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Treatment of Palatally Displaced Canines Using Miniscrews for Direct or Indirect Anchorage: A Three-Dimensional Prospective Cohort Study on Tooth Movement Speed

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Abstract: Palatally impacted canines are usually challenging to treat in terms of both biomechanics and possible side effects. Different therapeutic approaches have been reported with or without the use of temporary anchorage devices, including the canine-first approach. Two groups of patients with palatally impacted canines were compared, observing their canine movement measured on consecutive CBCTs after three months of treatment. In the control group, impacted canines were treated with direct anchorage on miniscrews, and in the test group with indirect anchorage using a miniscrew-supported transpalatal arch. The primary outcome was the canine movement speed; the secondary outcome was the change in the root length of adjacent teeth. The median monthly apex speed was 1.05 mm in the control group (IR [0.74, 1.64]) and 0.72 mm in the test group (IR [0.27, 1.30]). The median monthly cusp displacement was 1.89 mm in the control group (IR [1.04, 2.84]) and 1.08 mm in the test group (IR [0.81, 1.91]). Approximately 50% of teeth adjacent to an impacted canine underwent a negative root length change of less than 1 mm in the majority of cases, but no significant differences were found in root length changes between groups. No statistically significant differences in the reported speeds were found, and no miniscrew failures were observed in either group.

Keywords: palatally displaced canines; miniscrew; CBCT superimposition; impacted teeth; mouth rehabilitation; orthodontic anchorage techniques

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1. Introduction

The second most frequently impacted tooth is the upper canine, considering the third molar as the tooth most frequently associated with impaction [1]. Different therapeutic approaches have been proposed to solve canine impaction, including surgical exposure with or without guided orthodontic eruption [2–6], or other treatment options such as dental autotransplantation. The "canine first" approach could be preferable when side effects such as damage to adjacent teeth should be avoided; Kokick and Mathews already proposed the approach of allowing natural eruption of the impacted cuspid after surgical exposure. This approach was first described by Bishara et al. in 1976 [7,8].

In any case, proper anchorage preparation and management are key factors for efficient canine movement and reducing undesirable changes in the posterior teeth. Skeletal anchorage has been proposed to increase the stability of anchorage unity and to solve canine impaction alone [9], or along with other appliances such as brackets or aligners [10–12]. Miniscrews can be placed either in the inter-radicular space or, alternatively, in the paramedian area of the palate, where high success rates and effectiveness of treatment have been documented [13].

Thus, the primary aim of this study was to quantitatively evaluate the efficiency of the treatment of impacted canines according to the amount of displacement of the impacted canines over time, by comparing two different anchorage units based on the use of temporary anchorage devices: movement of impacted canines directly anchored to the temporary anchorage devices (TADs), or by means of a miniscrew reinforced transpalatal arch (mTPA) with a fully digital 3D-printed structure. The hypothesis of the experiment was the null hypothesis, i.e., that there would be no differences in the descriptors of the movement produced by the analyzed traction systems.

The secondary outcome was the measurement of adjacent root length changes. This evaluation was performed by means of CBCTs' overlap recorded before treatment and during orthodontic therapy.

2. Materials and Methods

2.1. Prospective Controlled Study

The present prospective controlled clinical multicenter study was conducted in two different orthodontics departments: Department of Orthodontics of the Genova University and the Orthodontics Department of Naples University, Federico II. The PICO framework was used to design the study, and the CONSORT checklist was used to report the results.

2.2. Population

Subjects diagnosed with one or more palatally displaced canines in need of orthodontic treatment were enrolled. The subjects were fully informed about the nature of the study, along with the potential risks and benefits of participating in this study, and then they signed an informed consent form. The research protocol was approved by the Ethics Committee of the University of Naples (number 1236/19). The following selection criteria were applied:

Inclusion criteria:

1. Patients of both sexes aged between 12 and 30 years;
2. Presence of one or two palatal maxillary impacted canines, with the need for surgical exposure and orthodontic treatment.

Exclusion criteria:

1. Presence of periodontal disease;
2. Patients with systemic diseases such as arthritis, diabetes, etc.;
3. Pregnant patients;
4. Previous orthodontic treatment;
5. Smokers.

2.3. Intervention

The treatment protocol involved patients whose impacted canines were treated by means of skeletal anchorage. Surgical intervention was similar in all patients and consisted of local anesthesia, mucosal incision, flap design, and osteotomy. Then, the technique varied according to the position of the canine. In cases of superficial impaction, the open technique was preferred to simplify the procedure, while a closed technique was necessary for better access to deeply impacted canines.

A direct button with a chain was bonded to the exposed tooth after surgical exposure with the standard adhesive technique protocol: 30″enamel etching, rinsing, drying, tooth priming, and application of bonding on the button (Transbond XT system, 3M, Maplewood, MN, USA), followed by button positioning and 20″ light curing. In both groups, a force equal to 50 gr of activation was used for canine movement. Strength was measured with a pen orthodontic dynamometer (Dontrix, YDM Corporation, Tokyo, Japan).

2.4. Comparison

Two groups of patients were tested and compared by observing their canine movement measured on consecutive CBCTs. Two different approaches were evaluated: the test group with direct anchorage, and the control group with indirect anchorage.

2.4.1. Test Group (Indirect Anchorage)

Patients were followed at Genova University. One or two miniscrews were placed in the test group after local anesthesia. Titanium type IV miniscrews, with a diameter of 1.7 mm and a length of 8 mm (OrthoEasy® Pal, Forestadent) were inserted in the palate in the area between the first premolar and the first molar. The inclination of the miniscrew was tilted at 45° with respect to the alveolar bone. Pre- and post-insertion radiographs of the interradicular implant sites were taken to check the distance of the screws from the neighboring roots.

Patients were asked if a one-visit protocol was favorable, in which case the miniscrews were placed using a surgical guide and the mTPA was applied immediately after the miniscrew insertion. The TPA design was digitally realized and the structure was 3D printed using the selective laser melting (SLM) approach. Digital miniscrew insertion planning was obtained using a combination of the STL upper arch file superimposed on the CBCT file. One operator imported the maxillary stereolithography (STL) file and CBCT on a dedicated software platform (OnyxCeph3; Image Instruments, Chemnitz, Germany) and matched them. The superimposition procedure included selecting different points on the view of the STL file (e.g., the buccal sides of central incisors, premolars, and molars) and selecting the same points on the CBCT.

One or two miniscrews were then virtually added to the matched file and placed in the area between the first premolar and the first molar. The proper inclination and position were checked using the STL file and the CBCT. The CBCT views were used to control the miniscrew–root distance and the depth of the maxillary bone. Once the project was completed, a new maxillary STL file was generated with holes corresponding to the miniscrews' position, in which the laboratory analogs were successively positioned. The STL file with the miniscrews' position was 3D printed (DentaModel; Asiga, Alexandria, Australia). The first part of the guide was obtained by thermoforming 2.5 mm thick polyethylene terephthalate glycol discs (Erkodur freeze; Erkodent, Cologne, Germany). The thermoformed sheet was cropped to free the space of the screw positions. Afterward, miniscrew analogs were inserted, and the metal sleeves were placed on the analog's head together with the blade used to insert the miniscrews. The last step included using resin (Leocryl; Leone, Sesto Fiorentino, Italy) to fix the metal sleeves to the thermoformed part. The guide was first checked in the patient's mouth to ensure precision and stability.

A digitally designed mTPA with customized bands was anchored to the miniscrews. If a two-step procedure was chosen by the patient, an intraoral scan of the miniscrews' position was obtained with the body scan, which was used to design and adequately create the mTPA. Elastic traction and titanium–molybdenum alloy (TMA) cantilevers were applied to the mTPA and activated to apply a proper force to resolve impaction (Figure 1).

2.4.2. Control Group (Direct Anchorage)

Patients were followed at the Orthodontics Department of Naples University, Federico II. One miniscrew per impacted canine was placed in an area between the first premolar and the first molar, on the buccal side or palatally depending on the position of the canine and the other teeth. The inclination of the miniscrew was tilted at 45° with respect to the alveolar bone, depending on the clinical and anatomical conditions. Pre- and post-insertion radiographs of the interradicular implant sites were taken to check the distance of the screws from the neighboring roots. Under local anesthesia, a type IV titanium miniscrew with a diameter of 1.7 mm and a length of 8–10 mm (OrthoEasy® Pins, Forestadent) was inserted. A TMA 0.019 $\times$ 0.025 cantilever was modeled and applied directly to the miniscrew. The TMA cantilever and the TAD were inserted simultaneously into the patient's mouth immediately after canine exposure and were activated in distalization and extrusion (Figure 2).

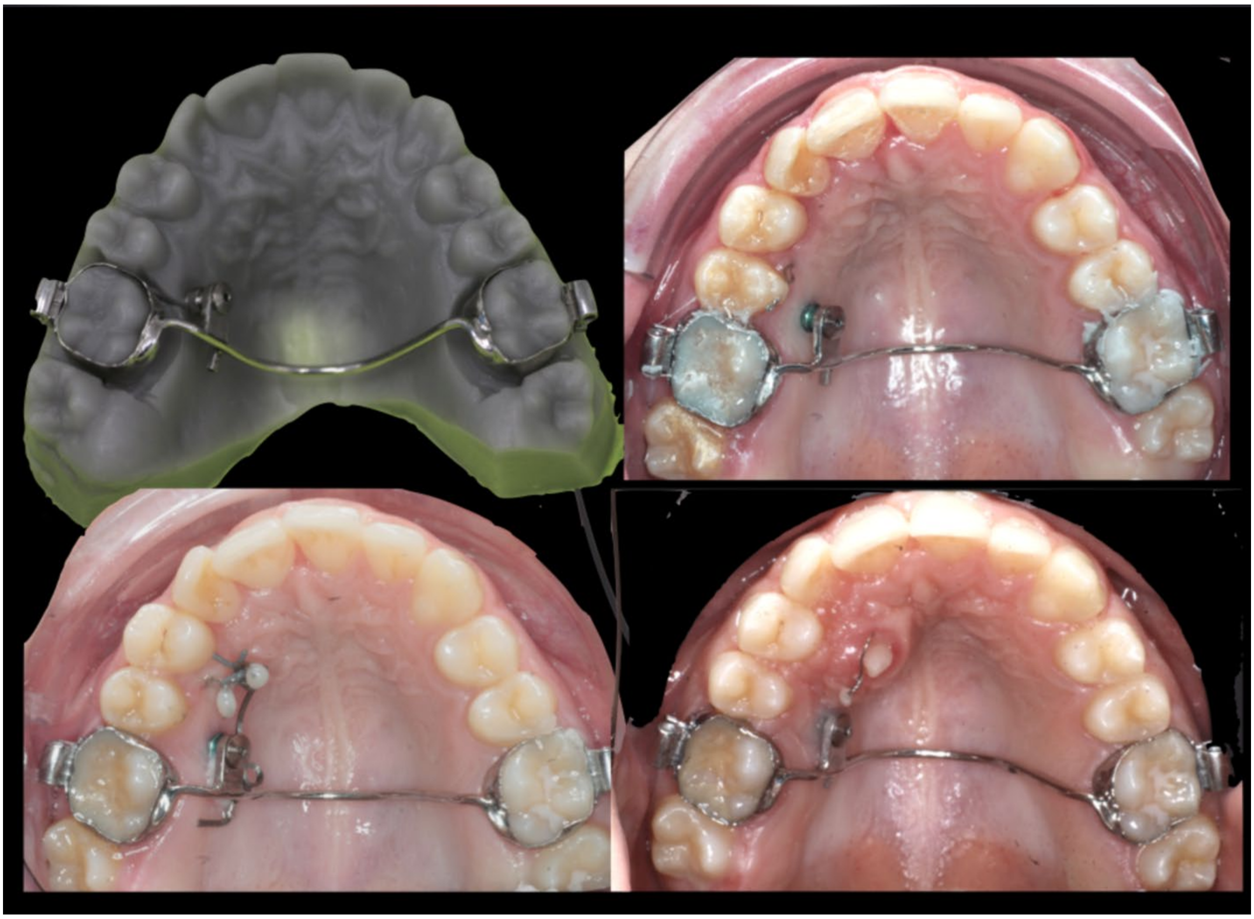

Figure 1. mTPA: indirect anchorage with digitally planned TPA anchored to miniscrews.

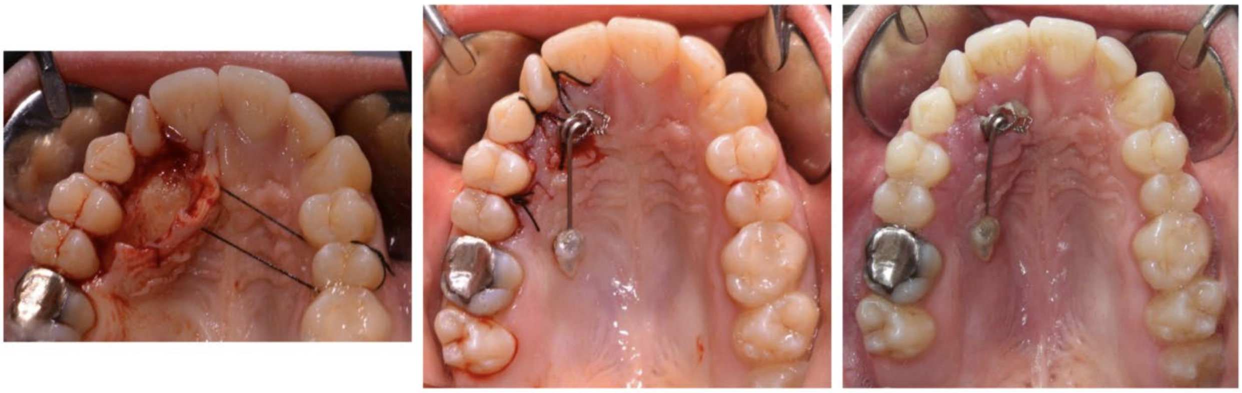

Figure 2. Direct anchorage group.

A first cone-beam CT (CBCT; T0) was required before the surgical exposure of the canine and the beginning of traction to determine the exact position of the impacted tooth as well as to set up the proper biomechanics. A second CBCT was required three months after the start of canine movement. The second cone-beam CT showed the seat and position reached by the canine after three months of traction, or T1.

2.4.3. Evaluation of the Results

A comparison of quantitative canine movement after traction on miniscrews with direct anchorage and on miniscrews with indirect anchorage was the primary outcome.

The secondary outcome was the changes in the root length of adjacent teeth (i.e., lateral incisor and first premolar), using the contralateral teeth where there were no impacted canines as controls for the efficiency of the test approach. This displacement was assessed and calculated by overlapping the cone beams at T0 and T1. The cone-beam overlap method was the same used in a previously published article [14] and was made possible by using the CMF registration module in SlicerCMF (https://sites.google.com/a/umich.edu/dentistry-image-computing/access, accessed on 1 September 2020) and two other software platforms. The superimposition enabled the evaluation of the canine's position before traction and that reached three months from the start. Displacement was therefore assessed by measuring the distance between the apex of the canine at T0 and the apex of the canine at T1, as well as the distance between the cusp at T0 and the cusp at T1.

By superimposing two cone-beam CTs, the same radiological image position of a tooth at two different times was made visible (Figure 3).

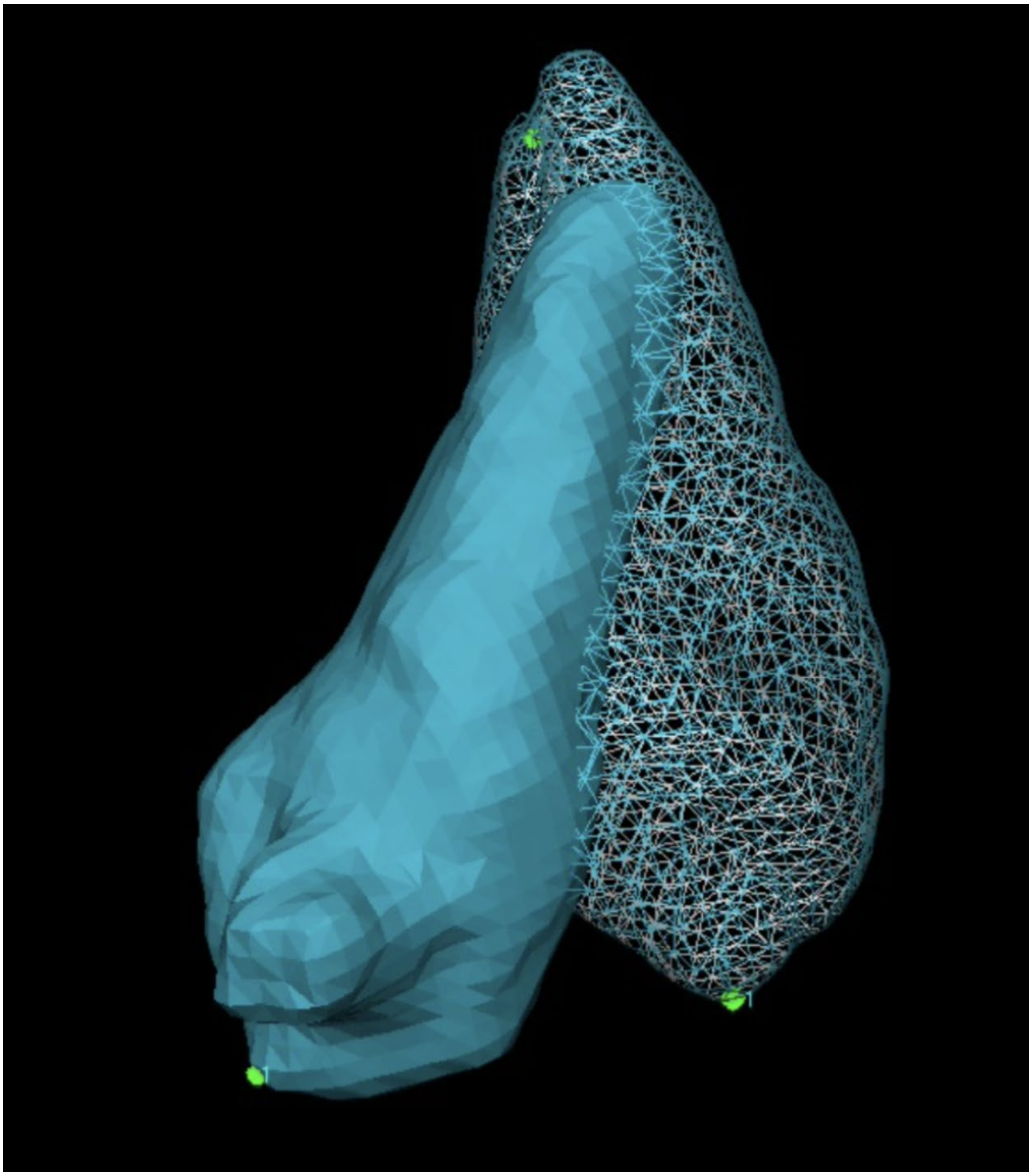

Figure 3. Superimposition and comparison of the same canine before treatment and at T2.

2.5. Sample Size

The sample size estimation calculated that 12 patients would achieve 95% power to detect a mean canine tip displacement difference of 4.3 mm between groups, with an assumed standard deviation of differences of 3.4, and with a significance level (alpha) of 0.05 using a *t*-test. The sample size calculation was performed on the basis of results from a previous study [14].

2.6. Statistical Analysis

Data were analyzed by a statistician and tested for normality with the Shapiro–Wilk test. Continuous variables are given as means with standard deviations (SDs) or as medians with interquartile ranges (IRs), whereas categorical variables are given as numbers and/or percentages of subjects. To evaluate the differences between groups in the duration of observation intervals and the movement of the canine's apex, the Mann–Whitney U test was used. To evaluate the differences between groups in the cusp shift, the two-sample *t*-test was used. To evaluate differences over time in adjacent teeth's root length, the Mann–Whitney U test was used again. Differences with $p < 0.05$ were deemed to be significant.

Data were acquired and analyzed using the R v3.4.4 software environment [15].

3. Results

A total of 35 patients undergoing orthodontic treatment for palatally impacted canines were recruited for this study. The test and control groups included 17 patients each. During the observation period, six patients decided not to undergo a second CBCT, and for another patient a second CBCT was not requested because the canine had already erupted (Figure 4).

A total of 27 patients (mean age: 14.4 ± 1.2 years; 13 M and 14 F) were analyzed in the present study; 13 patients (7 M, 6 F) formed the control group, while 14 patients (7 M, 7 F) were in the test group. Twenty canines in the control group and fifteen canines in the test group were included in the analysis of both apex displacement and cusp displacement. Timespan, apex displacement, and speed are given as medians with interquartile ranges, while cusp displacement is given as the mean (standard deviation). Timespan, displacement, and speed values with a summary of the used tests are reported in Table 1.

Table 1. Median or mean of displacements in each group; *p*-value: Mann–Whitney U test or Student's *t*-test. mTPA: miniscrew with transpalatal arch.

	Control Group (13 Patients, 20 Teeth)	**Test Group (mTPA) (14 Patients, 15 Teeth)**	***p*-Value**
Timespan (days)	85.50 [73.00, 99.00]	130.00 [108.00, 189.00]	<0.001
Apex			
Displacement (mm)	3.09 [2.07, 4.70]	3.32 [1.75, 4.54]	0.868
Speed (mm/day)	0.03 [0.01, 0.04]	0.03 [0.02, 0.05]	0.507
Monthly Speed (mm/month)	1.05 [0.74, 1.64]	0.72 [0.27, 1.30]	0.205
Cusp			
Displacement (mm)	5.71 (3.10)	5.31 (3.50)	0.722
Speed (mm/day)	0.06 [0.03, 0.09]	0.04 [0.03, 0.06]	0.210
Monthly Speed (mm/month)	1.89 [1.04, 2.84]	1.08 [0.81, 1.91]	0.210

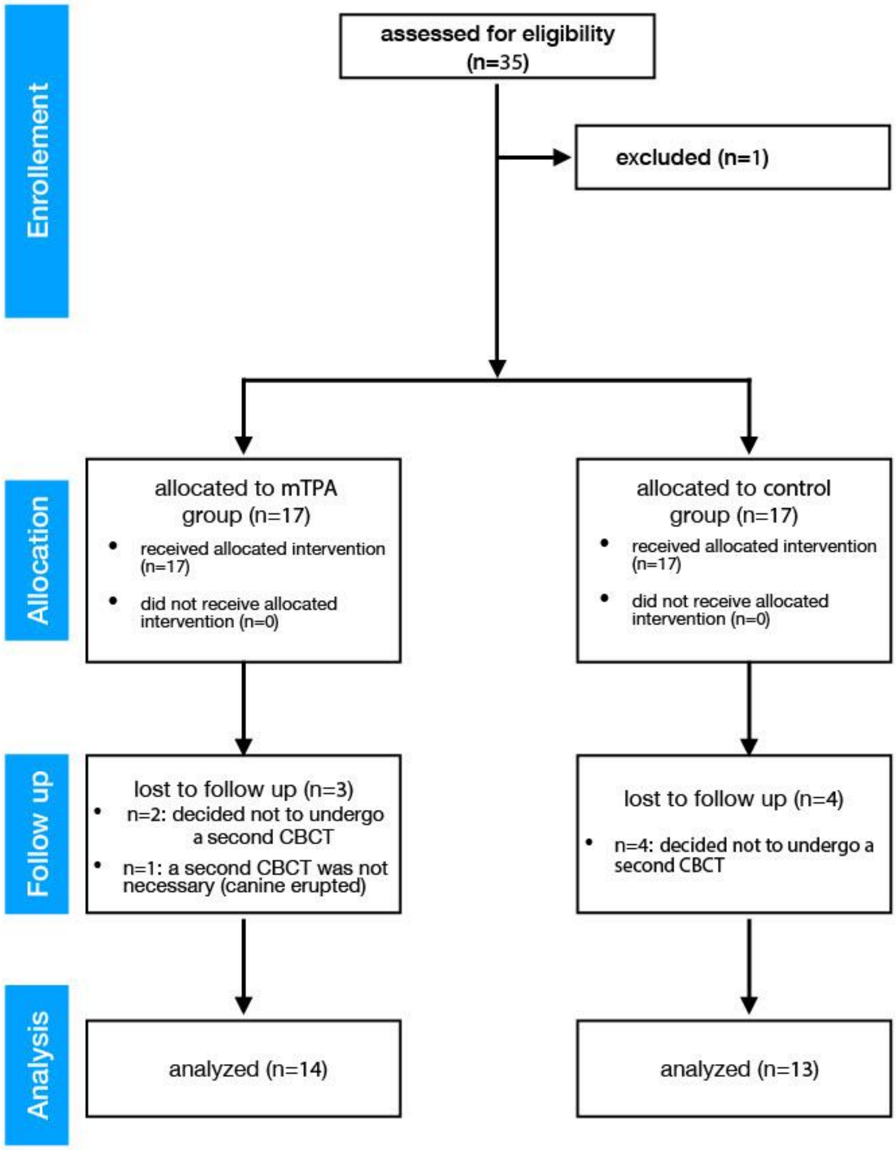

Figure 4. Flowchart of the study.

The median monthly apex speed was 1.05 mm in the control group (IR [0.74, 1.64]) and 0.72 mm in the test group (IR [0.27, 1.30]). The median monthly cusp displacement was 1.89 mm in the control group (IR [1.04, 2.84]) and 1.08 mm in the test group (IR [0.81, 1.91]). No statistically significant differences in the reported speeds were found (Figure 5).

Root length changes were tested on a sample of 58 adjacent teeth; 42 teeth were adjacent to an impacted canine (control group) and 16 teeth were adjacent to a non-impacted canine (test group); 29 teeth of the sample were second incisors, while 29 were first bicuspids. Teeth in the test group showed a median root length change of 0.01 mm, while teeth in the control group showed a median root length change of −0.01 mm; 50% of teeth adjacent to an impacted canine underwent a negative root length change, which was less than 1 mm in the majority of cases, but no significant differences were found in root length changes between the test group and the control group.

No significant differences were found in root length changes between lateral incisors and first bicuspids. No miniscrew failures were observed.

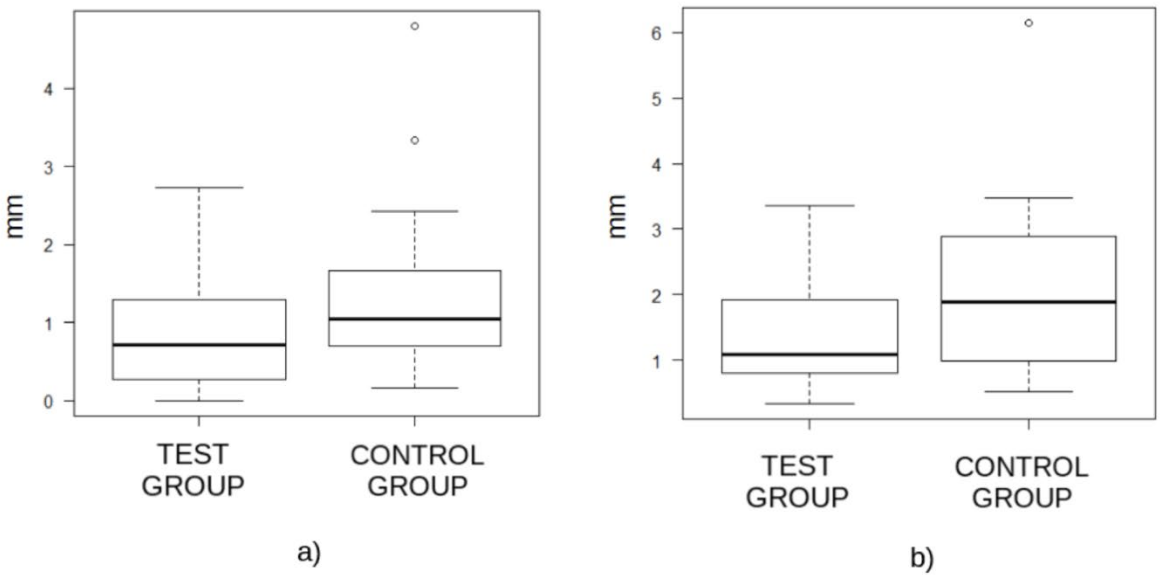

Figure 5. (**a**) Median and interquartile range of monthly apex speed in each group; (**b**) median and interquartile range of monthly cusp speed in each group.

4. Discussion

4.1. Limits of the Study

Participants in the test and control groups were followed up at two different institutions by different clinicians. The analyzed canines were not stratified by classification of the impaction. The present study did not detect possible differences between groups lower than 4.3 mm. The difference in median observation timespan was significant, due to differences in the availability of radiographic resources and the low compliance of patients in repeating the scan at the exact time.

4.2. Interpretation and Generalizability

When approaching the treatment plan for a maxillary impacted canine, one of the most relevant factors to be evaluated is anchorage. Becker et al. [16–18] showed that poor anchorage can be one of the most frequent reasons for impacted canine treatment failure. Poor anchorage indicates a failure in the control of reactive force during orthodontic treatment, causing unwanted tooth movement as well as making the treatment more difficult.

During canine traction, it is also possible to face another side effect: root resorption of adjacent teeth due to the compressive intrusive forces generated or, alternatively, due to incorrect force vector planning [19,20]. Another possible risk during canine traction is orthodontically induced external root resorption (OIRR), as shown by Weltman et al. [20].

For all of these reasons, the canine-first approach with miniscrews as anchorage was proposed [4–6,21–23]. The rationale behind this treatment is to avoid any side effects on teeth adjacent to the impacted canine, including root resorption and undesirable tooth movement. Kokich also reported the "reducing time in orthodontic appliances" as an important factor; in fact, this kind of therapeutic choice could limit the overall treatment time wearing the brackets. Therefore, this approach could be a valid option for the treatment and management of palatally impacted canines, as it allows the first step of the treatment with minimal effort both for the patients and the clinician, and it avoids any possible side effects by using the proper force vectors.

In the present study, all of the impacted canines were successfully treated, and no lesions on adjacent teeth were detectable at T2. Direct anchorage approaches have previously been proposed and represent a valuable method, even though they can present some difficulties in the clinical management—especially for less experienced orthodontists.

mTPA, on the other hand, with a completely digital approach and the use of surgical guides and planning, can result in a useful and efficient alternative.

A previously published study [24] reported a lateral incisor root length reduction of 1.87 mm compared to the untreated side, while in the present study the median reduction was −0.04 (IR [−0.53, 0.10]) mm and 0.01 mm (IR [−0.55, 0.16]) for lateral incisors and first premolars of the treated side, respectively (Table 2).

Table 2. Differences over time in the root length of adjacent teeth (mm, N = 58); *p*-value = Mann–Whitney U test adjusted using the Bonferroni method.

	Minimum	25%	Median	75%	Maximum	*p*-Value
Test Teeth N = 16	−0.10	−0.05	0.01	0.16	0.87	0.207
Control Teeth N = 42	−1.27	−0.54	−0.01	0.12	0.46	
Second Incisor N = 29	−0.78	−0.32	0.04	0.13	0.87	0.608
First Bicuspid N = 29	−1.27	−0.52	−0.03	0.16	0.77	

Both direct and mTPA anchorage resulted in similar values in terms of movement speed for both cusp and root measurements, although a slightly faster movement was detected for the direct anchorage group patients. The direct approach required less preparation, and the miniscrews could be placed on the same day as the exposure intervention and the start of traction. The mTPA requires lab phases and incurs greater costs; on the other hand, the bands can be successively used as part of the multibracket therapy. The mTPA was digitally planned as along with the surgical guide, enabling a one-visit protocol; alternatively, the traditional two-phase approach could be used. All of the TPAs were produced using the SLM technique, resulting in a more rigid structure in comparison to traditional TPAs. The single-miniscrew approach is noteworthy and simple to manage, but it should be noted that some authors prefer the use of two miniscrews to reduce any stability issues due to the activation of the traction [10].

Clinically, both approaches led to the exposure of the impacted canine and successive completion of the orthodontic treatment. The use of a transpalatal bar allowed for simpler use of the cantilevers, as well as removal and substitution if necessary, and the digitally planned bands with buccal tubes could be useful for the final part of canine guidance in the arch if necessary, via the use of labial-directed forces. The single-screw approach, on the other hand, allows for extremely simple management of the movement and less encumbrance for the patient. Both systems showed a 100% success rate in terms of miniscrew survival.

Both approaches showed a 1 mm/month movement speed rate for the root apex and a slightly faster movement for the control group (direct anchorage) in terms of the cusp movement, although this difference was not statistically significant between groups. All canines successfully erupted, and no noticeable side effects were observed.

Three-dimensional (3D) analysis is a powerful tool and can provide significant and detailed information for diagnosis, treatment plans, and the evaluation of results; these significant advantages have already been widely demonstrated in other applications [25,26] and can be reasonably used for further investigations and better understanding of orthodontic therapies.

5. Conclusions

Both direct and indirect anchorage showed stability during the treatment. While taking into account all of the discussed limitations of this study and the observable differences within the present sample, no canine movement speed differences were found between groups. The average movement speed of the impacted canine under a 50-g force varied from a minimum of 0.7 mm/month for the root apex to 1.9 mm/month for the cusp. Adjacent teeth did not show any significant root length changes.

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Institutional Review Board Statement: This study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Ethics Committee of Università Federico II (protocol code 100/19, 10 September 2019).

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

Data Availability Statement: The data underlying this article can be shared upon reasonable request to the corresponding author.

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

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