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Root Canal Preparation of a Commercial Artificial Tooth versus Natural Tooth—A MicroCT Study

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Abstract: This study aimed to evaluate by microCT the preparation of the artificial teeth (ATs), TrueTooth®, versus natural teeth (NTs): (1) the time and number of pecking movements needed for preparation; (2) the root canal volume increase; (3) if the pulp-colored medium has any effect on the 3D analysis. Material and Methods: Artificial and natural maxillary molars were used. Fourteen AT distobuccal canals and fourteen NT buccal canals were used for the first and second aim and fourteen AT mesiobuccal canals for the third aim. Results: No statistically significant differences were observed regarding the time and number of pecking movements ($p > 0.05$); for the root canal volume increase, a statistically significant difference was observed ($p < 0.05$) with a higher mean value for NTs; however, in the group of ATs, there was a volume decrease in three cases. The AT mesiobuccal root canal mean volume increase was also negative. Conclusions: There are no differences between the time and number of pecking movements between NTs and ATs, so TrueTooth® can potentially be used in endodontic training. The volume increase between ATs and NTs was higher in NTs. However, some samples showed negative values, also seen in the AT mesiobuccal canal, confirming that the pulp-colored medium has an effect on the 3D analysis.

Keywords: endodontics; microCT; TrueTooth®; 3D printing; 3D analysis; endodontic training

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1. Introduction

Bacteria are the main cause of pulpal and periapical pathologies. Therefore, all endodontic procedures aim to eliminate pulp tissue, as well as as many bacteria as possible [1]. Root canal mechanical preparation is an important step to achieve this goal while simultaneously increasing the root canal volume to facilitate the decontamination of the root canal system by irrigants and medicaments [2,3]. To accomplish this, a variety of manual and rotary instruments have been proposed. The revolution in the manufacturing of root canal instruments has led to a great variety of these endodontic instruments when comparing the design, alloys, and type of movement.

Many new systems are available on the market, and clinicians require an impartial evaluation of their characteristics to help them in selecting systems to use clinically [1,2,4]. ProTaper Gold® (Dentsply Sirona) (PTG) uses control memory wire, which has a lower percentage of nickel (by weight), and because of the thermic treatments used during the manufacturing process, it does not rebound to its original shape after being flexed; this characteristic reportedly increases its flexibility [1–4].

Among the most-important basic topics under research concerning root canal preparation are: (1) the removal of dentin and the volume increase; (2) straightening and transportation; (3) unprepared root canal areas; and (4) working time [5,6].

Traditionally, for ex vivo studies and pre-clinical courses, extracted human teeth have been the standard practice [7–9]. However, natural teeth (NTs) have several drawbacks, which have been discussed in recent years: they are difficult to collect, and there are ethical considerations, potential cross-infection risks, storage drawbacks, and standardization issues [7,8,10,11]. When using NTs, the external and internal anatomy should be fairly balanced between the groups to avoid any anatomical bias [7,8,11,12], or studies might demonstrate the effect of canal anatomy rather than the variable of interest [13]. In the teaching environment also, students normally comment that the anatomical variability does not allow a valid assessment of their individual performance [14].

The most-common method used in ex vivo studies is to create pair-matched tooth samples according to their anatomical features, such as the tooth type, root length, root anatomy, degree and angle of curvature, and root canal diameter, or even with paired contralateral teeth [7,12].

Many methods are used for anatomy assessment, namely visual examination, radiographs, and micro-computed tomography (microCT). MicroCT allows a non-invasive, non-destructive, high-resolution, and 3D investigation [7]. De-Deus et al. (2020) compared the randomized method, radiographic method, and microCT method and concluded that microCT was able to provide better control of the confounding effects of anatomical variance. Nonetheless, this study also demonstrated the difficulty, time consumption, and high costs of this method [12]. Additionally, it should be noted that other tooth parameters should be taken into count, which cannot be sufficiently standardized by these methods, such as the age and ethnicity of the donor and environmental factors. These factors have an impact on the mechanical properties of the dentin, so a total standardization is, with the actual methods, almost impossible to achieve [15].

Three-dimensionally printed teeth that reproduce the features of natural teeth may overcome all these limitations [10,11,16] and are also suitable for practicing access opening, canal instrumentation, radiographic length control, and canal filling [8,16]. They are realistic and standardized, so the same level of difficulty is guaranteed for every single student, and consequently, they will be scored fairly [8–10,16]. Additionally, in ex vivo studies, this morphological standardization has a major impact on the results' credibility, since anatomical bias would not exist [12,13].

In the study of Gancedo-Caravia et al. (2020), it was concluded that replicas obtained from microCT scans better reproduced the internal anatomy, and in particular, TrueTooth® was the best replica for access cavity preparation training and root canal negotiation [5]. TrueTooth® (DELabs) is a 3D-printed replica of human teeth, designed for teaching access, negotiation, shaping, irrigation, and obturation for root canal iterative training [17], that is radio-opaque with a pulp-colored medium inside each canal space, which can be dissolved with sodium hypochlorite (NaOCl) [18]. TrueTooth® replica #15-001 is a maxillary molar with a distobuccal canal with a severe curvature and a large mesiobuccal canal, ribbon-shaped, with a moderate curvature [17]; these features are adequate for the purposes of the present study.

Nonetheless, it has been reported that, in 3D-printed teeth, it is difficult to remove the support material from parts with features having fine details [7,8]. In this way, canals could be filled partially or totally with the support material, and the effect of this material on microCT 3D analysis should be considered [15].

To the authors' knowledge, there are no studies that (1) compare the time and pecking movements needed for the preparation of TrueTooth® with NTs, (2) investigate if TrueTooth® is adequate for the evaluation of the canal preparation using microCT, and/or (3) analyze the effect of the support material on the variables of interest.

Hence, the aim of this study is to evaluate the preparation of TrueTooth® with the PTG system and compare this to NTs in the following aspects: (1) the time and number of pecking movements needed for the root canal preparation; (2) the root canal volume increase; and (3) if the pulp-colored medium has any effect on the 3D analysis by microCT in order to assess if TrueTooth® can be used in endodontic training and/or microCT studies. The null hypothesis is that the time, pecking movement, and root canal volume increase are equal between TrueTooth® and NTs and that the TrueTooth® pulp-colored medium has no effect on the variables of interest.

2. Materials and Methods

2.1. Specimen Selection

Based on previous studies [19–21], a sample size calculation was performed using the G*Power 3.1.9.7 software for windows (Heinrich Heine, Universität Düsseldorf, Germany), and the *t*-test for 2 independent groups was used with an α-type error of 0.05 and a β power of 0.80 (a large effect size equal to 1 was considered for sample size calculation for all variables), resulting in a required size of 14 samples per group.

2.2. Natural Specimen Selection

This research work, with ethics committee approval (IAO-23-0104), used an initial pool of 65 maxillary permanent molars, extracted for reasons unrelated to this study, collected and stored in distilled water until use. Radiographs were taken in the mesiodistal and buccolingual directions to ensure that the inclusion criteria were met. The inclusion criteria were teeth with fully formed apices, the absence of root fractures, no signs of external and internal resorption or decayed tissue in the region of interest, the absence of previous endodontic treatment, the absence of calcifications, teeth with separated canals and apical foramens, and a degree of curvature between 20° and 50°. The degree of curvature was measured according to Schneider's method [22]. It was determined drawing two lines: the first was parallel to the long axis of the canal, and the second line was drawn from the apical foramen to intersect with the first at the point where the canal began to leave the long axis of the tooth. Based on these criteria, and to economize the resources, the buccal canals of 7 teeth were selected. All the preparations were performed by a single operator with 15 years of clinical experience in the field of endodontics and previous experience in PTG system use. The teeth were mounted in place using the ProTrain system® (Simit Dental, Mantova, Italy).

The endodontic cavities were prepared using a round diamond bur #4 and an Endo-Z™ bur (Dentsply-Maillefer, Ballaigues, Switzerland) driven by a high-speed handpiece under water cooling. The buccal canals were explored by advancing passively into the canal a K-file #10 (Dentsply Sirona) until the tip of the file was just visible through the apical foramen. The working length (WL) was determined by reducing 1 mm from that value.

2.3. Artificial Specimen Selection

For the AT group, fourteen TrueTooth® replicas (#15-001) were used in the study. The 14 distobuccal canals were used for comparison with the 14 natural buccal canals, and the 14 mesiobuccal canals were used to access the effect of the pulp-colored medium. ATs were prepared equally to NTs.

2.4. Initial MicroCT Scanning

The specimens were then scanned using a microCT device (Skyscan 1174; Bruker, microCT) using microCT imaging at 50 KV and 800 mA energy, and a 0.25 mm-thick aluminum filter was used with rotational steps of 1° increments for a total rotation of 180° with a 16.65 µm image pixel size.

The degree of homogeneity between the groups, regarding the initial volume, WL, and degree of curvature was assessed and confirmed statistically ($p > 0.05$), indicating adequate paring of NT buccal canals and AT distobuccal canals.

2.5. Root Canal Preparation

An electric motor (X-Smart® Plus, Dentsply Sirona) was used to operate the files with in-and-out pecking motion (2–3 mm amplitude), in a continuous clockwise rotation, according to the manufacturer's recommendations. The number of pecking movements for each file needed to reach the WL and the time that the file was rotating inside the canal until reaching the WL were recorded, using a start-stopwatch. If the file did not reach the WL with 3 pecking movements, the file was removed from the canal to clean the debris from the flutes. During this period, the start-stopwatch was stopped. A glide path was created by using a ProGlider® instrument (PG) (Dentsply Sirona) until the WL was reached. All files from the PTG system (Dentsply Sirona) were used up to the WL in the sequence Sx, S1, S2, F1, and F2 (tip size 25, 0.08 taper). Patency was checked after use of each instrument with a K-file #10 (Dentsply Sirona). For all groups, the instruments were used to prepare only two canals, and after that, they were discharged. Root canal irrigation was performed between each file with 5.25% NaOCl (Cerkamed) using an IrriFlex® 30G needle (PD Dental) inserted in the canal as apically as possible. A total of 25 mL was used to irrigate each canal. After drying the canals with absorbent paper points F2 PTG, a new microCT was performed according to the same scanning and reconstruction parameters as those established initially.

2.6. MicroCT Analysis

Images were reconstructed using the NRecon v 1.7.46 software (Bruker microCT) and superimposed with geometric alignment using the DataViewer v 1.5.6.2 software (Bruker microCT). The CTAnv v 1.20.3.0 software (Bruker microCT) was applied to calculate the quantitative parameters. The region of interest was set for each sample from the furcation region to the apex of the root.

2.7. Total Time of Preparation

The times that each file took to reach the WL (PG and all the files from the PTG system) were added to obtain the total time of preparation needed for each canal.

2.8. Total Number of Pecking Movements

The numbers of pecking movements needed for each file (PG and all the files from the PTG system) to reach the WL were added to obtain the total number of pecking movements needed for the preparation of each canal.

2.9. Root Canal Volume Increase

The initial volume (IV) and final volume (FV) were obtained, the IV being the preoperative volume of the root canals and the FV being the volume of the root canals after the preparation. Based on these values, the root canal volume increase was calculated using the following formula: FV − IV.

2.10. Statistical Analysis

The data collected were processed using the IBM SPSS Statistics vs. 26.0 software, considering a significance level of 0.05 in all situations of statistical inference. Statistical analysis was performed using the Mann–Whitney U-test for 2 independent groups.

3. Results

Table 1 shows the mean, minimum, and maximum values of the total time of the preparation and the total number of pecking movements needed for the NT buccal canals' and the AT distobuccal canals' preparation. No statistically significant differences were observed between the NTs and ATs regarding the time of preparation and number of pecking movements ($p > 0.05$).

Table 1. Mean, minimum, and maximum values of the time of preparation and number of pecking movements for natural tooth buccal canals and artificial tooth distobuccal canals.

Parameter		Natural Teeth	Artificial Teeth
Total time of preparation (s)	Mean Min–Max	64.3 (52–87)	63.5 (51–71)
Total number of pecking movements	Mean Min–Max	33.50 (26–38)	25.86 (12–44)

s, seconds; Min, minimum; Max, maximum.

Table 2 shows the mean, minimum, and maximum values of the initial root volume, final root volume, and root canal volume increase of NT buccal canals and AT distobuccal canals. A statistically significant difference was observed between NTs and ATs ($p < 0.05$) with a higher mean value for NTs; however, it should be noted that, in the group of ATs, there were negative values for this parameter.

Table 2. Mean, minimum, and maximum values of the initial volume, final volume, and volume increase in natural tooth buccal canals and artificial tooth distobuccal canals.

Parameter		Natural Teeth	Artificial Teeth
Initial root canal volume (mm^3)	Mean Min–Max	2.68 (0.52–7.44)	2.70 (2.56–2.82)
Final root canal volume (mm^3)	Mean Min–Max	4.07 (1.42–9.91)	3.40 (2.08–4.15)
Root canal volume increase (mm^3)	Mean Min–Max	1.39 (0.34–2.77)	0.71 (-0.74–1.51)

mm^3, cubic millimeters; Min, minimum; Max, maximum.

Table 3 shows the mean, minimum, and maximum values of the initial root volume, final root volume, and root canal volume increase of the AT mesiobuccal canals to evaluate the effect of the pulp-colored medium. The 3D analysis of the AT mesiobuccal root canal is illustrated in Figure 1 (before tooth preparation) and Figure 2 (after tooth preparation). For the effects of the comparison, Figure 3 (before tooth preparation) and Figure 4 (after tooth preparation) illustrate a mesiobuccal root canal of an NT.

Table 3. Mean, minimum, and maximum values of the initial volume, final volume, and volume increase of artificial tooth mesiobuccal canals.

Parameter		Artificial Tooth Mesiobuccal Root Canal
Initial root canal volume (mm^3)	Mean Min–Max	7.45 (7.00–8.05)
Final root canal volume (mm^3)	Mean Min–Max	6.14 (5.30–7.86)
Root canal volume increase (mm^3)	Mean Min–Max	−1.32 (−2.14–0.86)

mm^3, cubic millimeters; Min, minimum; Max, maximum.

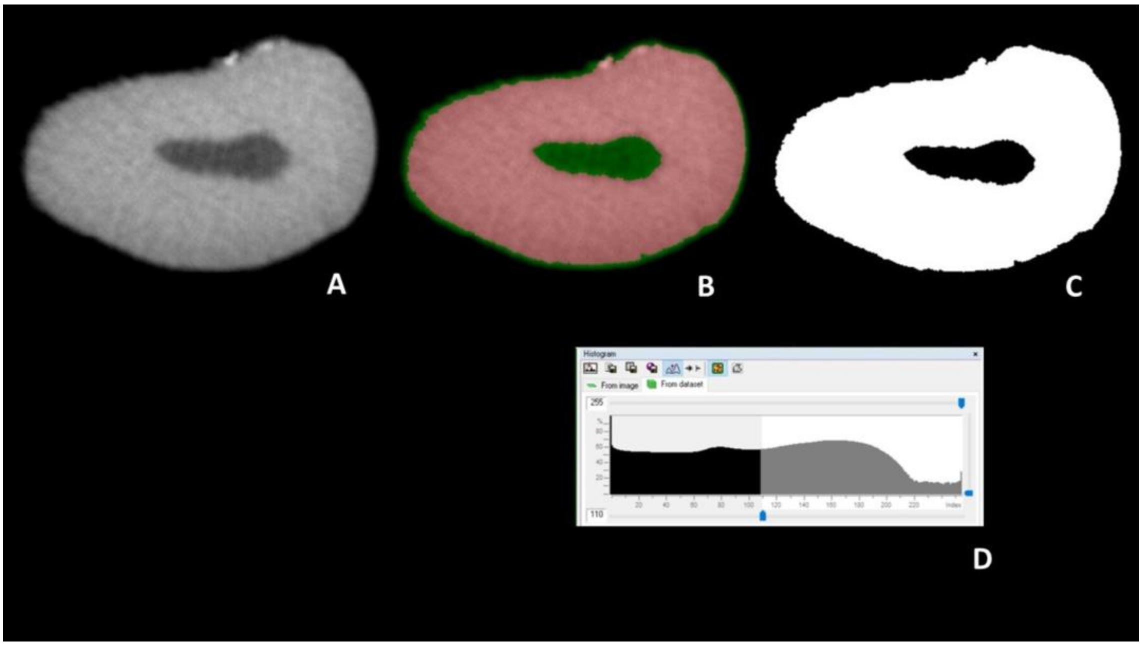

Figure 1. AT mesiobuccal root before instrumentation: (**A**) raw image from microCT dataset; (**B**) image with threshold applied; (**C**) binarized black and white image; (**D**) histogram with selected threshold values.

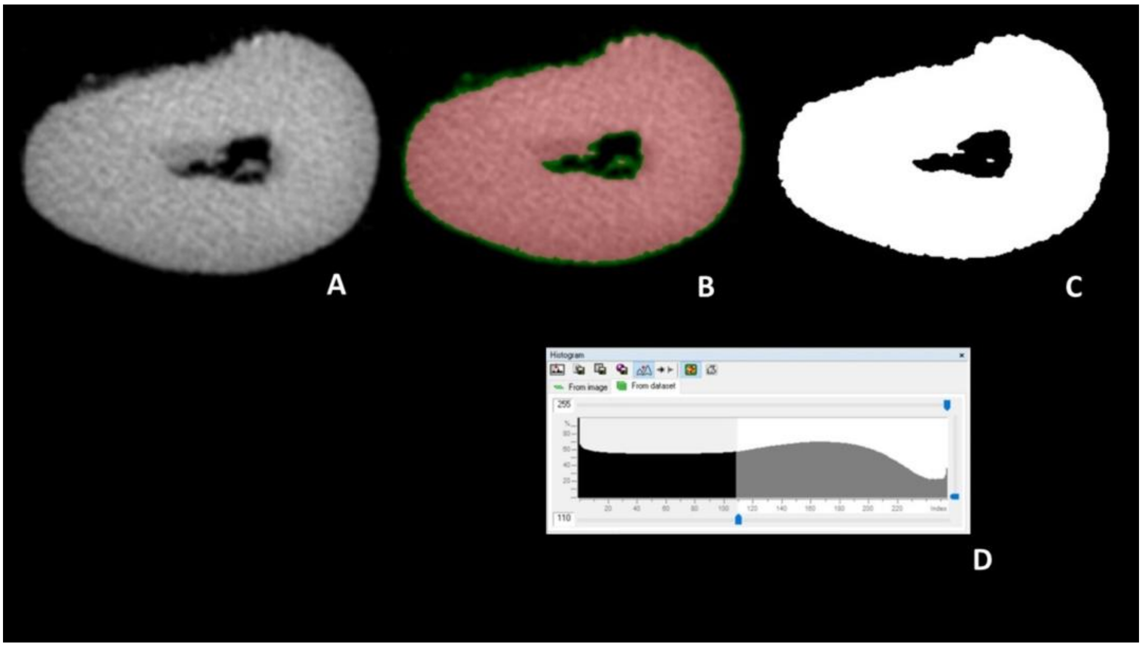

Figure 2. AT mesiobuccal root after instrumentation: (**A**) raw image from microCT dataset; (**B**) image with threshold applied; (**C**) binarized black and white image; (**D**) histogram with selected threshold values.

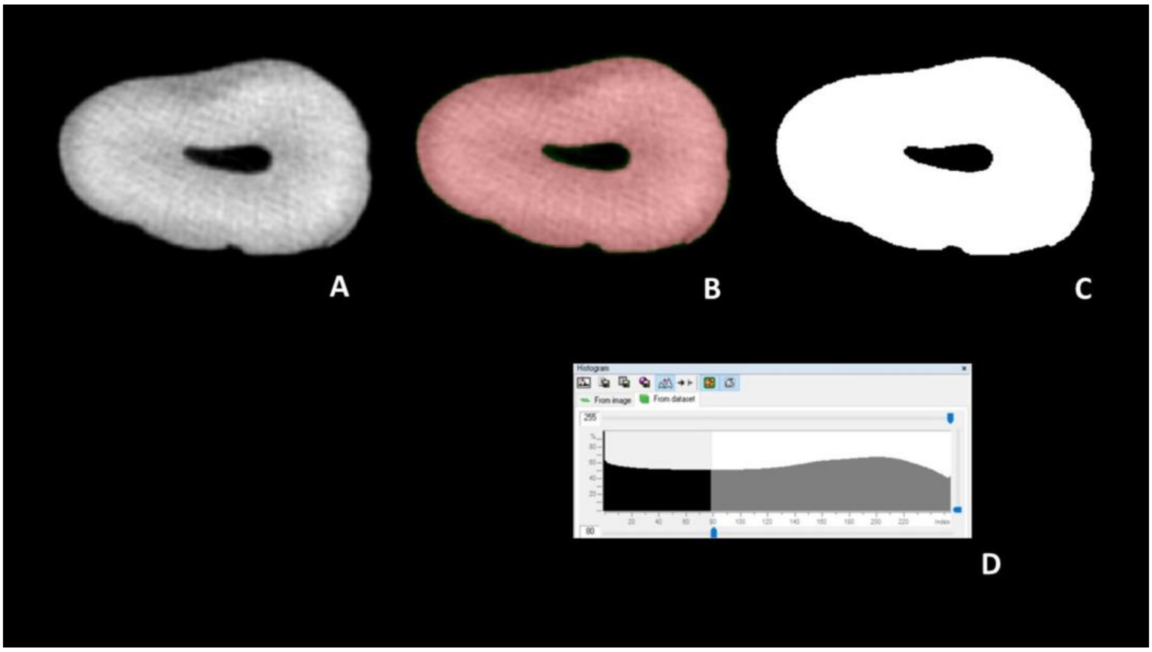

Figure 3. NT mesiobuccal root before instrumentation: (**A**) raw image from microCT dataset; (**B**) image with threshold applied; (**C**) binarized black and white image; (**D**) histogram with selected threshold values.

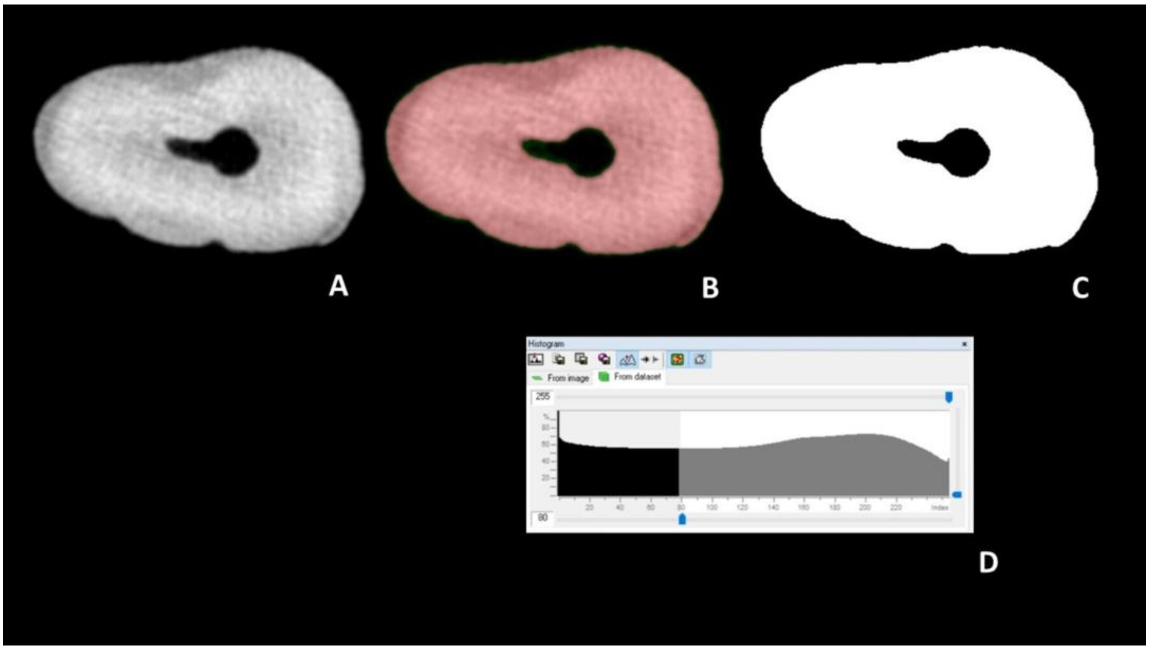

Figure 4. NT mesiobuccal root after instrumentation: (**A**) raw image from microCT dataset; (**B**) image with threshold applied; (**C**) binarized black and white image; (**D**) histogram with selected threshold values.

4. Discussion

The first aim of this study was to evaluate the time and number of pecking movements needed to prepare NT canals versus AT canals. The mean time of preparation for ATs was one second less, and they needed fewer pecking movements for canal preparation. These findings indicate that, although being faster and needing fewer pecking movements to prepare the AT canals, perhaps due to the difference in the hardness between resin and human dentine [7,10,11], there were no statistically significant differences between them. Therefore, we accepted the null hypothesis. This result is in accordance with the results observed in the study of Luz et al. (2015), which compared the difference of the time of preparation needed by students and specialists, using hand-files, between NTs and ATs. They concluded that the time needed to prepare ATs was lower than NTs, in both groups [23].

In this study, the mean value of the preparation time for NTs was 64.3 s with the PTG system, which is less compared to the study of Arslan et al. (2017), which showed a mean value of 78 s. Nonetheless, the authors did not make any reference to whether the glide path was performed manually or mechanically or even if it was performed, and this could explain the difference between the two values [24]. The literature shows that a mechanical glide path is faster than a manual glide path [25,26]; furthermore, if a glide path is not performed, the root preparation time is longer [27].

In the study of Bitter et al. (2016), 43 students were divided in two groups; one group only trained on ATs (TrueTooth®), the test group, and the other on NTs, the control group. The students had to attend a training period, and after this period, both groups prepared an NT and an AT and were evaluated. It was concluded that students solely trained on ATs did not perform significantly different on NTs than those trained on NTs; nonetheless, in general, the performance of students tended to be better on ATs than NTs [9]. Furthermore, in the study of Gancedo-Caravia et al. (2020), students were asked to perform endodontic treatments on different commercial ATs, and then, their outcome was evaluated by three calibrated experienced endodontic educators. The ATs were compared from three perspectives: students' achievements, students' perceptions, and educators' perceptions. The educators considered that replicas obtained from microCT scans better reproduced the internal anatomy, and specifically, TrueTooth® was the best replica for the training of access cavity preparation and negotiation. On the other hand, students rated and performed on TrueTooth® less well due to the greater level of difficulty compared to ATs [5]. The results of these two studies, and the results of the present study, regarding preparation time and the number of pecking movements needed for root canal preparation support that TrueTooth® can potentially be used for endodontic training. However, future studies are needed using different preparation systems, with different geometries and movements of preparation.

The second aim of this study was to evaluate if the root canal volume increase was similar between ATs and NTs. In fact, there was a significant statistical difference between ATs and NTs, the root canal volume increase being higher in NTs. However, as we stated before, after the canal preparation of ATs, some samples showed negative values; this would mean a loss of volume after preparation, and this situation seems absurd. With these results, the null hypothesis cannot be accepted nor rejected, and these results must be observed in conjunction with the results of the 3D analysis of the AT mesiobuccal canal.

Nonetheless, in our study, the mean value for the root canal volume increase in the NT group was 1.39 mm^3. In the literature, the root canal volume increase using the PTG system ranges from 1.33 to 2.77 mm^3 [1,2,28,29]. Nonetheless, it has been shown that variations in canal geometry before preparation may have a greater effect on the observed changes than the preparation techniques themselves [30], and this can explain the differences between the results of the studies.

In a literature review, Reis et al. (2022) reported the problems that 3D-printed teeth still present and the need to answer these problems before these teeth can be used routinely in ex vivo studies. One of the problems presented is the absence of studies that describe a protocol for support material removal and/or the effect of this material on the variables of interest [15]; in this way, our third aim was to assess if the pulp-colored medium had any effect on the 3D analysis by microCT, and it was observed that the mean value of the root canal volume increase was negative, confirming the results of the comparison of the volume increase between ATs and NTs; in this way, the pulp-colored medium had an effect on the 3D analysis. Therefore, we cannot accept the null hypothesis. As illustrated in Figures 1 and 2, the density of the pulp-colored medium, after preparation, was higher than before canal preparation, and its density became like the density of the resin that comprises the root. Therefore, after canal preparation, the 3D analysis software cannot separate and identify these as two different materials. Nonetheless, prior to the preparation, this was possible. This situation did not occur in NTs, as seen in Figures 3 and 4, since the pulp tissue existing in the canals before the preparation is not a confounding material for the 3D analysis software.

To the author's knowledge, there are no studies that have evaluated this feature with microCT, so we cannot compare our results to others. We hypothesized that the density changes may be due to the friction heat of the files rotating inside the canal and that the pulp-colored medium is condensed against the root canal walls in the areas that the files do not touch. This friction heat has been described and used in non-surgical endodontic retreatments [31]. When the results between the AT mesiobuccal and distobuccal canals were compared, the negative results were greater in the mesiobuccal canal; as mentioned before, this is a large ribbon-shaped canal, and it has been reported that oval and long oval root canals are difficult to prepare, because there is a tendency for the file to remain in the center of the canal and not reach all the dentinal walls, which does not allow an adequate preparation [32,33]. This could explain these differences. For a comparison with our results, future studies using TrueTooth® are needed, using, for example, different irrigation protocols, systems, and movements of preparation and also different TrueTooth® replicas with other canal anatomies.

Regarding non-commercial 3D-printed teeth, it was stated that there are no studies that have demonstrated that the internal root canal anatomy is free of support material, and most of the studies did not explain the protocol used for removing it from inside the root canals or even if this was performed [34–39]. In this way, canals could be filled partially or totally with the support material [15]; our findings for this situation pose questions about the results of ex vivo studies that use 3D-printed teeth.

In this way, based on our findings, it is our opinion that ATs, commercial or non-commercial, can be routinely used in future microCT studies without raising these questions about the results' validity, and a prior evaluation of the support material effects should be performed for each type of AT. Since the support material is different in different printing techniques/materials, future studies with 3D-printed teeth should always present a well-described support-material-removal protocol and demonstrate that the ATs used in the respective study are support-material-free or at least demonstrate that the used AT support material has no effect on the variables of interest.

5. Conclusions

There were no statistically significant differences between the time and number of pecking movements between NTs and ATs, so it can be concluded that TrueTooth® is an adequate replica that can potentially be used in endodontic training. There was a significant statistical difference between ATs and NTs, the root canal volume increase being higher in NTs. However, some samples showed negative values, and in the 3D analysis of the AT mesiobuccal canal, the mean value of the root canal volume increase was negative, confirming that the pulp-colored medium had an effect on the 3D analysis.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee (Comité de Ética) of Instituto Asturiano de Odontologia (IAO-23-0104).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy and ethical restrictions (undergoing PhD thesis).

Conflicts of Interest: The authors declare no conflict of interest.

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