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Novel Digital Technique to Analyze the Influence of the Operator Experience on the Accuracy of the Orthodontic Micro-Screws Placement

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Abstract: To analyze the influence of the operator experience on the accuracy of orthodontic self-tapping micro-screws placement, a total of 60 orthodontic self-tapping micro-screws were randomly distributed into two study groups: Group A. Orthodontic micro-screws placement by an orthodontist with 10 years of experience ($n = 30$); and B. Orthodontic micro-screws placement by an orthodontist student without experience ($n = 30$). Cone-beam computed tomography scans and intraoral scans were performed before and after the orthodontic self-tapping micro-screws placement and uploaded in 3D implant-planning software to analyze the deviation angle and the horizontal deviation measured at the coronal entry point and apical endpoint between orthodontic micro-screws planned and performed. In addition, intraoperative complications such as root perforations after orthodontic self-tapping micro-screws placement and fracture of the orthodontic self-tapping micro-screws during their placement were also analyzed. The paired *t*-test revealed statistically significant differences at the apical endpoint ($p = 0.004$) of planned and performed orthodontic self-tapping micro-screws between the orthodontist with 10 years of experience and the orthodontist student without experience. However, the paired *t*-test revealed no statistically significant differences at the coronal entry point ($p = 0.220$) and angular deviations ($p = 0.602$) of planned and performed orthodontic self-tapping micro-screws between the orthodontist with 10 years of experience and the orthodontic student without experience. Furthermore, five root perforations were observed in the no experience study group and three orthodontic self-tapping micro-screws were fractured in each study group. In conclusion, the results show that the greater experience of the operator influences the accuracy of orthodontic micro-screws placement, resulting in less intraoperative complications.

Keywords: orthodontics; micro-screws; orthodontic anchorage; mini-implants; temporary anchorage devices

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1. Introduction

In recent years, orthodontics has increasingly focused its interest on temporary anchorage devices (TADs) through orthodontic micro-screws. TADs are widely used in orthodontic therapy due to their feasibility in managing vertical control, sagittal tooth movement, maxillary suture expansion, midline correction, etc. [1,2]. Compared with conventional methods, the high versatility, comfort and easy handling of micro-screws have seen an increase in their use [3]. Orthodontic micro-screws have been manufactured both in titanium and stainless steel alloy; however, stainless steel alloy has been widely recommended because the material alloy does not influence the success rate of orthodontic micro-screws, nor the efficiency, and stainless steel alloy has a lower cost than titanium alloys [4]. Indeed, self-tapping and self-drilling micro-screws are mainly used as TADs thanks to their reported short- and long-term success rates compared to conventional methods in the maxillary buccal area. However, the placement of self-drilling orthodontic micro-screws has been reported to show greater accuracy between interproximal dental roots, which might be explained by the way in which manual insertion allows the clinician to relocalise the direction during self-drilling and subsequent micro-screw placement [5]. Self-tapping orthodontic micro-screws require a pre-drilled hole before inserting a larger micro-screw. This process might increase inaccuracy and potentially risk root perforation [6]. Micro-screws are usually placed in maxillary buccal insertion sites, mainly between the maxillary first molars and second premolars, because this allows a simple and effective technique for managing premolar extraction cases, which also shows a high success rate (90.3%) [7]. In contrast, mandible insertion sites have a lower success rate due to the higher bone density of the mandible that might require the use of self-tapping orthodontic micro-screws to penetrate the cortical bone [8,9]. Papageorgiou et al. [10] reported a 13.5% failure rate related to the micro-screw placement parameters [11,12], type of tooth movement [13,14], anatomical location [1] and the inherent characteristics of the micro-screw itself. In addition, operator inexperience regarding the accuracy and outcome of micro-screw placement remains a concern.

The aim of this work is to analyze and compare the accuracy of micro-screw placement depending on the experience of the operator. The null hypothesis (H_0) states that there is no difference between the operator's experience regarding the accuracy of micro-screw placement and intraoperative complications.

2. Materials and Methods

2.1. Study Design

A randomized controlled in vitro study was conducted on 84 maxillary teeth, extracted for periodontal and orthodontic reasons, which were selected between December 2019 and February 2020 at the Dental Centre of Innovation and Advanced Specialties of Alfonso X El Sabio University (Madrid, Spain). This study followed the principles defined in the statement by the German Ethics Committee on the use of organic tissues in medical research (Zentrale Ethikkommission, 2003), and was authorized by the Ethical Committee of the Faculty of Health Sciences, University Alfonso X el Sabio (Madrid, Spain), in December 2019 (Process No. 04/2019). All patients provided informed consent to transfer the teeth for the study.

2.2. Experimental Procedure

The teeth were embedded into 6 epoxy resin models, (Ref. 20-8130-128, EpoxiCure®, Buehler, IL, USA) each containing 14 teeth. Sixty micro-screws (Dual Top® Anchor System, JEIL Medical Corporation, Guro-gu, Seoul, Korea) (Figure 1A) were randomly distributed (Epidat 4.1, Galicia, Spain) into the following study groups: Group A. Micro-screw placement by an orthodontist with 10 years' experience (*n* = 30); and B. Micro-screw placement by an orthodontic student with no experience (*n* = 30). The age of the study population of group A ranged between 35 to 49 years old (39 ± 4.7 years), while the age of the study population of group B ranged between 23 to 26 years old (24 ± 1.4 years).

A three-dimensional (3D) surface scan was made (True Definition, 3M ESPE™, Saint Paul, MN, USA) with 3D in-motion video imaging technology (Figure 1B). Afterwards, the epoxy resin models (Ref. 20-8130-128, EpoxiCure®, Buehler, IL, USA) were scanned using cone-beam computed tomography (CBCT) (WhiteFox, Acteón Médico-Dental Ibérica S.A.U.-Satelec, Merignac, France) with the following exposure parameters: 105.0 kilovolt peak, 8.0 milliamperes, 7.20 s, and a field of view of 15 × 13 mm (Figure 1C,D). Finally, the datasets from the digital workflow were uploaded to 3D implant planning software (NemoScan®, Nemotec, Madrid, Spain) to allow the ideal virtual planning of the selected orthodontic micro-screws: 1.6 mm diameter, 6.0 mm length active part and an inactive part of 2.3 mm (Ref. 16-G2-008, Dual Top® Anchor System, JEIL Medical Corporation, Guro-gu, Seoul, Korea). The process was achieved by matching the 3D surface scan (True Definition, 3M ESPE™, Saint Paul, MN, USA) and CBCT (WhiteFox, Acteón Médico-Dental Ibérica S.A.U.-Satelec, Merignac, France) datasets by aligning the key points of the dental crowns. The virtual micro-screws were placed at a depth of 6 mm with respect to the cortical plate, and were inserted at an insertion angle of 90° with respect to the longitudinal axis of the teeth (Figure 1E). Subsequently, a single operator (per group) screwed 10 stainless steel alloy self-tapping micro-screws (Dual Top® Anchor System, JEIL Medical Corporation, Guro-gu, Seoul, Korea) into each experimental model according to the recommendations of Cozzani et al. [15].

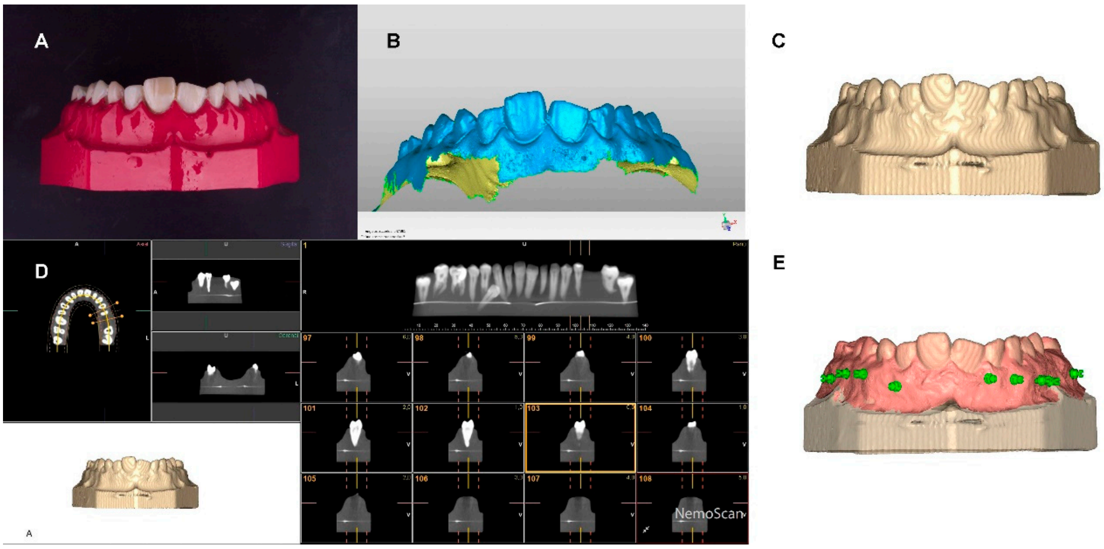

Figure 1. Epoxy resin model with embedded teeth (**A**). standard tessellation language (STL) digital file from the intraoral scanner (**B**), 3D reconstruction (**C**) of the computed tomography (CBCT) scan ("A") occlusal view (**D**) and virtually planned orthodontic micro-screws (**E**).

2.3. Measurement Procedure

With the stainless steel alloy self-tapping micro-screws in place (Dual Top® Anchor System, JEIL Medical Corporation, Guro-gu, Seoul, Korea), postoperative CBCT scans (WhiteFox, Acteón Médico-Dental Ibérica S.A.U.-Satelec, Merignac, France) were taken of the experimental models. Then, virtual micro-screw (Dual Top® Anchor System, JEIL Medical Corporation, Guro-gu, Seoul, Korea) planning and postoperative CBCT scans of the experimental groups were imported to the 3D implant planning software (NemoScan®, Nemotec, Madrid, Spain). Both CBCT scans (WhiteFox, Acteón Médico-Dental Ibérica S.A.U.-Satelec, Merignac, France) were matched to analyze the deviation angle (measured in the center of the cylinder) and horizontal deviation (measured at the coronal entry point and apical endpoint) (Figure 2A–J) by an independent observer.

Root perforations, accidentally caused by the orthodontist with 10 years' experience and the orthodontic student with no experience, as well as self-tapping micro-screw fractures, were analyzed with the 3D implant planning software (NemoScan®, Nemotec, Madrid, Spain) (Figure 3A–I).

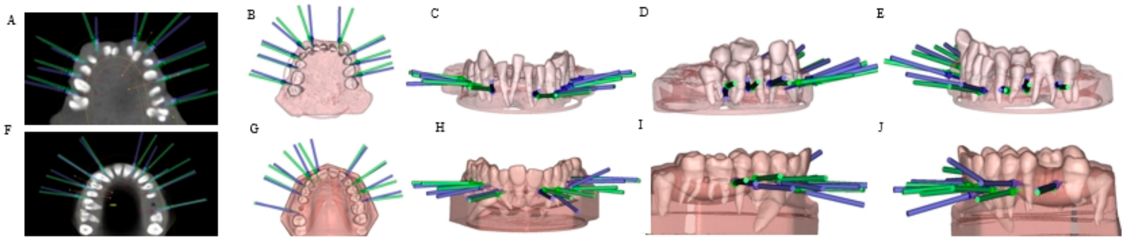

Figure 2. Deviations measurement procedure of the orthodontic self-tapping micro-screws planned (green cylinder) and performed (blue cylinder) by an orthodontic student without experience (**A**–**E**) and by an orthodontic with 10 years of experience in the two study groups (**F**–**J**).

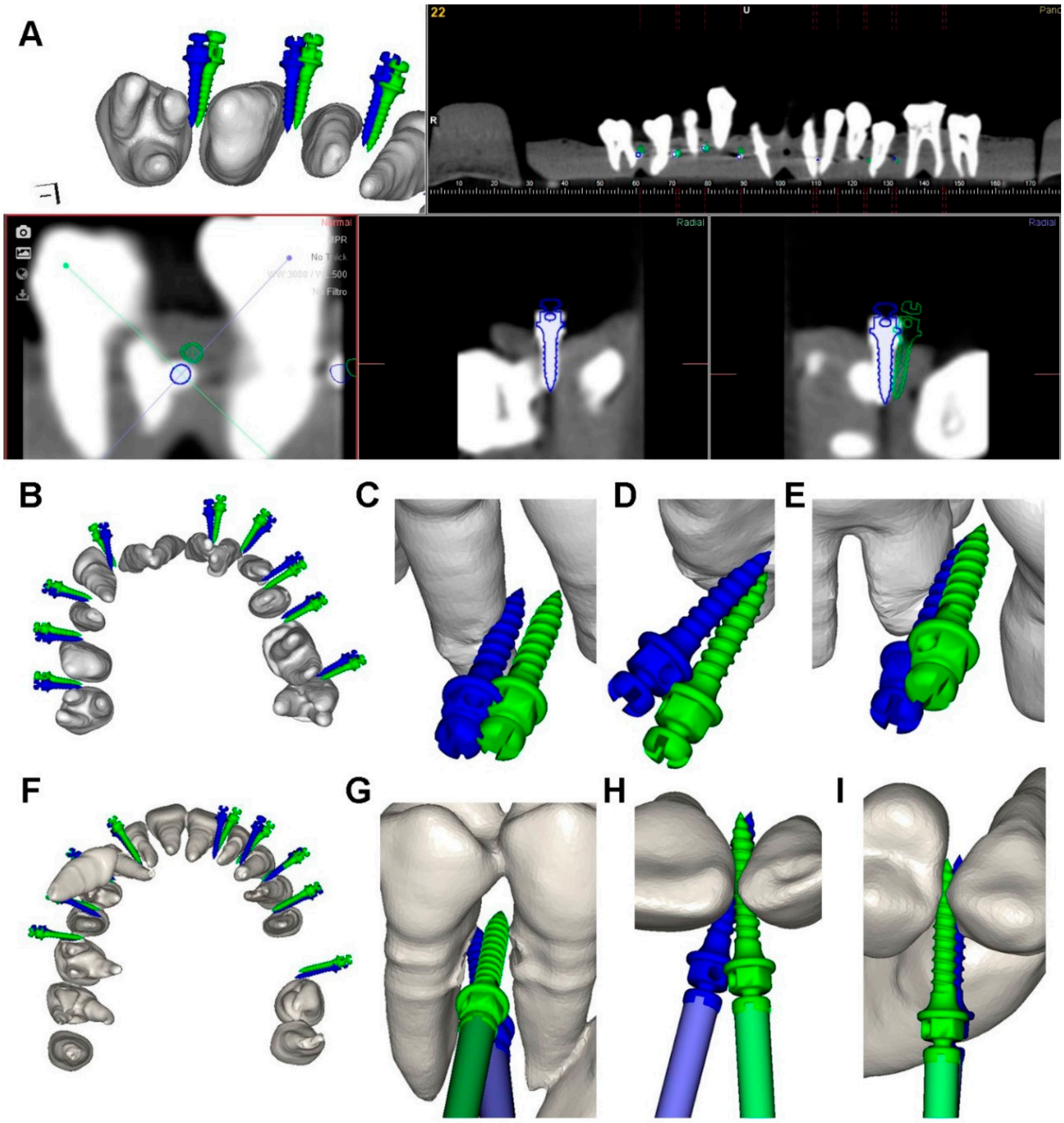

Figure 3. Root perforation analysis at the 3D implant planning software in coronal, saggital and transversal planes (**A**). Detail of the virtual planned orthodontic micro-screw (green micro-screw) and placed orthodontic micro-screw (blue micro-screw) of the orthodontic students without experience study group (blue micro-screw) (**B**–**E**) and the orthodontist with 10 years of experience study group (blue micro-screw) (**F**–**I**).

2.4. Statistical Tests

These variables were statistically analyzed with SPSS 22.00 for Windows. Descriptive statistical analysis was expressed as means and standard deviation (SD) for quantitative variables. Comparative analysis was performed by evaluating the mean deviation between the planned and the placed micro-screws using Student's *t*-test. Since variables showed a normal distribution, $p < 0.05$ was considered statistically significant.

3. Results

The means and SD values for coronal, apical and angular deviation of the orthodontic self-tapping micro-screws are displayed in Table 1.

Table 1. Descriptive deviation values at coronal (mm), apical (mm), and angular (°) levels of the two study groups.

		n	Mean	SD	Minimum	Maximum
Coronal	10 years' experience	30	1.37 [a]	0.43	0.70	1.90
	No experience	30	1.60 [a]	0.34	1.00	2.10
Apical	10 years' experience	30	0.67 [a]	0.25	0.40	1.20
	No experience	30	1.22 [b]	0.42	0.80	2.10
Angular	10 years´ experience	30	6.82 [a]	3.85	2.50	14.30
	No experience	30	8.09 [a]	6.00	1.30	21.00

[a,b] Statistically significant differences between groups ($p < 0.05$).

The paired *t*-test revealed no statistically significant differences at the coronal entry point deviations of planned and performed orthodontic self-tapping micro-screws between the two groups ($p = 0.220$) (Figure 4).

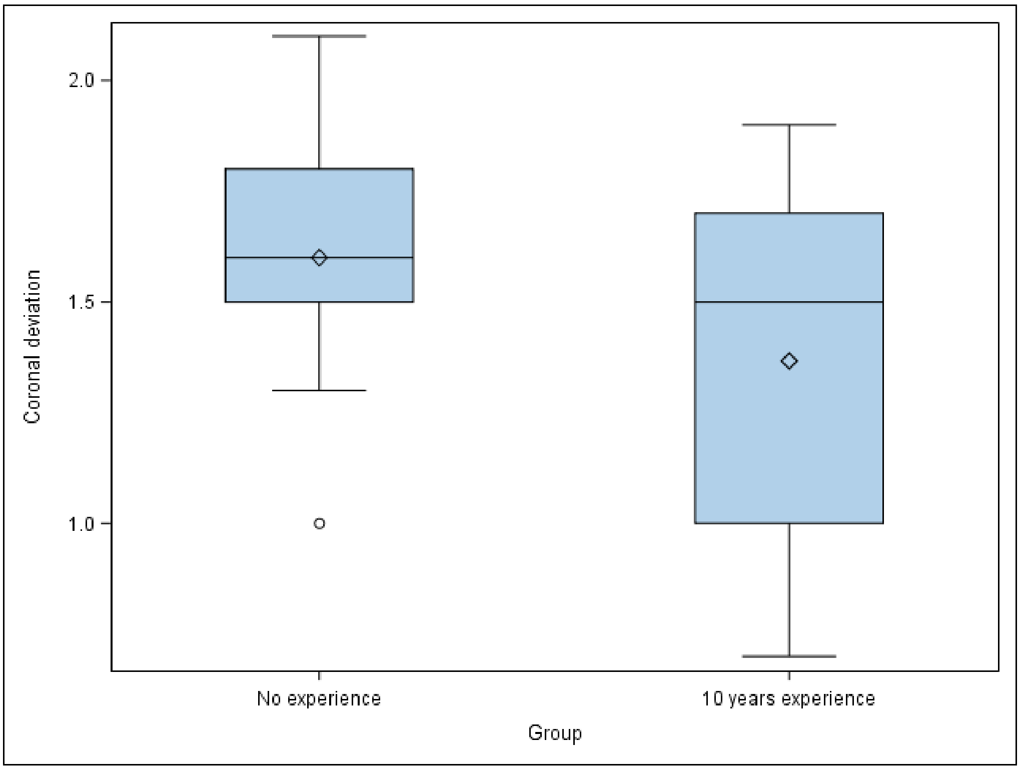

Figure 4. Box plot of the coronal deviations of planned and performed orthodontic self-tapping micro-screws between the two study groups.

However, the paired *t*-test revealed statistically significant differences at the apical end-point deviations of planned and performed orthodontic self-tapping micro-screws between the two groups ($p = 0.004$) (Figure 5).

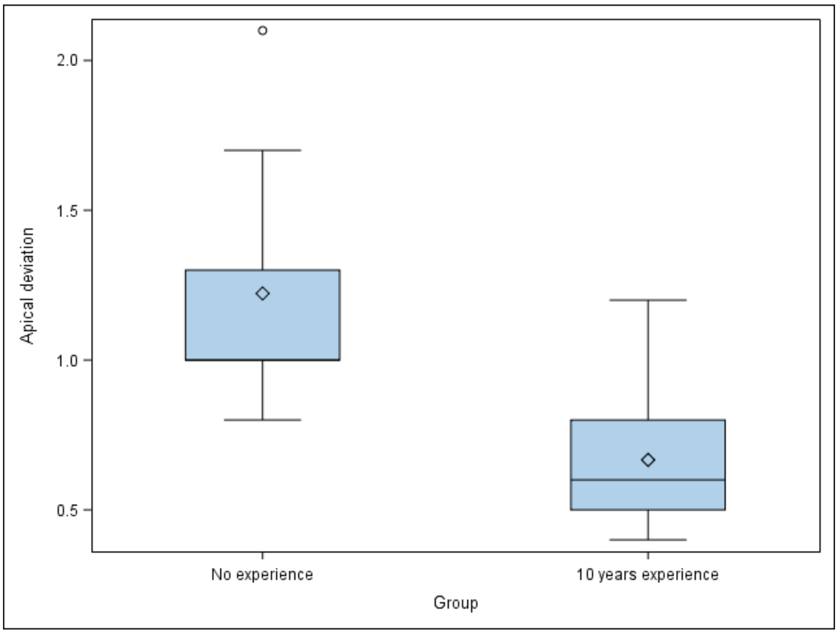

Figure 5. Box plot of the apical deviations of planned and performed orthodontic self-tapping micro-screws between the two study groups.

The paired *t*-test revealed no statistically significant differences at the apical end-point deviations of planned and performed orthodontic self-tapping micro-screws between the two groups ($p = 0.602$) (Figure 6).

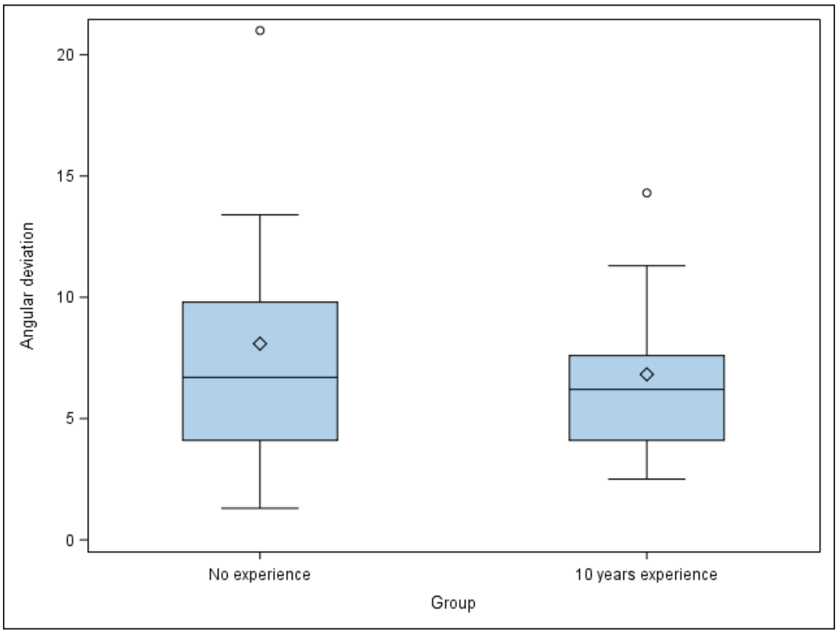

Figure 6. Box plot of the angular deviations of planned and performed orthodontic self-tapping micro-screws between the two study groups.

Five root perforations were observed in the no experience study group after the orthodontic self-tapping micro-screws placement. However, no root perforation was observed in the 10 years' experience study group. In addition, three orthodontic self-tapping micro-screws were fractured during their placement in each of the study groups.

4. Discussion

The results of the present study rejected the null hypothesis (H_0) that states that there would be no difference between the operator's experience regarding the placement accuracy of the micro-screws and the intraoperative complications.

Micro-screws are frequently used to achieve absolute anchorage during tooth movement, and one of the most frequent intraoperative complications is screw loss and pulpal and periodontal ligament damage resulting from root contact [16]. Root contact is described as a potential risk factor for clinical failure of micro-screw anchorage [17]. Because the dental root process becomes narrower and interradicular bone space increases to the apex, an oblique insertion angle is recommended to prevent root perforations. Unlike the vertical insertion angle, the oblique insertion angle also increases the bone-micro-screw contact surface and micro-screw stability [18]. However, Drescher et al. reported that an oblique insertion angle might influence the accuracy of orthodontic micro-screws' placement and hence could increase the risk of intraoperative complications [19]. Furthermore, the oblique insertion angle could lead to the exposition of the orthodontic micro-screw head over the mucous, which could increase dental plaque accumulation. In addition, Noble et al. reported that oblique insertion angles of orthodontic micro-screws might require a higher cortical bone penetration, which might increase the tension at the bone-micro-screw interphase, increasing the tooth movement and promoting release of cytokines, macrophages and inflammatory mediators, which could affect the stability and hence the survival of orthodontic micro-screws [20]. Nevertheless, Perillo et al. recommended placing the micro-screw at an angle of 90° to prevent dental root perforations, increasing orthodontic micro-screws primary stability [21], but Poggio et al. reported that an angle between 30–40° reduces the risk of root contact and allows the placement of longer orthodontic micro-screws, which influences their stability [22]. Pickard et al. reported that the insertion angle also influences the mechanical resistance of orthodontic micro-screws and concluded that orthodontic micro-screws of 1.8 mm diameter and 6.0 mm length placed at an insertion angle of 90° with respect to the longitudinal axis of the teeth showed higher resistance values than orthodontic micro-screws placed at 45° with respect to the longitudinal axis of the teeth [23]. Cozzani et al. agreed with the above results and concluded that the optimal insertion angle for Jeil orthodontic micro-screws was within 90°, according to its characteristics [15]. This is why the Jeil orthodontic micro-screws in our study were placed at an insertion angle of 90° with respect to the longitudinal axis of the teeth.

Suitable locations for orthodontic micro-screws placement should be analyzed preoperatively through radiographic techniques to avoid intraoperative complications and ensure orthodontic micro-screws' stability and retention. Schnelle et al. analyzed the inter-radicular insertion locations through orthopantomography scans and reported that orthodontic micro-screws of 1.2–2 mm diameter could be placed safely at 3–4 mm inter-radicular spaces, leaving 1 mm of bone tissue around the orthodontic micro-screw and avoiding dental root damage [24]. Tepedino et al. described the interradicular width of maxillary and mandible teeth to analyze the potential risk of dental root damage during orthodontic micro-screws placement and reported that interradicular spaces of 3 mm width were usually located in the upper anterior teeth (mainly between central incisors and lateral incisors and canines) and in the lower posterior teeth (mainly between first and second molars and between the first molars and the second premolars) [25]. In addition, Poggio et al. reported that the interradicular width was usually wider and considered safer at the apical root third [22]. However, dental crowding is a concern and might condition the orthodontic micro-screws placement election site. In addition, Landin et al. compared the influence of blind placement, preoperative periapical radiographs, orthopantomography scans and small-volume CBCT scans on the outcome of orthodontic micro-screws placement and reported that the preoperative evaluation of placement using small-volume CBCT scans significatively reduced the risk of dental root perforation [26]. In our study, a CBCT exam was also used to analyze the suitable position of orthodontic micro-screws placement to avoid the risk of dental root perforation. Furthermore, Al Samak et al. reported the relevance of cortical bone width on the primary stability of orthodontic micro-screws and highlighted the use of CBCT scans to measure this parameter [27].

Dental root damage is considered an undesirable intraoperative complication related to orthodontic micro-screws placement that might lead to loss of the orthodontic micro-screws and a possible dental root complex injury. Ghanbarzadeh et al. reported that most of the dental root perforations performed through self-tapping and self-drilling orthodontic micro-screws showed reparative cementum formation, while 24.5% of the dental root process perforations did not show histological signs of tissue reparation. However, all teeth maintained pulp tissue response within the normal range [28]. Gurdan et Szalma reported a success rate for Jeil self-drilling orthodontic micro-screws of 89.8% for an average loading period of 8.1 months; however, the authors related the failure rate of orthodontic micro-screws to the anatomic location placement [29]. In addition, previous studies reported a higher bone-micro-screw contact and therefore initial stability and higher success rate of self-drilling orthodontic micro-screws, compared to self-tapping orthodontic micro-screws [30–32]. The accuracy of orthodontic micro-screws is a concern and the outcome might improve significatively with stereolithographic surgical guides based on CBCT scan [16]. Postoperative bleeding has been reported an incidence in patients with comprised haemostasis after oral surgery [33]; furthermore, Kim et al. [34] and Ziebura et al. [35] described gingival bleeding as a complication associated with orthodontic micro-screws placement; additionally, Simurda et al. highlighted the influence of von Willebrand´s disease on the incidence of postoperative bleeding in patients with haemostasis disorders submitted to surgical procedures [36]; therefore, De Padua et al. recommended the application of plasma-derived, von Willebrand Factor (VWF)-containing Factor VIII concentrate (pdVWF/FVIII) to prevent peri- and post-operative bleeding after invasive oral procedures [37].

Operator experience has been shown to influence the accuracy of orthodontic micro-screws placement, increasing the risk of dental root damage and orthodontic micro-screw loss; however, further clinical studies are necessary to analyze the outcome and clinical complications.

5. Conclusions

In conclusion, within the limitations of this in vitro study, the results show that the experience of the operator influences the accuracy of stainless steel alloy orthodontic micro-screws placement, resulting in less intraoperative complications.

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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 high size.

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

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