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Research Article

Comparing virtual setup software programs for clear aligner treatment

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ABSTRACT

Background: The aim of this study was to compare the outcomes of the same amount of tooth movement among four different virtual setup software programs.
Methods: This retrospective study included 32 patients who underwent Invisalign treatment. Patients' initial stereolithography (STL) files were imported to three different software programs (SureSmile Aligner [Dentsply Sirona, Charlotte, NC], Ortho Insight 3D [Motion View software, Chattanooga, TN], and Ortho Analyzer [3Shape, Copenhagen, Denmark]). After virtually moving teeth based on the numbers from ClinCheck Pro (Align Technology, Inc., Santa Clara, CA) tooth movement tables, final STL files were exported from all four software programs. ClinCheck Pro final STL files were used as references, while final STL files from the other software programs were used as targets. Superimpositions were performed between references and target STL files using Geomagic Control X software (3D Systems, Rock Hill, SC), and color-coded maps were obtained to illustrate potential differences.
Results: Intraclass correlation coefficient showed a high degree of reliability for repeated methodology (0.995–0.997). The differences among absolute averages (Abs Avg.), averages of positive values (+Avg.), and negative values (−Avg.) for both upper and lower models were significant among all software programs (ClinCheck Pro, SureSmile Aligner, Ortho Insight 3D, and Ortho Analyzer), for both upper and lower STL files, the smallest difference was found between ClinCheck Pro and SureSmile Aligner with a median of (0.03, 0.31, −0.19) mm for upper and (0.02, 0.29, −0.17) mm for lower STL files (Abs Avg., +Avg. and −Avg.), respectively. The biggest difference was found to be between ClinCheck Pro and Ortho Analyzer with a median of (0.05, 0.46, −0.45) mm for upper and (0.06, 0.48, −0.40) mm for lower STL files. There were no significant differences in the number of aligners per patient.
Conclusions: Final outcomes of the same amount of tooth movement in four different software programs differed significantly. The number of aligners per patient remained unchanged.

1. Background

Clear aligner treatment has become very popular in orthodontics over the past decade. Nonetheless, the concept of moving teeth without brackets and wires is not new. Kesling [1] was the first to describe a "Tooth Positioning Appliance", which was meant to be used for finishing after conventional orthodontic treatment with fixed appliances. It required a diagnostic wax-up made following the biological limitations of tooth movements and taking into consideration the anchorage available [1]. The Positioner was supposed

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to correct slight rotations, reduce spaces, and improve arch form and axial inclinations [1].

Even though computer-aided design and manufacturing were introduced in the 1950s at the Massachusetts Institute of Technology [2], it wasn't until 20 years later that Biggerstaff [3] used it for computer-aided orthodontic treatment planning. He described a computer model for realigning teeth into "normal" occlusion [3]. More than 2 decades later, two graduate students from Stanford University founded Align Technology, the company that initiated the use of computer-aided design and manufacturing technology for orthodontic tooth movement [4]. Invisalign (Align Technology Inc., Santa Clara, CA) was the first company to make custom-made clear aligners for orthodontic tooth movement [5]. The initial focus was on low to moderate crowding and space closure, but over the years it became possible to treat more complex orthodontic problems and malocclusions [6–11].

Nowadays, more companies are offering the virtual tooth movement concept either as a ready-made product in the form of clear aligners or printable files of virtual setups, or software packages that allow clinicians to make their own virtual setups for fabricating indirect bonding trays and in-house aligners.

The available software packages use different combinations of algorithms and forms of data input. Our goal with this research was to evaluate if using the same numbers for tooth movement during the orthodontic setup, would bring the same final results, using different software programs. Therefore, this study aimed to compare and analyze the final outcomes of four virtual setup software programs after applying the same amount of tooth movement.

2. Methods

The study was approved by the institutional review board of Case Western Reserve University (number 20200158). A chi-square test showed that the minimum sample size of 24 patients was calculated to answer the research question, with a 0.05 α value and 90% power, using the G*Power program for Windows.

The sample of this retrospective study consisted of 32 adult patients (8 men and 24 women, age range from 20 to 68 years, and mean age of 32 years) who underwent Invisalign treatment at the Department of Orthodontics School of Dental Medicine. The inclusion criteria were Class I malocclusion, with mild crowding and no missing teeth, except for the third molars, presenting a ClinCheck from the SmartTrack era, and table with tooth movements. The exclusion criteria were the use of Class II, Class III, or cross elastics, impacted teeth, tooth malformation, centric occlusion/centric relation discrepancy, history of facial trauma, and craniofacial anomalies.

After selecting the eligible cases, based on the mentioned inclusion and exclusion criteria, the final stereolithography (STL) files from the approved ClinCheck (Align Technology) and respective tooth movement tables were exported from the ClinCheck Pro software. Each patient's initial STL files were imported to the other three software programs—SureSmile Aligner (Dentsply Sirona, Charlotte, NC), Ortho Insight 3D (Motion View software, Chattanooga, TN), and Ortho Analyzer (3Shape, Copenhagen, Denmark)—where teeth were moved based on each patients' ClinCheck tooth movements table, so the numbers from the ClinCheck tables were exactly added to the other three software programs. The final outcomes of both upper and lower virtual models obtained with the four software programs were exported and saved as STL files. The ClinCheck Pro final STL files were used as references, while the final STL files from the other three software programs were used as targets. Best-fit superimposition was performed using Geomagic Control X software (3D Systems, Rock Hill, SC), and color-coded maps were obtained. The study workflow is outlined in Fig. 1.

The best-fit superimposition tool was used to superimpose each set of a reference and a target STL file in Geomagic Control X software. Only teeth surfaces were included. Color-coded maps with maximum deviation range were used and tolerance was automatically set to −1.5 to 1.5 mm and −0.25 to 0.25 mm, respectively, and used to illustrate the differences (Figs. 2 and 3). The minimum, maximum, average, and SD values, as well as the average of positive and the average of negative values, were used for the quantification of differences.

The number of aligners that were required to achieve the same amount of tooth movement was compared among the four software programs. In the ClinCheck Pro and SureSmile Aligner programs the number of aligners is automated, while in Ortho Insight 3D and Ortho Analyzer software programs, the number of aligners depends on the clinician's preference, determining the amount of tooth movement per aligner (millimeters/degrees). In this study, tooth movement preferences were set at 0.25 mm and 1.25° per aligner, based on information released by Align Technology Inc. on how much movement is provided per aligner.

Finally, the number of attachments was compared among the software programs. ClinCheck Pro and SureSmile Aligner have automated attachments, but clinicians can also edit, add, or delete them. In Ortho Insight 3D and Ortho Analyzer software programs attachments are placed manually. Each software program has a different library of attachments and they come in different shapes and sizes. Only the software programs with automatically generated attachments were evaluated.

All measurements were performed by a single investigator. The intraoperator reliability was assessed by intraclass correlation coefficient on 30% of the samples with variables being measured at two time points, with an interval of 3 weeks.

2.1. Statistical analysis

Statistical analyses were performed using SPSS software (SPSS 25.0 Inc., Chicago, IL). Bartlett test was used to evaluate data homogeneity. The appropriateness of the variables to normal distribution was examined by visual (histogram and probability graphics). The Shapiro–Wilk normality test was performed and revealed that some variables were normally distributed, while others were not. Because the absolute averages (Abs Avg.), averages of positive values (+Avg.), and averages of negative values (−Avg.) were not normally distributed, the Kruskal–Wallis test was used to determine the differences. Because the number of aligners was normally distributed, the one-way ANOVA was applied to determine whether there was an association between the type of software and the number of aligners. The post hoc Bonferroni analysis was used for the within-group comparison. $P \leq 0.05$ were considered statistically significant.

3. Results

3.1. Overall difference

The intraclass correlation coefficient showed high reliability and reproducibility of the measurements (0.995–0.997). The Shapiro–Wilk test showed that Abs Avg., +Avg., and −Avg. were not normally distributed, and the Bartlett test showed that all groups had different variances. The differences among Abs Avg., +Avg., and −Avg. for both upper and lower models were significant among all software programs (ClinCheck Pro, SureSmile Aligner, Ortho Insight 3D, and Ortho Analyzer). The smallest difference was found to be

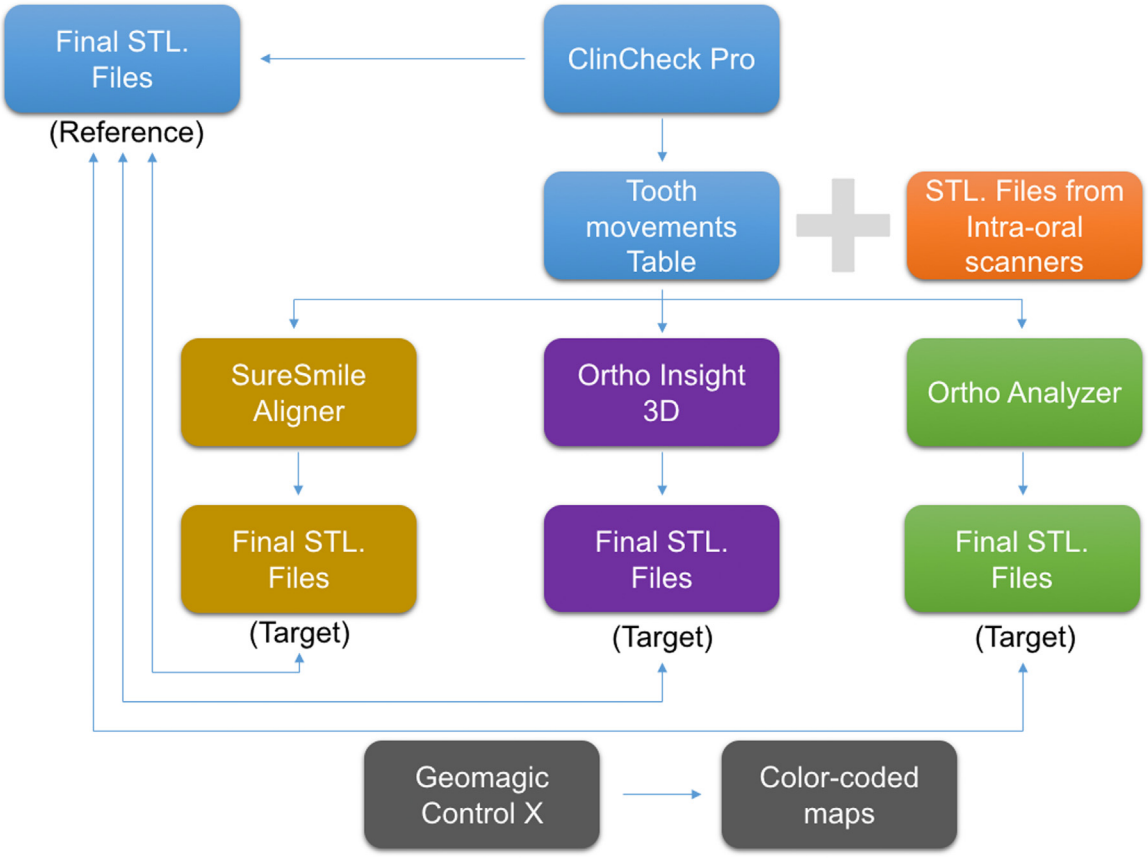

Fig. 1. Study workflow showing the final STL files (ClinCheck Pro) used as reference and the final STL files from the other three software programs used as targets.

Table 1
Summary of median and percentile differences for absolute averages, averages of positive values and averages of negative values for upper STL files among four different software programs

Upper STL files		Percentile							Adj. Sig.
		5	10	25	50	75	90	95	
Abs.	ClinCheck Pro - SureSmile Aligner	0.00	0.00	0.01	0.03	0.05	0.08	0.09	0.00
Avg.	ClinCheck Pro - Ortho Insight 3D	0.02	0.03	0.05	0.06	0.07	0.09	0.08	0.00
	ClinCheck Pro - Ortho Analyzer	0.01	0.01	0.02	0.05	0.08	0.13	0.26	0.00
+Avg.	ClinCheck Pro - SureSmile Aligner	0.26	0.27	0.29	0.31	0.34	0.39	0.45	0.00
	ClinCheck Pro - Ortho Insight 3D	0.12	0.17	0.25	0.32	0.36	0.52	0.68	0.00
	ClinCheck Pro - Ortho Analyzer	0.16	0.22	0.37	0.46	0.61	0.89	1.18	0.00
−Avg.	ClinCheck Pro - SureSmile Aligner	−0.32	−0.27	−0.23	−0.19	−0.16	−0.15	−0.13	0.00
	ClinCheck Pro - Ortho Insight 3D	−0.67	−0.49	−0.37	−0.29	−0.22	−0.15	−0.13	0.00
	ClinCheck Pro - Ortho Analyzer	−1.11	−1.01	−0.56	−0.45	−0.36	−0.21	−0.16	0.00

Note: P values are from the post hoc test.
Abs., absolute; Adj. Sig., adjusted significance; Avg., average; STL, stereolithography.

between ClinCheck Pro and SureSmile Aligner and the biggest between ClinCheck Pro and Ortho Analyzer (Tables 1 and 2).

3.2. Number of aligners

There were no statistically significant differences in the number of aligners per patient among the four different software programs (Table 3).

3.3. Number of attachments

The average number of attachments in ClinCheck Pro was 12 and in SureSmile Aligner seven. Comparing the 2 automated methods used (ClinCheck Pro and SureSmile Aligner) attachments were placed on the same teeth in 78% of the cases.

4. Discussion

The purpose of this study was to compare the final outcomes of four different virtual setup software programs after applying the same amount of tooth movements. To our best knowledge, this was one of the first studies to do this type of comparison.

The initial hypothesis that the final outcome of the four virtual setup programs would be the same, was rejected. Teeth were virtually moved the same amount in (SureSmile Aligner, Ortho Insight 3D, and Ortho Analyzer) software programs based on numbers extracted from the ClinCheck Pro table tooth movements. Although,

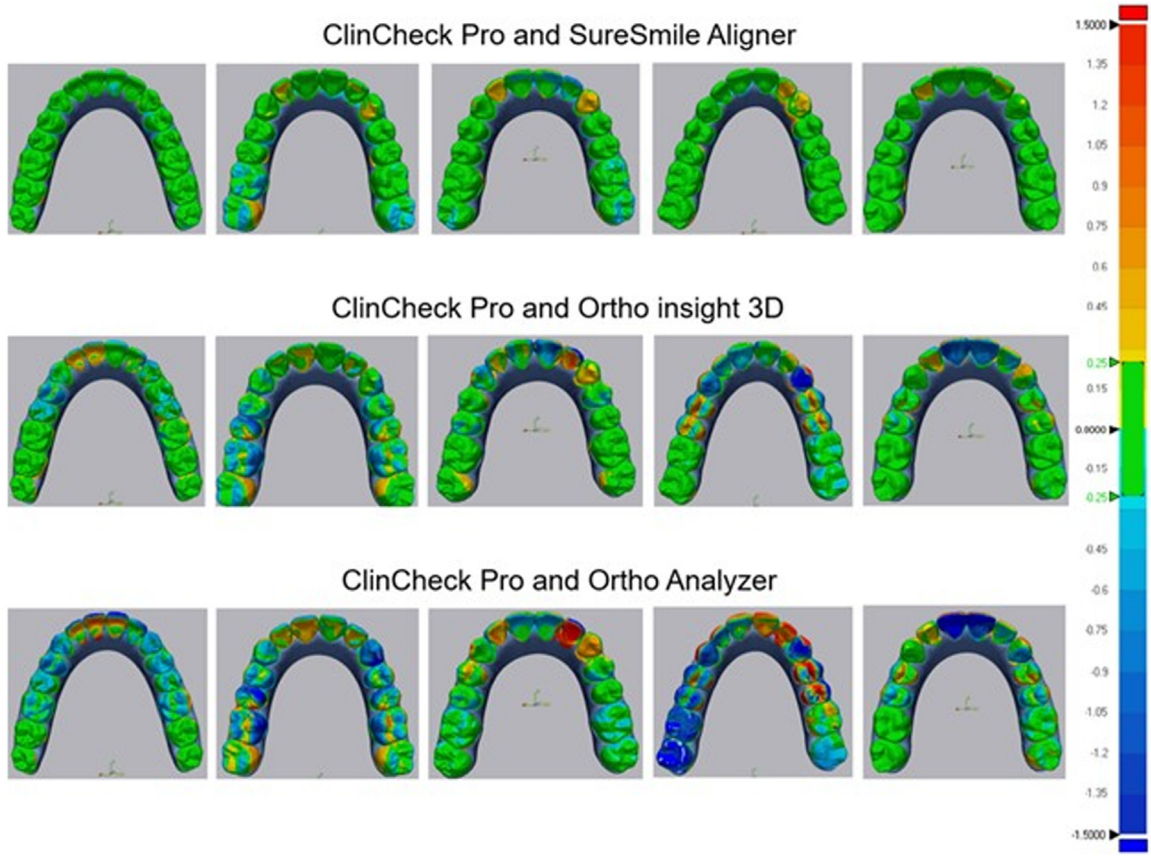

Fig. 2. Color-coded maps of upper models of five cases. Reference - Final STL files (ClinCheck Pro). Target - final STL files (SureSmile Aligner, Ortho Insight 3D, and Ortho Analyzer).

Table 2
Summary of median and percentile differences for absolute averages, averages of positive values and averages of negative values for lower STL files among four different software programs.

Lower STL files		Percentile							Adj. Sig.
		5	10	25	50	75	90	95	
Abs. Avg.	ClinCheck Pro - SureSmile Aligner	0.00	0.00	0.01	0.02	0.05	0.09	0.19	0.00
	ClinCheck Pro - Ortho Insight 3D	0.00	0.01	0.03	0.06	0.07	0.09	0.11	0.00
	ClinCheck Pro - Ortho Analyzer	0.00	0.01	0.03	0.06	0.10	0.15	0.18	0.00
+Avg.	ClinCheck Pro - SureSmile Aligner	0.23	0.24	0.27	0.29	0.33	0.38	0.40	0.00
	ClinCheck Pro - Ortho Insight 3D	0.18	0.21	0.24	0.30	0.36	0.61	0.85	0.00
	ClinCheck Pro - Ortho Analyzer	0.26	0.35	0.41	0.48	0.76	0.92	1.09	0.00
−Avg.	ClinCheck Pro - SureSmile Aligner	−0.26	−0.24	−0.21	−0.17	−0.15	−0.14	−0.13	0.00
	ClinCheck Pro - Ortho Insight 3D	−0.81	−0.57	−0.37	−0.29	−0.23	−0.18	−0.13	0.00
	ClinCheck Pro - Ortho Analyzer	−1.04	−0.91	−0.54	−0.40	−0.32	−0.28	−0.23	0.00

Note: P values are from the post hoc test.
Abs., absolute; Adj. Sig., adjusted significance; Avg., average; STL, stereolithography.

Table 3
Summary of mean and SD of number of aligners required to achieve same amount of tooth movements in four different software programs

Number of Aligners		Min.	Max.	Mean	SD	95% CI		Sig.
						Lower bound	Upper bound	
Number of upper Aligners	ClinCheck Pro	11	35	20.25	5.85	18.14	22.36	0.21
	SureSmile Aligner	7	28	17.28	5.46	15.31	19.25	
	Ortho Insight 3D	8	35	19.44	6.62	17.05	21.83	
	Ortho Analyzer	9	34	19.84	6.31	17.57	22.12	
Number of lower Aligners	ClinCheck Pro	13	35	20.47	5.71	18.41	22.53	0.83
	SureSmile Aligner	12	34	20.72	5.77	18.64	22.8	
	Ortho Insight 3D	8	35	19.44	6.62	17.05	21.83	
	Ortho Analyzer	9	34	19.84	6.31	17.57	22.12	

CI, confidence interval; Max., maximum; Min., minimum; Sig., significance.

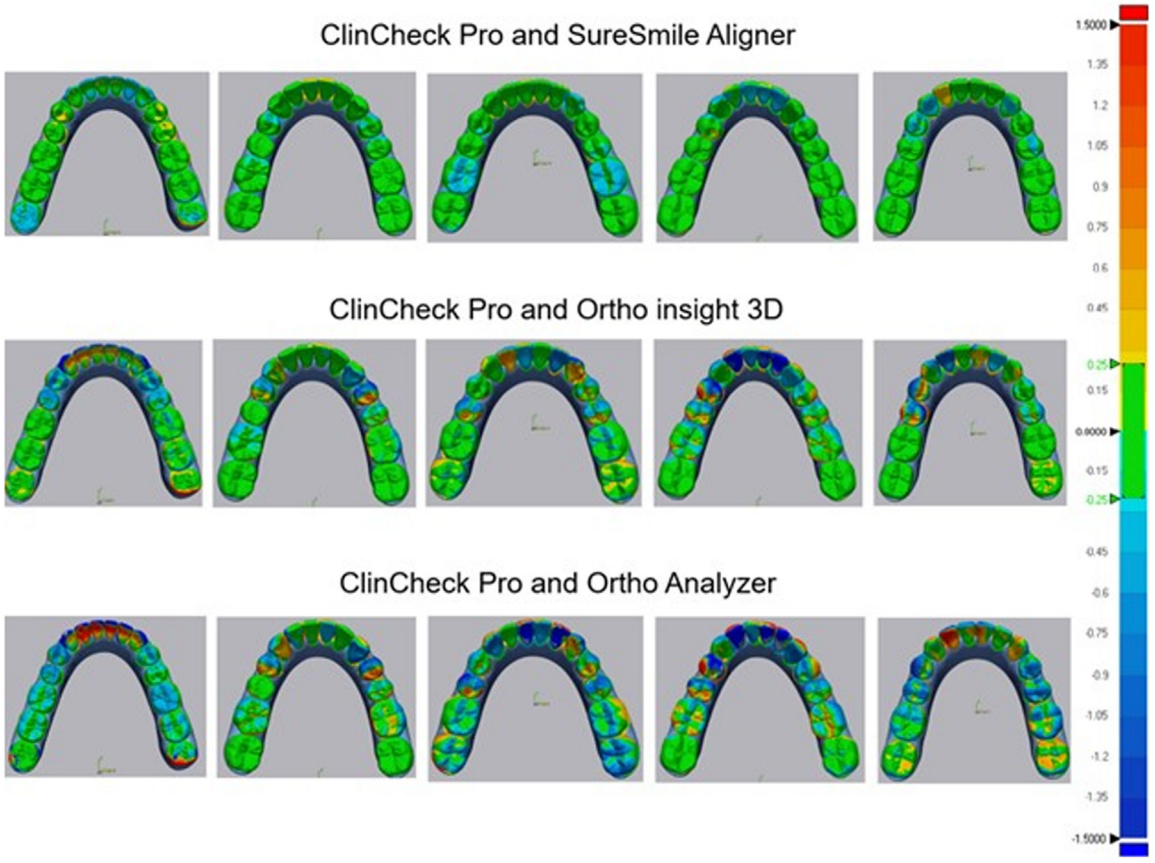

Fig. 3. Color-coded maps of lower models for five cases. Reference - Final STL files (ClinCheck Pro). Target - final STL files (SureSmile Aligner, Ortho Insight 3D, and Ortho Analyzer).

using the same numbers did not mean reaching the same outcome, as corroborated by this study.

One explanation could be that different software programs have different steps and use different ways to segment teeth and prepare the models. ClinCheck Pro and SureSmile Aligner use automated segmentation, while Ortho Insight 3D and Ortho Analyzer require manual steps to segment and prepare teeth for virtual movements, which may lead to errors. A second explanation could be that the software packages use different centers of rotation when altering the inclination of teeth which could lead to different staging of the tooth movement sequence and could lead to a different number of aligners for each software program.

The flow for digitizing teeth in the Ortho Insight 3D software goes as follows: setting the facial axes, measuring teeth, detecting landmarks, and aligning roots with crowns. This means that the software predicts the position of the roots. Two studies tested the accuracy of predicting root inclinations and teeth long axes using Ortho Insight 3D software and concluded that root predictions could not be considered accurate or reliable [12,13]. To overcome this problem, software programs now offer superimposing STL files on cone beam computed tomography images to increase the accuracy of predicting root positioning.

The flow in Ortho Analyzer software is different: setting points, defining cuts, and setting rotation centers. Changing the rotation center could lead to different outcomes for the same amount of tooth movement. Figure 4 illustrates an example of this using Geomagic Control X color-coded map when superimposing models of the same patient after moving the upper left central incisor with

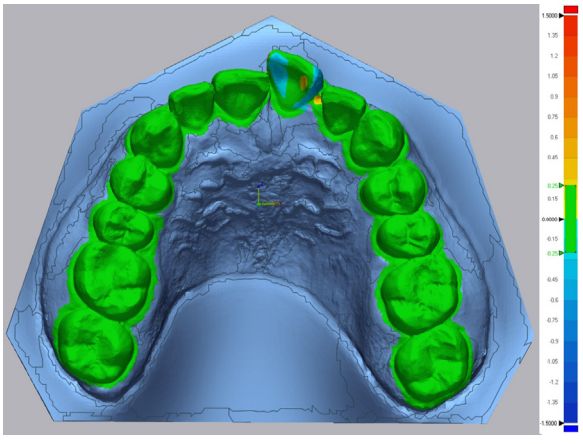

Fig. 4. Color-coded map to illustrate the difference after moving the upper left central incisor the same amount with only changing the long axis angle.

the same amount of inclination, angulation, and rotation with only changing the tooth long-axes angle.

The three software programs had significantly different final-outcome setups compared with ClinCheck Pro, which may cause difficulties for practitioners who prefer to use different software programs and want to compare values. This could be of significant importance when switching to in-house aligners.

In all four software programs, tooth movements were divided into six variables. ClinCheck Pro software uses letters to refer to

Table 4
Summary of names and values of different types of tooth movements in four different software programs

ClinCheck Pro	SureSmile Aligner	Ortho Insight 3D	Ortho Analyzer
Extrusion (E)/Intrusion (I)	Occlusal (+)/Gingival (−)	Occlusal (+)/Gingival (−)	Extrusion (−)/Intrusion (+)
Translation Buccal (B)/ Lingual (L)	Buccal (+)/Lingual (−)	Facial (+)/Lingual (−)	Forward (+)/Backward (−)
Translation Mesial (M)/ Distal (D)	Mesial (+)/Distal (−)	Mesial (+)/Distal (−)	Left (−)/Right (+)
Rotation Mesial (M)/ Distal (D)	Rotation Mesial (+)/Distal (−)	Rotation Mesial (−)/Distal (+)	Rotation Mesial (−)/Distal (+)
Angulation Mesial (M)/ Distal (D)	Angulation Mesial (+)/ Distal (−)	Angulation Mesial (+)/ Distal (−)	Angulation Mesial (+)/ Distal (−)
Inclination Buccal (B)/ Lingual (L)	Torque Facial (+)/Lingual (−)	Torque Buccal (+)/ Lingual (−)	Inclination Buccal (+)/ Lingual (−)

different types of movements, meanwhile, the other three software programs use positive and negative values for tooth movements. Certain movements have different names among these four software programs, and some have opposite values (Table 4). Tooth movement can happen in any direction, numbers could have positive or negative values. That is why averages of positive and negative values are important to interpret in addition to the averages. Camardella et al. [12] used this method when investigating differences between different base designs made using two methods of 3D printing techniques. To quantify the average deviation, average positive and negative differences were calculated.

Dhingra et al. [14] compared the differences in tooth movements when implementing the same virtual setup on the following four different software packages: ClinCheck Pro, Ortho Analyzer, SureSmile, and Ortho Insight 3D. It was shown that there are statistically significant differences in extrusion/intrusion, translation buccal/lingual, the number of aligners, and the number of attachments when implementing the same virtual setup on different software packages.

One more thing to keep in mind is that the tooth movements table in ClinCheck Pro shows both crown and root movements in the setup. Although, we were not able to copy the root movements because the other three software programs do not offer this feature.

The objectives of an orthodontic virtual setup are to provide excellent occlusion, with simultaneous and balanced contact points, with proper alignment and leveling to achieve harmonious teeth positioning and stable occlusion. This research showed that the software programs evaluated have different outcomes when using the same numbers to move the teeth, indicating that the professional should analyze each software and case in an individualized way to achieve the ideal results with the virtual setup.

5. Conclusions

The final outcomes of the same amount of tooth movement of the four software programs evaluated differed significantly. There were no significant differences in the number of aligners per patient when using different software programs.

CRediT authorship contribution statement

Manhal Eliliwi: Investigation, Methodology, Data curation, Writing – original draft, Validation, Formal analysis, Visualization. **Tarek ElShebiny:** Conceptualization, Methodology, Validation, Formal analysis, Writing – review & editing, Supervision, Project administration. **Luciane Macedo de Menezes:** Writing – review & editing. **Neda Stefanovic:** Writing – review & editing. **Juan Martin Palomo:** Writing – review & editing, Supervision.

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This study was approved by the institutional review board of Case Western Reserve University.

Data availability

The data sets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

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