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RESEARCH ARTICLE

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Automated artificial intelligence-based three-dimensional comparison of orthodontic treatment outcomes with and without piezocision surgery

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Abstract

Objective(s): This study aims to evaluate the influence of the piezocision surgery in the orthodontic biomechanics, as well as in the magnitude and direction of tooth movement in the mandibular arch using novel artificial intelligence (AI)-automated tools.

Materials and Methods: Nineteen patients, who had piezocision performed in the lower arch at the beginning of treatment with the goal of accelerating tooth movement, were compared to 19 patients who did not receive piezocision. Cone beam computed tomography (CBCT) and intraoral scans (IOS) were acquired before and after orthodontic treatment. AI-automated dental tools were used to segment and locate landmarks in dental crowns from IOS and root canals from CBCT scans to quantify 3D tooth movement. Differences in mesial-distal, buccolingual, intrusion and extrusion linear movements, as well as tooth long axis angulation and rotation were compared.

Results: The treatment time for the control and experimental groups were 13.2 ± 5.06 and 13 ± 5.52 months respectively ($P = .176$). Overall, anterior and posterior tooth movement presented similar 3D linear and angular changes in the groups. The piezocision group demonstrated greater ($P = .01$) mesial long axis angulation of lower right first premolar ($4.4 \pm 6°$) compared with control group ($0.02 \pm 4.9°$), while the mesial rotation was significantly smaller ($P = .008$) in the experimental group ($0.5 \pm 7.8°$) than in the control ($8.5 \pm 9.8°$) considering the same tooth.

Conclusion: The open source-automated dental tools facilitated the clinicians' assessment of piezocision treatment outcomes. The piezocision surgery prior to the orthodontic treatment did not decrease the treatment time and did not influence in the orthodontic biomechanics, leading to similar tooth movements compared to conventional treatment.

KEYWORDS
cone beam computed tomography, Damon system, dental long axis, image processing, computer-assisted, imaging, three-dimensional, self-ligating braces

1 | INTRODUCTION

The high prevalence of malocclusions combined with patient's self-awareness of the importance of good oral health and the increased aesthetic requirements from society has led to an increase in the demand for orthodontic treatment.[1–3] To address patients' expectations of shorter orthodontic treatment times, particularly in areas with challenging biomechanics such as the mandibular arch, which demonstrates smaller rate of tooth movement than the maxillary teeth,[4,5] the piezocision has been proposed as a minimally invasive technique for accelerating tooth movement and allowing for faster soft tissue healing.[6]

Piezocision consists of cuts in the cortical bone with the use of a piezotome, preserving soft tissues, nerves and blood vessels and allowing faster soft tissue healing.[7] The cortical bone cuts performed with the piezocision aim to induce a healing and remodelling process in bone at the surgical site. Previous studies indicate that piezocision increases blood flow, transferring inflammatory mediators such as cytokines, neurotransmitters and growth factors, which lead to induced remodelling of the bone. This process may accelerate tooth movement through regional acceleratory phenomenon.[8–11]

Even though studies have reported that piezocision shortens orthodontics treatment time,[6,12,13] the literature still shows controversial results.[14,15] In addition, the influence of this procedure in the teeth responses to orthodontic forces (biomechanics), as well as changes in the amount and direction of orthodontic three-dimensional tooth displacement remains unknown.

Cone beam computed tomography (CBCT) and intraoral scans (IOS) allow complementary imaging information when assessing skeletal and dental changes.[8,15,16] CBCT is a useful tool to generate craniofacial images with adequate resolution, allowing a precise evaluation of anatomical structures including dental roots and root canals.[16] The IOS is a non-invasive imaging tool that provides a real-time digitally accurate and well-detailed impression of the dental crowns.[17,18]

However, both imaging modalities have limitations. While in CBCT scans the visualization of dental crowns is not accurate due to partial volume averaging, possible metallic artefacts and dental intercuspation during the image acquisition, the IOSs do not allow evaluation of the dental roots. The integration of these image modalities may optimize its diagnostic value, granting researchers and clinicians a comprehensive and enhanced analysis of the roots, root canals and crowns,[12,17–20] also aiding in critical tooth position assessments. Additionally, the advent of innovative artificial intelligence (AI)-based tools[19–26] have facilitated merging root canals and crown segmentations, as well as automatic placement of landmarks and quantification of tooth movement.

Therefore, the aim of this study was to evaluate, using novel AI-automated dental tools, the effect of the piezocision surgery on orthodontic biomechanics in the mandibular arch and whether it changes the magnitude and direction of tooth movement by evaluating the tooth rotation, long axis angulations and linear three-dimensional (3D) changes.

2 | MATERIALS AND METHODS

2.1 | Study design and ethics

This retrospective secondary data analysis from a clinical trial performed in the University of CES was approved by the University of Michigan Institutional Review Board (HUM00233815). Forty patients aged from 18 to 40 years with Angle's Class I and mild Class II or III malocclusion, adequate periodontal health and dental mild to severe crowding malocclusion, with little index from 1.81 to 14.61 mm, were included in this study. All patients were treated by an Orthodontist of the University of CES with self-ligating appliance. Twenty patients received the piezocision surgery immediately before treatment and were assigned to the experimental piezocision group, while 20 patients did not undergo piezocision and were assigned to the control group. The patient allocation to the groups was performed through a randomized draw. Patients with missing data that could interfere with the secondary 3D analysis were excluded, resulting in the exclusion of one patient from each group. Therefore, a total of 38 patients were selected: control (n = 19) and piezocision (n = 19). Based on the study of Kiling and Baka,[27] who reported a little's irregularity index variation of 7.6 ± 1.5 in patients that performed piezocision, this sample will provide 95% confidence interval and at least 95% power.

2.2 | Study protocol

2.2.1 | Piezocision

Before performing piezocision, a comprehensive orthodontic evaluation was conducted to determine if the technique is suitable for the patients. This includes assessing the patient's overall oral health and their treatment interest. The procedure was planned with a multidisciplinary team composed by an experienced orthodontist, oral surgeon and periodontist. The treatment plan outlines the specific teeth that require accelerated movement and the locations for the incisions. The surgical bone cuts procedures were conducted under local anaesthesia in all the patients from the experimental group before starting the orthodontic treatment. In order to perform the piezocision, gingival vertical interradicular incisions were initially performed on the buccal surface of the attached gingiva in the lower arch from the right to the left first molar. The incisions started from 2 to 3 mm beyond the interdental papilla until the scalpel reached the depth of the cortical bone. Lastly, a piezotome was inserted through each incision, penetrating in 1–2 mm of the buccal cortex thickness. After the surgery, no suture was needed and all the patients were instructed about oral hygiene. Follow-up appointments were scheduled with 1 and 2 weeks after the procedure to monitor the progress of tooth movement and ensure that healing is proceeding as expected.[15]

2.2.2 | Orthodontic treatment

All patients were orthodontically treated with passive self-ligating bracket system (Damon SL; Ormco, Orange, Calif). For both groups, the wires were changed when no deflection was observed during the insertion in the brackets and the same sequence of arch wire was performed: Copper-nickel-titanium 0.014″, 0.018″, or 0.014″ × 0.025″ and 0.018″ × 0.025″; beta titanium (TMA) 0.017″ × 0.025″ and stainless steel 0.017″ × 0.025. The treatment time for the control and piezocision groups were 13.2 ± 5.06 and 13 ± 5.52 months respectively.

2.2.3 | Imaging data

CBCT and IOS were obtained before (T1) and after (T2) the orthodontic treatment. The CBCT scans were acquired using the Veraviewepocs 3D R100 (J Morita Corp, Tokyo, Japan) according to the following acquisition protocol: 90 kV; 3–5 mA; 0.16 mm^3 voxel size; scan time, 9.3 s; and field of view of 100 × 80 mm. Two CBCT scans were acquired from the subjects in this study. The acquisition protocol was adjusted following radiology ALADAIP (As Low As Diagnostically Acceptable being Indication-oriented and Patient-specific.) principles to minimize the radiation dose to patient and surroundings to a level as low as reasonably achievable.[28] During the CBCT acquisition, all patients were awoken with Camper's horizontal plane parallel to the ground and were not occluding. All images were stored in Digital Imaging and Communications in Medicine (DICOM) files. The IOSs were acquired with the TRIOS 3D intraoral scanner (version 1.3.4.5; 3 Shape, Copenhagen, Denmark) with an accuracy of 6.9 ± 0.9 μm, following the manufacturer's instructions. All digital models were stored as stereolithograph (STL) files.

2.2.4 | Variables

This study analysed demographic, cephalometric baseline data, treatment time, as well as 3D tooth movement in the mandibular arch: mesiodistal and buccolingual long axis angulation; mesiodistal rotation; mesiodistal, buccolingual, extrusion/intrusion linear and 3D scalar displacement.

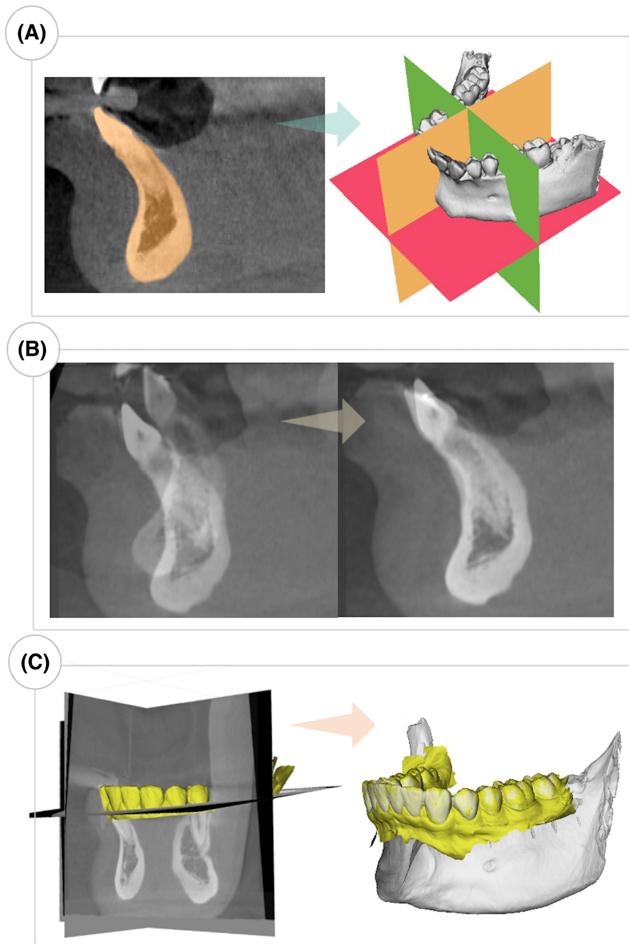

FIGURE 1 Semi-automated tools to CBCT and IOS imaging pre-processing. A, T1 orientation of the CBCTs scans and segmentations. B, T2 registration according to the T1 CBCTs oriented. C, Registration of T1 and T2 IOSs according to the T1 CBCTs oriented and T2 CBCTs registered respectively.

2.2.5 | Image processing

All CBCT imaging data from T1 and T2 were automatically anonymized and converted into single NIfTI files, using the 'SlicerBatchAnonymize' extension from the Slicer software, version 5.2.2 (www.slicer.org), while all IOS STL files were converted to vtk files using the same software. The image pre-processing included T1 CBCT orientation,[15] T2 registration,[29] as well as T1 and T2 IOS registration to the CBCT scans[30] with validated semi-automated tools (Figure 1) and completely automated tools (Figure 2).[8,19–24,26,31,32]

The T1 CBCTs orientation was performed positioning the mandibular 3D model as follows: The lower border of the mandible, mesial surface of first molars and midline were aligned, respectively, with the axial, coronal and sagittal axis.[15] Subsequently, the T2 CBCT images were manually approximated to the T1 images and a voxel-based registration was performed.[30] The coordinate matrix from the CBCTs orientation and registration were applied to the scans and segmentations, which were later converted in 3D models, allowing the IOS registration. The IOS models were

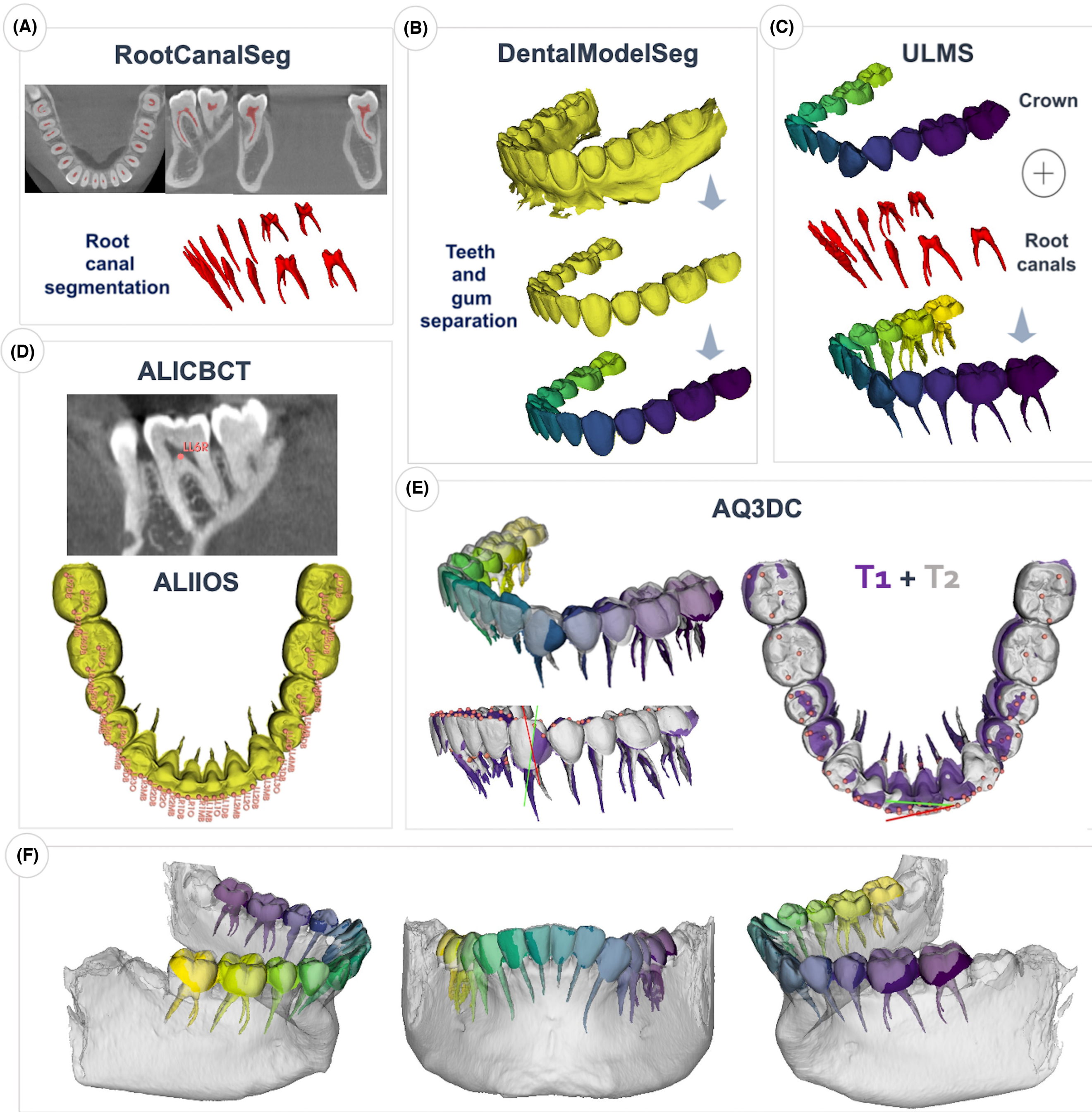

FIGURE 2 Automated tools to CBCT and IOS imaging processing. A, CBCT segmentation of the root canals. B, Crown and gingiva IOS segmentation. C, Merging of the CBCTs root canals with the IOS crowns. D, CBCT and IOS automated landmark identification. E, Automated quantification of the tooth movement. F, Superimposition of the IOS and merged root canals with the CBCT scan 3D model.

registered with their respective T1 and T2 CBCT 3D models from the scans using occlusal landmarks and the surface registration[30] model in the Slicer software, version 5.2.2 (https://www.slicer.org/).

After CBCT and IOS orientation and registration steps, the 3D models of the root canals present in the CBCT images and teeth crowns from the IOS were merged, allowing the model superimposition, landmark placement, evaluation and quantification of the tooth long axis changes between T1 and T2 (Tables S1–S3).

2.3 | Study error

To avoid potential sources of bias, the landmark placement procedure was repeated three times with an interval of 15 days. Systematic errors were evaluated with the intraclass correlation coefficient (ICC) and Bland–Altman test. The Jamovi software, version 2.3 was used for the analyses.[33] The ICC values ranged from 0.85 to 0.99 mm and 0.82 to 0.99°, indicating excellent intraexaminer repeatability of the landmarks for angular and linear measurements. The Bland–Altman method was also performed, revealing strong agreement in the intra-examiner measurements. The estimated bias was small (0.003 mm and 0.1°), indicating a positive agreement, while the 95% confidence interval for the bias ranged from −0.02 to 0.03 mm and from 0.1 to 0.4°, demonstrating a close level of agreement.

2.4 | Statistical approach

The data were stored in Microsoft Excel and exported to the Jamovi software, version 2.3,[33] in which the analyses were performed adopting 95% confidence intervals. The normality of the outcomes was evaluated with the Shapiro-Wilk test. The parametric data was analysed with Student's *t*-test, while the non-parametric data with the Mann-Whitney *U* test. To adjust the *P*-values for multiple testing, the Bonferroni correction was applied by multiplying each *P*-value by the total number of variables ($P \times 98$). All the data were expressed as the mean and standard deviation.

3 | RESULTS

3.1 | Sample characteristics

The mean age of the patients in the control and piezocision groups was 24.9 ± 5.3 and 26.4 ± 7.3 years respectively. The control group showed sex distribution of six females and 13 males, while the piezocision showed a distribution of four females and 15 males. This distribution was not statistically different between the groups ($P = .461$). Regarding the treatment time, the groups did not differ ($P = .918$). Moreover, none of the cephalometric baseline variables and the Littles's irregularity index were statistically different

TABLE 1 Demographic and cephalometric variables at baseline, little's irregularity index, 3D buccolingual comparisons between control (CL) and piezocision (PZ) groups.

Baseline variables	CL (n = 19)	PZ (n = 19)	*P*-value[a]
Age	24.9 ± 5.3	26.4 ± 7.3	.703[b]
Sex (F/M)	6/13	4/15	.461[c]
Treatment time	13.2 ± 5.06	13 ± 5.5	.918
SNA (°)	81.9 ± 3.6	83.4 ± 3.2	.184
SNB (°)	78 ± 4	79 ± 2.1	.155
ANB (°)	3.9 ± 2.1	3.8 ± 2.4	.927
Mandibular plane angle (°)	19.4 ± 5.3	18.9 ± 4.4	.768
Gonial angle (°)	116.4 ± 6.2	116.7 ± 7.3	.906
U1-PP (°)	113.8 ± 7.2	110.9 ± 7	.209
L1-MP (°)	100.8 ± 5.7	98.3 ± 7.6	.255
Wits appraisal (mm)	1.6 ± 2.7	2 ± 2.5	.614
Overjet (mm)	3.1 ± 1.1	3.3 ± 1.5	.673
Overbite (mm)	2.4 ± 1.2	3 ± 1.9	.220
Molar relation (mm)	−1.3 ± 2.3	−0.6 ± 1.5	.277[b]
Little's irregularity Index	**CL (n = 19)**	**PZ (n = 19)**	***P*-value[b]**
Baseline	6.17 ± 2.61	6.55 ± 1.86	.612[b]
Changes (T1-T2)	5.5 ± 2.6	6 ± 1.8	.223[b]
3D buccolingual changes (T1-T2)	**CL (n = 19)**	**PZ (n = 19)**	***P*-value[b]**
Anterior teeth linear displacement	0.8 ± 1 B	0.5 ± 0.4 B	.1
Anterior teeth long axis angulation	1.6 ± 4.1 B	3.8 ± 2.8 B	.6
Posterior teeth linear displacement	0.6 ± 0.5 B	0.2 ± 1.4 L	.1
Posterior teeth long axis angulation	1.8 ± 5 B	4.2 ± 3.2 B	.7

Abbreviations: B, Buccal; CL, Control; F, Female; L, Lingual; L1, Lower 1; M, Male; MP, Mandibular; PP, Palatal plane; PZ, Piezocision; U1, Upper 1.
[a]Student's *t*-test.
[b]Mann-Whitney *U* test.
[c]Pearson's chi-square test (n).
*$P < .05$.

TABLE 2 Lower right angular and linear tooth movement changes (T1–T2) comparison between control (CL) and piezocision (PZ) groups, based on digital dental models and CBCT regional superimpositions.

Right tooth movement	Second molar			First molar			Second premolar		
Angulation (°)	CL	PZ	*P*-value	CL	PZ	*P*-value	CL	PZ	*P*-value
Mesiodistal	4.5 ± 7.7 D	0.3 ± 5.3 D	.062[a]	2.3 ± 6.5 D	1.3 ± 6.1 D	1.0[b]	0.5 ± 4.9 M	2.6 ± 6.1 M	.262[a]
Buccolingual	0.39 ± 27.6 B	2.9 ± 6.9 B	.930[a]	1.2 ± 4 B	1.8 ± 6.1 B	.763[a]	7.1 ± 5.2 B	6 ± 5.6 B	.586[a]
Mesiodistal rotation	0.7 ± 6.4 MR	1.1 ± 7.3 DR	.407[a]	0.2 ± 6 DR	2.9 ± 2.8 DR	.354[b]	0.58 ± 7.8 MR	1.9 ± 6.8 DR	.316[a]
Linear movement (mm)	CL	PZ	*P*-value	CL	PZ	*P*-value	CL	PZ	*P*-value
Mesiodistal	0.04 ± 1 D	0.3 ± 0.6 M	.153[a]	0.1 ± 0.7 D	0.1 ± 0.6 M	.385[b]	0.4 ± 0.6 M	0.5 ± 0.8 M	.635[a]
Buccolingual	0.08 ± 0.9 L	0.08 ± 0.6 B	.624[a]	0.3 ± 0.5 B	0.3 ± 0.5 B	.863[a]	1.4 ± 0.7 B	1.3 ± 0.9 B	.745[a]
Extrusion/Intrusion	0.08 ± 0.6 E	0.1 ± 0.6 E	.793[a]	0.4 ± 0.7 E	0.6 ± 0.4 E	.484[a]	0.8 ± 0.6 E	0.7 ± 0.8 E	.613[a]
3D Scalar displacement	1.3 ± 1.3	1.1 ± 0.4	.116[a]	1.1 ± 0.6	1.1 ± 0.4	.804[b]	1.8 ± 0.8	2 ± 0.7	.468[a]
Lower right teeth									

Abbreviations: B, Buccal; CL, Control; D, Distal; DR, Distal rotation; E, Extrusion; I, Intrusion; L, Lingual; M, Mesial; MR, Mesial rotation; PZ, Piezocision.

Statistically significant values presented in bold.

[a] Student's *t*-test.

[b] Mann-Whitney *U* test.

$^*P < .05$.

between the groups, demonstrating that all patients had similar malocclusion (Table 1).

3.2 | 3D angular and linear tooth movement

Groups comparisons for each tooth are presented in Tables 2 and 3. Comparisons of 3D buccolingual movements of anterior and posterior teeth are presented in Table 1. Of the 56 angular measurements performed, changes were statistically significant in only two (3.5%) of the variables comparing the groups. The piezocision group demonstrated greater ($P = .01$) mesial long axis angulation of lower right first premolar (4.4 ± 6°) compared with control group (0.02 ± 4.9°), while the mesial rotation was significantly smaller ($P = .008$) in the experimental group (0.5 ± 7.8°) than in the control (8.5 ± 9.8°) considering the same tooth. Regarding the 42 linear tooth movements evaluated, no significant differences were identified between the groups (Tables 2 and 3). The piezocision group did not demonstrate improved control of torque compared with the control group, showing no significant difference in the incisors flaring ($P = .6$) and posterior teeth buccal angulation ($P = .7$) (Table 1) (Figure 3). After applying the Bonferroni correction, no significant differences were found in the 3D angular and linear tooth movement between the groups ($P \times 98 > .05$).

4 | DISCUSSION

In this study, we innovatively evaluated the influence of piezocision surgery on orthodontic biomechanics, magnitude and direction of tooth movement using AI-based automated tools. Previous studies have investigated orthodontic treatment with and without piezocision,[6,7,14,15,34] but none has quantified tooth movement three-dimensionally, considering detailed IOS crowns and root canal segmentations from CBCTs simultaneously to determine changes in tooth long axis and 3D linear displacements. The influence of the piezocision in the teeth responses to orthodontic forces, changes in the amount and direction of orthodontic three-dimensional tooth displacement remains unclear. The understanding of how this procedure affects the magnitude of tooth movement is crucial in treatment planning, especially considering complex orthodontic cases.

This study groups showed similar responses to orthodontic forces, as well as magnitude, and direction of tooth movement in

First premolar			Canine			Lateral incisor			Central incisor		
CL	PZ	*P*-value	CL	PZ	*P*-value	CL	PZ	*P*-value	CL	PZ	*P*-value
0.02 ± 4.9 D	4.4 ± 6 M	**.019**[a]	4.1 ± 4.6 M	4.9 ± 5.4 M	.603[b]	1.1 ± 8.8 D	3.2 ± 5.3 M	.146[b]	1.1 ± 8.8 D	3.2 ± 5.3 M	.146[b]
9.6 ± 4.3 B	8.1 ± 5.8 B	.435[b]	4.2 ± 5.5 B	1.6 ± 6.1 B	.793[a]	5.2 ± 6.5 B	5.3 ± 6.9 B	.979[a]	5.2 ± 6.5 B	5.3 ± 6.9 B	.979[a]
8.5 ± 9.8 MR	0.5 ± 7.8 MR	**.008**[a]	14.7 ± 16.7 MR	9.9 ± 18.4 MR	.408[a]	0.6 ± 12.4 MR	0.4 ± 11.3 MR	.947[a]	5.4 ± 10.1 DR	7.2 ± 22.5 DR	.977[b]
CL	PZ	*P*-value	CL	PZ	*P*-value	CL	PZ	*P*-value	CL	PZ	*P*-value
0.4 ± 0.6 M	1.8 ± 0.8 M	.170[a]	0.7 ± 1.1 M	0.7 ± 0.9 M	.729[b]	0.8 ± 1.3 D	0.2 ± 0.7 D	.091[a]	0.8 ± 1.3 D	0.2 ± 0.7 D	.09[a]
1.6 ± 0.6 B	1.4 ± 0.9 B	.530[a]	1.4 ± 1 B	0.8 ± 0.9 B	.050[a]	1.6 ± 1.6 B	1.2 ± 1.4 B	.511[b]	1.6 ± 1.6 B	1.2 ± 1.4 B	.454[a]
0.6 ± 0.7 E	0.5 ± 0.6 E	.609[a]	0.01 ± 1 E	0.1 ± 1.1 E	.474[b]	0.1 ± 0.8 I	0.2 ± 1.5 I	.488[b]	0.1 ± 0.8 I	0.2 ± 1.5 I	.488[b]
2 ± 0.6	2 ± 1.9	.974[a]	2.1 ± 1.1	1.8 ± 0.8	.318[a]	2.4 ± 1.4	2.1 ± 1.3	.435[b]	2.4 ± 1.4	2.1 ± 1.3	.435[b]
											

most of the measurements. The treatment time did not statistically differ between groups. Out of the 98 three-dimensional assessments that were performed and compared between the groups, only two (2.04%) showed statistically significant differences. In the experimental group, only a greater mesial long axis angulation and smaller mesial rotation were identified in the lower right first premolar, with no greater movements observed in the incisors. These findings are consistent with the study of Uribe et al,[34] who performed a randomized clinical trial and found no evidence that piezocision assisted orthodontics tooth movement in mandibular anterior crowding. Differences in the angulation or rotation of the teeth could also be caused by differences in bracket position or crown shape, or by the influence of piezocision. On the other hand, the present results are contradictory to the outcomes of a previous study that reported statistically more orthodontic tooth movement in the piezocision group for the levelling of mandibular anterior teeth.[27] When performing multiple tests, the likelihood of obtaining at least one significant result purely by chance increases, this fact may explain the statistical significance in only to variables. In order to control the risk of false positives when conducting multiple tests, the Bonferroni correction was performed. After adjusting the *P*-values, none of the variables were statistically different between the groups.

Due to the lack of studies and significant differences in methods, sample size, arches and groups of teeth studied, it was challenging to establish a comparison with previous reports. In this study, we evaluated the tooth movement of all lower teeth after correcting mild to moderate malocclusion, while the literature mainly reports different evaluations and methodologies, such as the levelling of only mandibular anterior teeth,[27] assessment of severe maxillary malocclusion,[6] evaluation of maxillary canine distalization,[14] en-masse retraction utilizing miniscrews,[35] transversal tooth movement of mandibular lateral segments,[15] second molar protraction and upper canine retraction.[36]

The automated AI-based dental tools used in this study are accurate[8,19–24,26,31,32] and facilitate the assessment and quantification of tooth movement, reducing the time needed by clinicians and researchers to analyse imaging processes and evaluations by at least 90%. It is important to note that while commercial companies such as Relu,[37] Diagnocat[38] and Materialise,[39] as well as previous studies, have demonstrated similar applications, most of their tools are not integrated into the same platform and are not easily accessible due to cost and code unavailability. Moreover, the applications reported in other software usually only allow individual analysis, requiring the imaging processing to be performed one by one, whereas in this

TABLE 3 Lower left angular and linear tooth movement changes (T1–T2) comparison between control (CL) and piezocision (PZ) groups, based on digital dental models and CBCT regional superimpositions.

Left tooth movement	Central incisor			Lateral incisor			Canine		
Angulation (°)	**CL**	**PZ**	***P*-value**	**CL**	**PZ**	***P*-value**	**CL**	**PZ**	***P*-value**
Mesiodistal angulation	2.1 ± 11.3 M	0.5 ± 10.1 D	.246[b]	0.1 ± 6 D	0.2 ± 8.7 D	.599[b]	5.6 ± 3.1 M	6.9 ± 5.6 M	.603[b]
Buccolingual angulation	5 ± 5.7 B	4.6 ± 7 B	.319[a]	8 ± 8.9 B	5.6 ± 6.5 B	.345[a]	3.2 ± 5.3 B	3.8 ± 7.6 B	.793[a]
Mesiodistal rotation	5.1 ± 10.5 DR	3 ± 12.8 DR	.598[a]	0.7 ± 12.4 DR	3 ± 12.8 DR	.192[b]	9.8 ± 13.5 MR	1.9 ± 22.5 MR	.212[b]
Linear movement (mm)	**CL**	**PZ**	***P*-value**	**CL**	**PZ**	***P*-value**	**CL**	**PZ**	***P*-value**
Mesiodistal	0.06 ± 0.6 M	0.1 ± 0.7 D	.358[b]	0.6 ± 0.7 D	0.1 ± 0.7 D	.105[b]	0.6 ± 0.9 M	1 ± 1 M	.172[a]
Buccolingual	1.4 ± 1.3 B	1.1 ± 1.3 B	.478[a]	1.5 ± 1.8 B	1.3 ± 1.3 B	.702[a]	1.3 ± 0.8 B	1 ± 1.5 B	.392[a]
Extrusion/Intrusion	0.02 ± 1 E	0.1 ± 1.9 I	.563[b]	0.2 ± 0.8 E	0.5 ± 1.5 I	.075[a]	0.08 ± 1 E	0.01 ± 1.3 I	.885[b]
3D Scalar Displacement	1.9 ± 1.2	2.2 ± 1.4	.603[b]	2.1 ± 1.6	2.1 ± 1.4	.938[a]	2 ± 0.7	2.2 ± 1.4	.885[b]
Lower left teeth									

Abbreviations: B, Buccal; CL, Control; D, Distal; DR, Distal rotation; E, Extrusion; I, Intrusion; L, Lingual; M, Mesial; MR, Mesial rotation; PZ, Piezocision.

[a]Student's *t*-test.

[b]Mann-Whitney *U* test.

$^{*}P < .05$.

study, each automated step was applied to the entire data set simultaneously. In addition of being open-access, the automated tools used in this study are also designed to be user-friendly for clinicians and researchers due to its simplicity, speed and precision.

The variances in the individual location of crowding among the patients before treatment posed a challenge in comparing tooth movement between groups. However, a careful baseline evaluation using cephalometric analysis was performed to reduce study bias considering the possible presence of different malocclusions (Table 1). Additionally, the tooth movement were evaluated in only two time points, in light of the fact that it is unrealistic to use CBCTs to follow tooth movements in multiple time intervals without diagnostic indications.[40] However, future studies will include development of tools for automated long axis prediction in IOS, without CBCT images, and automated IOS registration using only digital models as a reference. It is important to emphasize that automated AI-based tools are continuously being developed to provide trustworthy support for clinical decision-making. In this study, the automated landmark placement were confirmed and adjusted by a clinician when needed. This step assured an even more precise landmark placement, highlighting that continuous human interaction with clinician feedback is essential for improving the accuracy and precision of AI algorithms.[21,22]

This study consists of a secondary data analysis. The CBCT scans were originally acquired with the goal of evaluating dehiscences and fenestrations in patients, without the need for an invasive procedure such as flap elevation for direct assessment. CBCT provides a precise reproduction of the periodontium's anatomical details that cannot be achieved with 2D radiographies.[15] The scans had a small field of view and were acquired with adjusted parameters to reduce ionizing radiation effects as low as diagnostically acceptable.[41] Furthermore, this study followed the imaging selection recommendations for the use of CBCT in orthodontics by the American Academy of Oral and Maxillofacial Radiology (AAOMFR). The consensus recommendation of the AAOMFR is that pre- and post-treatment acquisition of CBCT scans is possibly indicated not only for skeletal discrepancies but also for dental malocclusions,[40] allowing the assessment of the complete tooth, including roots and crowns.

Overall, this study did not find any significant differences in orthodontic biomechanics responses when assessing torque, magnitude and direction of tooth movement, and treatment time using piezocision, suggesting that this procedure may not offer significant advantages over traditional methods in terms of teeth responses to orthodontic forces. While a more detailed assessment of piezocision effects on treatment timing for both the experimental and control groups has been previously published,[42] the outcomes presented in this study impacts clinical decision-making regarding options for accelerating tooth movement. Despite the conservative nature of this surgical procedure, clinicians must exercise critical thinking in weighing the cost–benefit of piezocision

First premolar			Second premolar			First molar			Second molar		
CL	PZ	*P*-value	CL	PZ	*P*-value	CL	PZ	*P*-value	CL	PZ	*P*-value
1.8 ± 4.8 D	4.8 ± 6.3 M	.119[a]	2 ± 4.7 M	3.7 ± 5.7 M	.201[a]	2.9 ± 4.5 M	0.4 ± 6 M	.163[a]	0.5 ± 5.6 M	3.2 ± 9 D	.154[b]
7.6 ± 5.4 B	8.8 ± 5.5 B	.499[a]	8.7 ± 3.5 B	8.4 ± 6.5 B	.730[a]	0.7 ± 4.9 B	1.3 ± 4.9 B	.706[a]	2.2 ± 6.6 B	3.1 ± 6.2 B	.954[b]
0.5 ± 9.7 MR	3 ± 12.8 MR	.302[a]	5.1 ± 7.8 DR	4.5 ± 8.9 DR	.799[b]	3.5 ± 4.2 DR	4.3 ± 5.3 DR	.619[a]	1.4 ± 5.5 DR	0.05 ± 9.3 MR	.543[a]
CL	PZ	*P*-value	CL	PZ	*P*-value	CL	PZ	*P*-value	CL	PZ	*P*-value
0.4 ± 0.5 M	0.5 ± 0.6 M	.600[a]	0.4 ± 0.4 M	0.7 ± 0.7 M	.159[a]	0.4 ± 0.4 M	0.3 ± 0.6 M	.686[a]	0.3 ± 0.6 M	0.1 ± 1.4 D	.163[b]
1.3 ± 0.7 B	1.2 ± 1.2 B	.686[b]	1.5 ± 0.7 B	1.7 ± 1.4 B	.869[b]	0.3 ± 0.4 B	0.6 ± 0.6 B	.165[a]	0.1 ± 0.8 B	0.1 ± 0.8 B	.945[a]
0.7 ± 0.8 E	0.5 ± 1 E	.573[a]	0.7 ± 0.5 E	0.6 ± 0.9 E	.906[a]	0.3 ± 0.5 E	0.5 ± 0.7 E	.331[a]	0.1 ± 0.5 I	0.03 ± 0.6 I	.533[a]
1.9 ± 0.7	1.9 ± 1.1	.751[b]	1.8 ± 0.6	2.2 ± 1.5	.620[b]	1 ± 0.3	1.2 ± 0.6	.136[a]	1.1 ± 0.4	1.2 ± 1.1	.544[b]
											

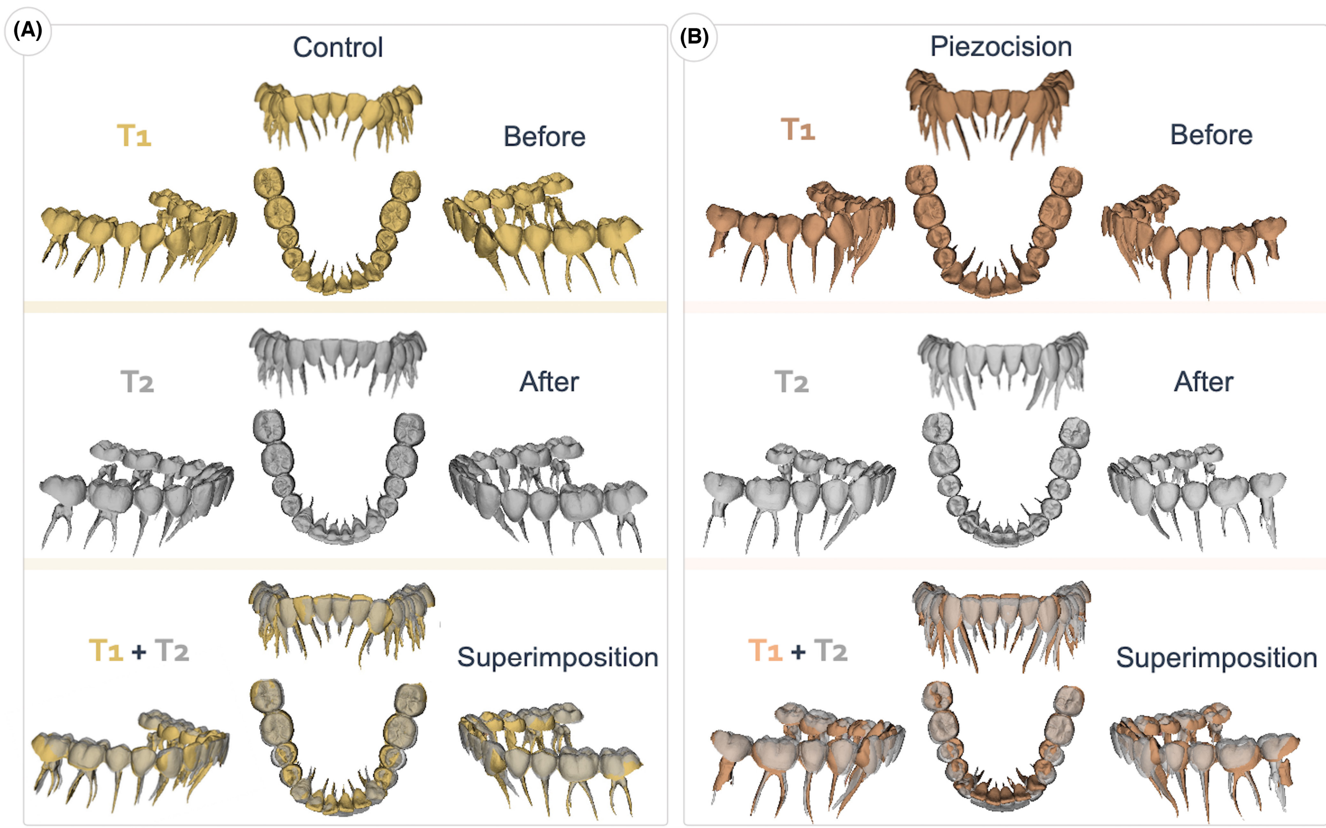

FIGURE 3 3D visualization of orthodontic changes with imaging superimposition in patients with similar malocclusion. A, Superimposition of the images of a control patient. B, Superimposition of a piezocision patient.

for patients, as it may increase levels of pain and apprehension during orthodontic treatment.[6] Importantly, in a long-term treatment evaluation, this study proofs that the piezocision did not show benefits for the patients. However, future studies considering early time points are important to analyse whether this procedure may be beneficial in earlier stages of the orthodontic treatment, improving the patient appearance in a short-term period after the bonding.

The open-access automated AI-based tools enabled the elucidation of relevant clinical aspects in piezocision surgery, providing 3D linear and long axis assessments. The automated quantification of tooth movement is a simple and accessible approach to improve treatment planning, particularly regarding detailed evaluations of individual tooth angulation and more predictable outcomes. Importantly, additional 3D studies may provide further insight to elucidate controversies surrounding piezocision surgery.

5 | CONCLUSION

Piezocision surgery did not affect orthodontic biomechanics response or influence the magnitude of tooth long axis angulation, rotation, buccolingual and mesiodistal displacements, as well as intrusion and extrusion movements. Notably, the development of novel open access AI automated dental tools has facilitated and provided a detailed evaluation of 3D tooth individual movement, which holds great promise for improving treatment planning and predictability. Therefore, the ongoing development and implementation of these tools in orthodontic practice should be prioritized to maximize their clinical benefits.

AUTHOR CONTRIBUTIONS

Gurgel M Conceptualization, formal analysis, investigation, methodology, validation, visualization, writing—original draft preparation and writing—review and editing. Alvarez MA Investigation, resources, visualization and writing—review and editing. Aristizabal JF Investigation, resources, visualization and writing—review and editing. Baquero B Data curation, software, validation and writing—review and editing. Gillot M Data curation, software, validation and writing—review &and editing. Al Turkestani N Methodology, validation, visualization and writing—review and editing. Miranda F Formal Analysis, visualization and writing—review and editing. Bianchi J Data curation, methodology, visualization and writing—review and editing. Ruellas A Conceptualization, methodology, validation, visualization, writing—original draft preparation and writing—review and editing. Ioshida M Methodology, validation, visualization and writing—review and editing. Yatabe M: Methodology, validation, visualization and writing—review and editing. Rey D Investigation, resources, visualization and writing—review and editing. Prieto J Data curation, software, validation and writing—review and editing. Cevidanes L Conceptualization, funding acquisition, methodology, project administration, supervision, visualization, writing—original draft preparation and writing—review and editing.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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