
	SCOT	*WVCT*
Sample 1	226.90	390.76
Sample 2	340.86	252.18
Sample 3	163.49	395.87
Sample 4	254.16	187.34
Sample 5	196.77	410.82
Sample 6	118.70	235.04
Sample 7	340.74	210.03
Sample 8	366.84	276.34
Sample 9	320.43	401.95
Sample 10	192.35	373.17
Sample 11	304.91	
Sample 12	353.50	

the surface so that the 5 mm spherical fixture could properly indent the tooth and not slip off the incisal board.

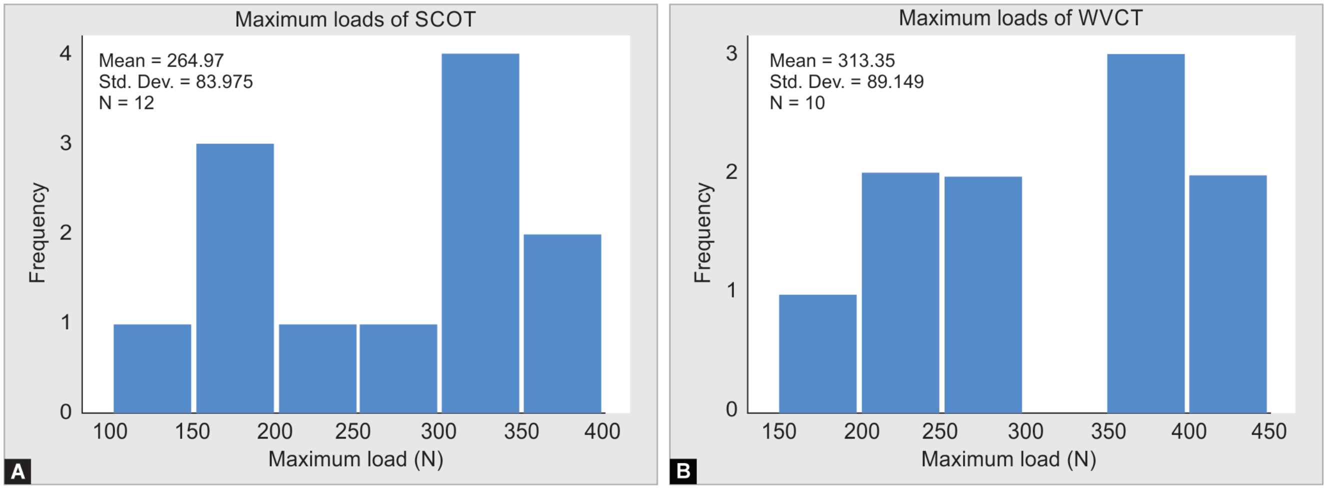
The load that indicated the first fracture (an abrupt load-drop during compression), resulting in a peak development on the extension curve, was identified as the fracture threshold (Figs 2 and 3). The load cell utilized was 1000 N, and the measurements were recorded in Newtons (N). The machine was connected to the Bluehill 3 software (version 3.15.1343) which collects all the information executed during the test.

Statistical Analysis

The data analysis indicates that the maximum load required for cracking the tooth to occur does not exhibit a Gaussian distribution. Hence, a nonparametric statistical analysis (Mann–Whitney *U* test) was used to assess if the WVCT could cause more cracks than the SCOT. Statistical analysis and graphical representations of data were done with SPSS software (IBM, Armonk, New York, USA).

Results

Figures 2 and 3 illustrate the compressive load at a crosshead speed of 1 mm min^{-1} of one sample from each group. These graphs show in detail the maximum load a sample could withstand before



Figs 5A and B: (SCOT and WVCT) Showing the distribution of the maximum load applied to the samples of the two groups SCOT (264.97 ± 83.975 N) and WVCT (313.35 ± 89.149 N)

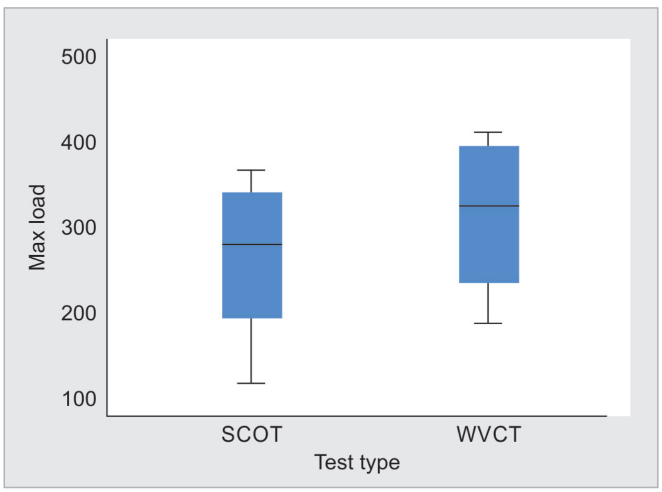


Fig. 6: This box plot showing the distribution of the maximum load of the two techniques

an abrupt load drop. Table 1 summarizes the maximum load of every sample in each group. The distribution of the maximum load applied on the different samples of the two groups is also shown in (Fig. 5) and is presented in the box plot in Figure 6. The Mann–Whitney test showed no statistically significant differences between the SCOT (264.97 ± 83.975 N) and the continuous WVCT (313.35 ± 89.149 N) on the fracture resistance of mandibular treated anterior. Thus the null hypothesis is accepted ($p = 0.159$).

Discussion

Testing *in vitro* the maximum load an endodontically treated teeth can withstand before fracture may help understand and evaluate the mechanical behavior of these teeth. In this study, mandibular incisors were used because according to the literature, they have a higher risk to fracture due to their anatomical position.[14] The *UTM* (Instron 5943; Instron, Norwood, Massachusetts, USA) in this study was used to assess the fracture resistance. The protocol used is similar to protocols that tested the load on treated teeth such as Isufi et al., Monaco et al., and Zogheib et al.[13,15,16] The resin replaced the alveolar bone and the wax layer acts as the periodontal ligament, in an attempt to simulate the oral situation as much as possible.

In this study, a comparison of two groups of treated mandibular incisors in which all access cavities are class I occlusal and all are restored by the same type of composite (Filtek Z250, 3M ESPE, St Paul, Minnesota, USA), without any post or coronal build-up. The protocol is thus established in order to eliminate other restoration parameters such as the type of coronary restoration, type of composite, etc., and to allow only the comparison between two obturation techniques with **Bio-C sealer®**. All the access cavities were realized by the same operator and in the most conservative way to minimize the bias. However, cavities may differ from tooth to tooth which could affect the results.[17]

On the contrary, no microscopic assessment of cracks, fissures or other areas of weakness has been performed on the teeth in question. However, De-Deus and Calvacante showed that preexisting microcracks evaluated under micro-CT do not play a role in the fracture resistance test in mandibular incisors roots.[12]

The compression test was performed using a 5 mm diameter ball which is placed with the long axis of the tooth at the level of the center of the incisal board. Using a universal testing machine (UTM) (Instron 5943; Instron, Norwood, Massachusetts, USA) communicates with the Bluehill 3 software (version 3.15.1343) which collects data in the form of graphs and displays the braking force in Newtons (N). The same concept of the machine was used in other studies such as Monaco et al., Zogheib et al., and Cavalcante et al.[12,13,16] On the contrary, some study protocols are based on an angulation of the compressive load relative to the axis of the tooth. This does not distribute the stress evenly over the entire tooth surface and may interfere with the results obtained.[18] In the present study, the compressive force follows the major axis of the tooth.

The maximum load on mandibular incisors with treated oval roots was assessed between the two groups SCOT and WVCT. The literature has shown that the prevalence of oval-shaped roots varies between 40 and 50% in mandibular incisors.[19,20] The fracture resistance test in these oval-shaped roots has shown no statistically significant differences between the SCOT and the WVCT (Mann–Whitney U test = 0.159; $p > 0.05$). These results provide evidence that a WVCT does not cause any excessive pressure on dentinal walls that may produce more cracks than a SCOT. The null hypothesis is therefore accepted: There is no significant difference between the two groups. A similar result was shown by De-Deus et al., after assessment of dentinal microcracks after root canal filling procedures: GuttaCore (GC), cold lateral compaction, and warm vertical compaction under micro-Ct evaluation. The results of the study proved that root fillings in all techniques did not induce the development of new dentinal microcracks.[21] In addition, a fracture resistance test was used to compare MTA fillapex® sealer in WVCT and SCOT to different obturation techniques and sealers (AH Plus, Dentsply). Ersoy et al. showed no statistical differences between the two obturation techniques with both sealers, AH Plus and MTA Fillapex®.[22] Contrariwise, Capar et al. studied the effect of shaping, filling, and retreatment in different obturation techniques: Cold lateral obturation, single-cone obturation, and wave vertical compaction. The result of this article showed that cold lateral obturation and wave vertical compaction caused more cracks than the single-cone technique.[23] In addition, Capar showed that each step of the root canal treatment decreases the fracture resistance of the treated tooth. This means that every root canal procedure can cause cracks in any part of the tooth structure: coronal, radicular or corono-radicular.

In this study calcium silicate-based sealer (Bio-C sealer®) was used to compare the two obturation technique, WVCT, and SCOT. According to Mohammed and Al-Zaka, calcium silicate-based sealer (TotalFill® BC) presented significantly better results compared with other sealers considering the fracture resistance.[24] This could be explained by the fact that calcium silicate-based endodontic sealers form a chemical link with the radicular dentin as hydroxyapatite is produced during the setting process. Another factor, according to the authors, is that it has a low contact angle due to its hydrophilic nature, allowing for easy distribution along canal walls. The results of the study agree with other studies performed in recent years.[25,26] To further justify this point of view, further studies should compare fracture resistance in different obturation techniques.

For the statistical analysis, we were using the two-sided student *t*-test for statistical analysis of significance. However, after checking the distribution of the curves, the datasets for the SCOT and WVCT showed that the curves did not have a normal distribution. Thus the two-sided Mann–Whitney *U* test was used. Grande et al. reported that the wide range in standard deviation is statistically acceptable and normal due to anatomical and morphological differences in extracted teeth and efforts to minimize these differences are highly important.[27] Furthermore, in a study published in 2015, De-Deus et al. did the sample size calculation[21] in which an effect size of 2.1 was estimated and put together with the alpha-type error of 0.05 and power beta of 0.95 parameters into an independent *t*-test family procedure (G*Power 3.1 for Macintosh; Heinrich Heine, Universität Düsseldorf, Dusseldorf, Germany). To demonstrate statistical significance between groups, the output required a minimum of 16 teeth (8 per group). The sample size in the present study was 22 specimens, which is acceptable, and the wide range in standard deviation could be due to the variety in cavities and anatomical complexities.[21]

Conclusion

Based on this *in vitro* study, no significant difference was found between the SCOT and the WVCT. Warm vertical compaction technique (WVCT) did not affect the fracture resistance. Further clinical research could be beneficial to determine the ideal obturation technique resulting in the highest tooth fracture resistance.

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