Original Article

Analysis of overcorrection to be included for planning clear aligner therapy: a retrospective study

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ABSTRACT

Objectives: To provide clinical information on overcorrection to be included in the initial digital setup to make clear aligner therapy (CAT) more efficient.

Materials and Methods: Prescription data for 150 patients (80 women and 70 men; mean age 33.7 $\pm$ 12.7 years) treated successfully with CAT (F22 Aligners, Sweden & Martina, Due Carrare, Italy) and requiring only a single, minimal finishing phase were acquired retrospectively. The inclusion criteria were Class I dental malocclusion with only minimal crowding ($\leq$3 mm), 12–20 aligner steps per arch, no use of auxiliaries or interarch elastics, and rotations $\leq$25° for round-shaped teeth. The prescribed and corrective movements to be achieved in the main and finishing treatment phases, respectively, were quantified by the dedicated clear aligner setup software. The magnitudes of inclination (buccal-lingual crown tipping), angulation (mesial-distal crown tipping), rotation, intrusion, and extrusion were extracted and analyzed by tooth type, maxilla and mandible, and both arches. Descriptive statistics, that is, mean, standard deviation, and percentage, were calculated for each movement investigated. Classification and regression trees (CART) were generated using the model-based recursive partitioning approach, and the corrective movements were correlated with respect to both the amount of the movements prescribed and the tooth type. Statistical significance was set at 5%.

Results: Inclination and rotation required the greatest correction, whereas angulation, intrusion, and extrusion required only minimal correction. Expressed as a percentage of prescribed movement, mean corrective movements were 20.5% for inclination, 14.5% angulation, 28.4% rotation, 11.7% extrusion, and 22% intrusion. According to CART, all corrective movements except extrusion depended on both tooth type and the magnitude of prescribed movement.

Conclusions: To achieve more efficient CAT, approximately 20% overcorrection should be added to the initial planning phase when planning challenging movements such as inclination and rotation. (*Angle Orthod.* 2022;93:11–18.)

KEY WORDS: Clear aligner therapy; overcorrection

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INTRODUCTION

During the past 15 years, a considerable number of studies on the effectiveness of clear aligner therapy (CAT) have been published. In 2009, Kravitz et al. reported the average effectiveness of clear aligners (CAs) as 41%.[1] The most predictable movement was considered lingual movement (47.1%), whereas the least predictable movements were extrusion (29.6%), mesial-distal crown tipping of the mandibular canines (26.9%), and rotation of the mandibular canines (29%).[1] Haouili et al. published an updated set of these results in 2020, reporting that, although movement accuracy had slightly improved (to 50%), rotations still had poor predictability (46%).[2] However, as overcorrection had been included during the initial digital planning phase, the authors declared that these percentages may have underestimated the real effectiveness of the Invisalign system (Align Technology, Santa Clara, Calif). Despite this, the percentage of CAT effectiveness remained quite low.[2] Similar findings have been reported by other authors, leading to the conclusion that nonoptimal effectiveness of this method is common.[3,4] Predictability is considered to be worse in cases considered more difficult,[5] specifically extraction cases,[6] cases with open bite or deep bite greater than 1.5 mm,[7] or when pure root movements (torque and translational movements) were necessary.[8]

Despite these limitations, CAT seems to be a reasonable choice in cases of mild–moderate difficulty, with results achieved being comparable with digital setup planning.[5] In addition, several auxiliaries, such as divots, interarch and extrusion elastics, and/or elastic derotation chains, can be used to improve outcomes. However, the need for mid-course correction is common and, unlike fixed appliances, CAT can be modified only minimally by the clinician during treatment. Hence, one or multiple finishing phases are often necessary for the prescribed outcomes to be achieved.[1] In fact, although the manufacturers of these systems estimate a much smaller percentage (20%–30%), multiple finishing phases have been reported in about 70%–80% of patients treated with CAs.[1] This is more likely when complex movements, such as derotation of round-shaped teeth (canines and premolars), torque movements, and intrusion of the incisors, are planned.[5,9]

Because a finishing phase is so commonly required in CAT, Bilello et al. suggested that it should be considered an extension of the treatment proper.[10] This would bring its accuracy to a high of about 95% for buccal-lingual tipping movements and a low of roughly 86% for rotations.[10] Despite these remarkable results in terms of effectiveness, the same authors stated that they used an additional 25 aligners, on average, per arch in the finishing phase. Together with those aligners used in the main treatment phase, this brought the overall treatment series to a total of about 50 aligners per arch overall. Such a long series of finishing aligners inevitably leads to increased cost, treatment duration, and chair time for the clinician that, ideally, should be as limited as possible to provide treatment that is both effective and efficient.

To improve the efficiency of CAT, some authors recommended the inclusion of overcorrection in the initial phase of virtual treatment planning.[3,4,8,11] Although Haouili et al. did include overcorrection in their study, the amounts used were empirical and not based on scientific evidence.[2] Otherwise, information on the magnitude of overcorrection that should be included is absent from the literature.

Therefore, the aim of this study was to provide clinically useful information regarding the overcorrection to be included in the initial treatment planning of CAT. This was achieved by evaluating the extent of the corrective movement required in the finishing phase in a large number of cases successfully treated using CAT, relating the corrective movements to both the amount of movement prescribed originally and tooth type.

The null hypothesis was that the same amount of overcorrection should be added to the initial setup for all planned movements investigated, regardless of the magnitude of movement prescribed or tooth type.

MATERIALS AND METHODS

Patients treated orthodontically with CAT (F22 Aligners, Sweden & Martina, Due Carrare, Italy) were selected retrospectively from the University of Ferrara's electronic database. All patients had required a finishing, or refinement, phase after the main treatment series to achieve the desired occlusal outcome. This study was approved by the University of Ferrara Postgraduate School Ethics Committee, registration number 7/2020, and the conducted research conformed with the Declaration of Helsinki.

Selected patients were those treated in the years 2016–2020 who met the following inclusion criteria:

- Class I dental malocclusion with minimal crowding in both arches ($\leq$3 mm)[12] treated with a series of 12–20 CAs per arch.
- No use of interarch elastics, auxiliaries (elastic derotation chains or extrusion elastics), miniscrews, cantilevers, or fixed buccal and lingual partial appliances.
- Permitted use of grip points and interproximal enamel reduction (IPR).
- Initial setup prescribing derotation movements of round-shaped teeth (premolars and canines) $\leq$25°, with no mesial-distal or forward-back translational movements.
- Positioning of grip points on teeth for derotations $\geq$10°.
- No previous history or active periodontal disease at the beginning of orthodontic therapy.

After this first selection phase, the corresponding finishing phases were assessed. For inclusion, these had to meet the following criteria:

- Single finishing phase with the number of total aligners $\leq$12.
- Exclusive use of aligners in the finishing phase.

After application of the inclusion criteria, 150 patients (80 women and 70 men; mean age 33.7 years ± 12.7) were selected. A table of dental movements, both those prescribed in the main treatment phase (prescribed movements) and in the subsequent finishing phase (corrective movements), was acquired for each patient using the appropriate setup software. Both angular and linear movements were quantified for each of the eight tooth types (incisors, canines, premolars, and molars for both the maxilla and mandible), by upper and lower arch separately, and by both arches together. Specifically, three angular movements (inclination [buccal-lingual crown tipping], angulation [mesial-distal crown tipping], and rotation) and two linear movements (intrusion and extrusion) were investigated.

Prescribed and additional corrective movements of inclination and angulation were performed through coronal movement, with the center of resistance being positioned digitally between the apical one-third and middle-root one-third in single-rooted teeth, and 2-mm apical to the furcation in multirooted teeth.[13] Only absolute values were considered for both angular and linear measurements with no distinction of direction. This was done because there was no difference in direction between the prescribed and corresponding corrective movement in any case. Prescribed angular and linear movements with absolute values of $\leq$2° and $\leq$0.2 mm, respectively, were considered not clinically important, and were, therefore, omitted from the statistical analysis.

The virtual setups and CAT were performed by two orthodontic specialist clinicians from the Department of Orthodontics of the University of Ferrara who were certified by the Italian Board of Orthodontic Aligners. CAT was carried out using polyurethane F22 Aligners with buccal grip points created using Gradia Direct LoFlo flow composite (GC Orthodontics Europe, Breckerfeld, Germany).

Statistical Analysis

First, a descriptive analysis of the 150 retrospectively selected cases was performed, recording the number of observations and the mean and standard deviation (SD) of each of the five types of movements investigated, both prescribed and corrective. The magnitude of each corrective movement was also reported as a percentage of the corresponding prescribed movement.

Subsequently, classification and regression trees (CARTs) were generated for each movement analyzed using model-based recursive partitioning. This approach was used to analyze the magnitude of corrective movements in the finishing phase (dependent variable) as a function of recursive partitions (splits) of the data, showing both the magnitude of prescribed movements in the main treatment phase and as a function of the tooth type (independent variables). Splits enable nonlinear and hierarchical relationships in data to be restored.

Statistical software R (R Foundation for Statistical Computing, Vienna, Austria) and associated packages were used, and the statistical significance was assessed at a threshold of 5%. As similar studies that previously analyzed the accuracy of CAT used sample sizes ranging from 20[4] to a maximum of 120 patients,[7] the sample size of the current study was deemed appropriate.

RESULTS

An adequate number of observations was obtained for all tooth types, with the exception of angulation ($n = 11$ and $n = 10$), extrusion ($n = 0$) and intrusion ($n = 9$) of molars and premolar extrusion ($n = 9$ and $n = 10$) and intrusion ($n = 19$ upper premolars). The mean values and their respective SDs of both prescribed and corrective movements are reported for each tooth type, for the maxilla and mandible, and for both arches (Tables 1 and 2). Specifically, for angular measures, the mean values of prescribed and corrective movements were 4.87° ± 2.52° and 0.85° ± 1.20° for inclination, 3.35° ± 1.26° and 0.45° ± 0.56° for angulation, and 9.01° ± 6.2° and 2.29° ± 3.08° for rotation (Table 1). For linear movements, they were 0.67 ± 0.33 mm and 0.07 ± 0.15 mm for extrusion and 0.75 ± 0.41 mm and 0.14 ± 0.2 mm for intrusion (Table 2). Expressed as a percentage of the prescribed movements, the amount of correction required in the finishing phase to achieve the prescribed outcomes averaged 20.5% for inclination, 14.5% for angulation, 28.4% for rotation, 11.7% for extrusion, and 22% for intrusion. The greatest correction necessary was recorded for rotation of the incisors (40.2% and 39.7%, upper and lower, respectively) and canines (28.8% and 28.7%, upper and lower, respectively) (Table 3).

Subsequently, CART analysis was performed on the data for each type of movement investigated. This revealed that the mean value of correction for inclination movement required at the incisors was 1.24° ($n = 646$) when the prescribed movement was $\leq$12.2°, and 2.49° ($n = 15$) when it was $\geq$12.2°. As for premolar and molar inclination, the mean value of corrective movement necessary was 0.44° ($n = 635$), whereas for the canines, this varied according to the magnitude of the prescribed movement, that is, 0.77° ($n = 301$) when the mean value of prescribed

Table 1. Mean Values and SD of Prescribed and Corrective Movements Required for Inclination, Angulation, and Rotation[a]

		Inclination						Angulation						Rotation					
			Prescribed		Corrective				Prescribed		Corrective				Prescribed		Corrective		
	Tooth Type	Number	Mean (°)	SD (°)	Mean (°)	SD (°)	%	Number	Mean (°)	SD (°)	Mean (°)	SD (°)	%	Number	Mean (°)	SD (°)	Mean (°)	SD (°)	%
Maxilla	Incisors	301	4.58	1.98	1.28	1.20	0.328	186	3.70	1.40	0.54	0.52	0.154	487	10.32	7.37	3.44	3.38	0.402
	Canines	135	4.16	2.13	0.74	0.86	0.201	63	2.99	0.88	0.61	0.78	0.225	220	9.68	5.20	2.59	3.13	0.288
	Premolars	272	4.95	2.39	0.51	1.08	0.110	52	3.05	0.93	0.24	0.51	0.088	226	6.29	3.77	0.68	1.78	0.107
	Molars	45	4.27	2.61	0.27	0.84	0.077	11	3.99	2.32	0.18	0.60	0.083	71	5.10	2.50	0.02	0.13	0.001
	All tooth types	753	4.62	2.22	0.84	1.14	0.211	312	3.46	1.32	0.49	0.60	0.155	1004	8.90	6.29	2.39	3.16	0.282
Mandible	Incisors	360	5.36	3.20	1.27	1.51	0.29	188	3.32	1.25	0.39	0.44	0.128	481	9.57	6.48	2.89	2.90	0.397
	Canines	174	4.64	1.94	0.86	1.01	0.20	73	3.07	0.96	0.51	0.68	0.167	225	10.23	4.96	2.68	3.43	0.287
	Premolars	274	5.19	2.62	0.44	0.83	0.10	61	3.24	1.33	0.37	0.59	0.133	285	8.03	4.91	0.98	2.48	0.138
	Molars	44	3.97	1.79	0.17	0.64	0.05	10	3.08	0.80	0.16	0.32	0.062	43	4.44	2.03	0.07	0.49	0.011
	All tooth types	852	5.09	2.75	0.86	1.25	0.200	332	3.24	1.19	0.41	0.53	0.135	1034	9.08	5.77	2.20	3.00	0.286
Total		1605	4.87	2.52	0.85	1.20	0.205	644	3.35	1.26	0.45	0.56	0.145	2035	9.01	6.02	2.29	3.08	0.284

[a] % indicates mean percentage of overcorrection needed for each of the movements investigated.

inclination change was $\leq$10.1° and 2.13° (n = 8) when it was $\geq$10.1° (Figure 1).

Regarding angulation, the mean value of corrective movement required at the lower incisors, premolars, and molars was roughly 0.35° (n = 322), whereas for the upper incisors and canines, it depended on the magnitude of the prescribed movement: 0.49° (n = 262) for prescribed movements $\leq$4.2° and 0.79° (n = 60) for prescribed movements $\geq$4.2° (Figure 2).

For rotation, correction required at the premolars and molars was, on average, 0.38° (n = 392) for prescribed movements $\leq$6.7° compared with 1.02° (n = 207) for prescribed movements $\geq$6.7°; for the incisors and canines, the mean amount of correction performed was 2° (n = 673) for prescribed movements $\leq$8.1°, 2.67° (n = 205) for prescribed movements between 8.1° and 10.3°, and 3.52° (n = 355) for those between 10.3° and 17.5° (Figure 3). For larger prescribed movements (>17.5°) of the lower incisors, upper canines, and premolars, the mean correction performed was 4.15° (n = 95) for prescribed movements of between 17.5° and 26°, whereas 6.93° (n = 12) of corrective rotation was required for a prescribed >26° of rotation of the same teeth. For upper incisors and lower canines, on the other hand, the amount of correction required was, on average, 6.96° (n = 99) (Figure 3).

For intrusion, an average of 0.04 mm (n = 139) of correction was recorded at the upper canines, premolars, and molars, whereas at the lower canines and incisors, the amount of correction depended on whether the magnitude of prescribed movement was less than or greater than 0.9 mm. For prescribed movements less than 0.9 mm, an average corrective movement of 0.11 mm (n = 283) was recorded at the upper incisors and lower canines, whereas at the lower incisors, it was 0.18 mm (n = 216). For prescribed movements greater than 0.9 mm, the mean corrective movement performed was 0.2 mm (n = 211) (Figure 4).

Table 2. Mean Values and SD of Prescribed and Corrective Movements for Extrusion and Intrusion[a]

		Extrusion						Intrusion					
			Prescribed		Corrective				Prescribed		Corrective		
	Tooth Type	Number	Mean (mm)	SD (mm)	Mean (mm)	SD (mm)	%	Number	Mean (mm)	SD (mm)	Mean (mm)	SD (mm)	%
Maxilla	Incisors	70	0.78	0.33	0.10	0.17	0.139	256	0.78	0.43	0.14	0.19	0.207
	Canines	30	0.62	0.32	0.06	0.15	0.124	79	0.70	0.36	0.07	0.14	0.143
	Premolars	9	0.42	0.11	0.01	0.03	0.022	19	0.47	0.29	0.01	0.02	0.013
	Molars	0	–	–	–	–	–	6	0.33	0.05	0.00	0.00	1,000
	All tooth types	109	0.71	0.33	0.08	0.16	0.125	360	0.74	0.41	0.11	0.18	0.179
Mandible	Incisors	17	0.56	0.17	0.05	0.11	0.080	323	0.82	0.42	0.19	0.22	0.295
	Canines	14	0.70	0.40	0.03	0.08	0.060	131	0.68	0.36	0.12	0.20	0.205
	Premolars	10	0.42	0.15	0.07	0.16	0.170	29	0.45	0.17	0.01	0.03	0.016
	Molars	0	–	–	–	–	–	6	0.45	0.32	0.00	0.00	1,000
	All tooth types	41	0.58	0.28	0.05	0.11	0.094	489	0.75	0.41	0.16	0.21	0.251
Total		150	0.67	0.33	0.07	0.15	0.117	849	0.75	0.41	0.14	0.2	0.220

[a] % indicates mean percentage of overcorrection needed for each movement investigated.

Table 3. Mean Percentage Overcorrection Needed for Each Movement Investigated

		Mean Percentage of Overcorrection Needed				
	Tooth Type	Inclination (%)	Angulation (%)	Rotation (%)	Extrusion (%)	Intrusion (%)
Maxilla	Incisors	32.8	15.4	40.2	13.9	20.7
	Canines	20.1	22.5	28.8	12.4	14.3
	Premolars	11,0	8.8	10.7	2.2	1.3
	Molars	7.7	8.3	0.1	–	100,0
	All tooth types	21.1	15.5	28.2	12.5	17.9
Mandible	Incisors	29.4	12.8	39.7	8.0	29.5
	Canines	19.9	16.7	28.7	6.0	20.5
	Premolars	10.2	13.3	13.8	17,0	1.6
	Molars	5.4	6.2	1.1	–	100,0
	All tooth types	20,0	13.5	28.6	9.4	25.1
Total		20.5	14.5	28.4	11.7	22

For extrusion, the mean corrective movement performed was 0.07 mm ($n = 150$), irrespective of the tooth type or the magnitude of movement prescribed. As a matter of fact, no recursive splits of data concerning these independent variables investigated are present (Figure 5).

DISCUSSION

Although the range of treatment indications for CAs has broadened over time, the predictability of all movements planned in the main phase of treatment does not reach anywhere near 100%. The average accuracy of CAT ranged between 41% and 73%,[1–3,8,14] depending mainly on the type of movement, its magnitude, and the tooth type investigated. Also of importance is the type of aligner and the material the aligner is made from, not to mention planning accuracy, the manual skill of the orthodontist, and patient compliance. Especially problematic movements to achieve are root torque, bodily translation,[8] and derotation of round-shaped teeth,[9] which often entail mid-course corrections and/or additional finishing phases.

The objective of this study was to obtain clinical information regarding the amount of overcorrection to be included in the initial planning of CAT to reduce the necessity for or duration of the finishing phase. A large cohort of cases treated with CAT were selected retrospectively, and the corrective movements required in the finishing phase were evaluated and compared with respect to the magnitude of movements prescribed in the main treatment phase and according to tooth type. Setups were performed by orthodontists experienced in CAT who did initial virtual planning with attention to orthodontic biomechanical principles. Inclination and angulation were planned through coronal movements (crown tipping), avoiding any root

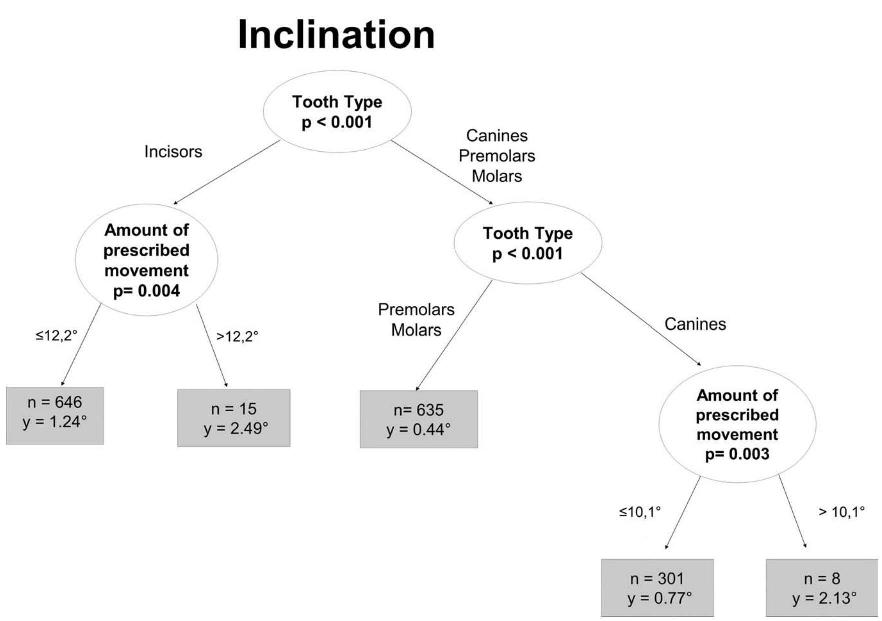

Figure 1. CART analysis of inclination (buccal-lingual crown tipping) movement.

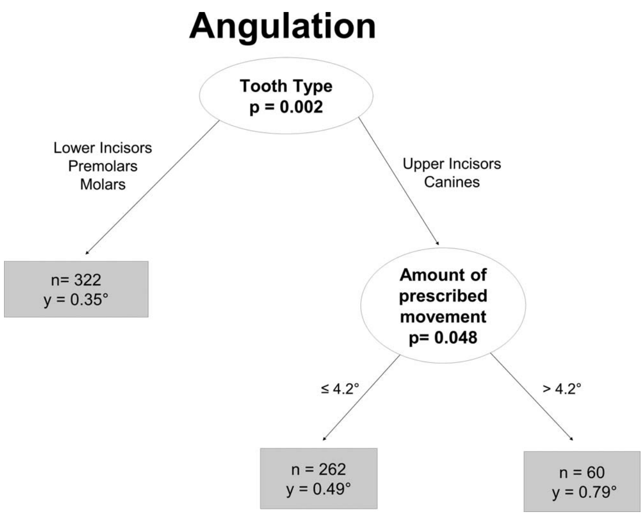

Figure 2. CART analysis of angulation (mesial-distal crown tipping) movement.

movement, as previously reported and suggested by Zhang et al.[15] In addition, cases that required only a single finishing phase with a small series of aligners were chosen for analysis. These inclusion criteria enabled the selection of cases treated successfully with CAT, avoiding potentially skewed data due to patient noncompliance or multiple finishing phases.

Although the current study was not conducted using the Invisalign system (Align Technology), which forms the bulk of the literature on the topic of CAT, the same biomechanical principles can be applied regardless of aligner brand, making the results generalizable. The CAs wear protocol used by patients in this study was the one most widely used in orthodontics: 22 h/d with tray replacement every 2 weeks.[11] Patients were seen monthly to monitor aligner fit (without the use of dental monitoring),[16] and progressive IPR was conducted until the prescribed amount had been reached.

The data confirmed that, despite careful planning with due attention to orthodontic biomechanical principles, a refinement phase, albeit short, is necessary for CAT to be completely successful. During the finishing phase, inclination needed to be corrected by an average of 20.5% of the initial prescription, angulation 14.5%, rotation 28.4%, extrusion 11.7%, and intrusion 22%. Based on this analysis, both inclination and rotation appear to be the movements that are the least accurate and, therefore, require the greatest amount of overcorrection in the initial planning phase.

CART analysis revealed correlations between the magnitude of corrective movements required and both the amount of the initial prescription and the tooth type. Specifically, the amount of correction performed during the finishing phase was found to be directly proportional to the magnitude of the movements initially planned and varied according to tooth type. Different tooth types not only have different coronal and radicular anatomy[14] but also are located in areas of the arches with differing bone density.[17] As a whole, the findings refuted the null hypothesis that all planned movements would require the same amount of overcorrection, regardless of tooth type or the magnitude of movement prescribed.

Analyzing the tooth type variable in depth revealed that more inclination and angulation replanning was needed in the esthetic anterior sectors (incisors and

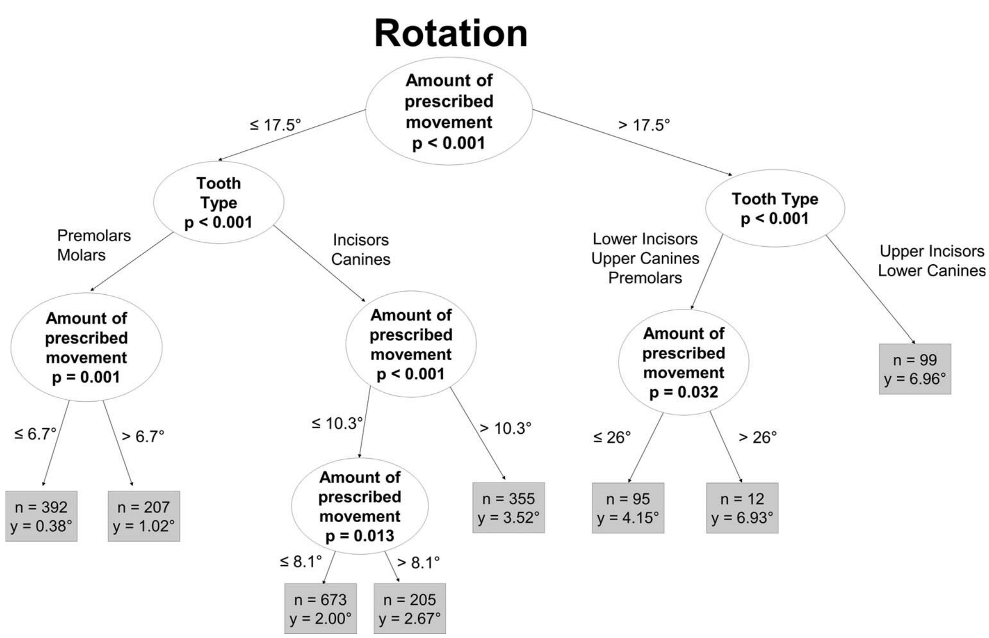

Figure 3. CART analysis of rotation movement.

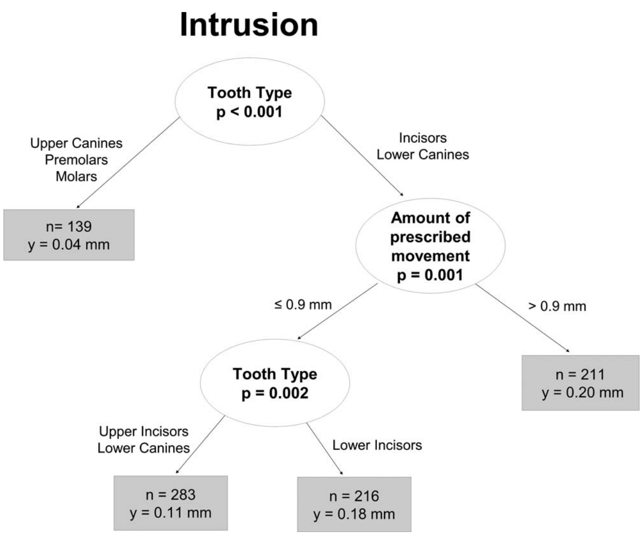

Figure 4. CART analysis of intrusion movement.

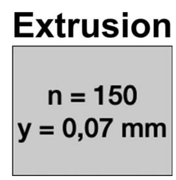

Figure 5. CART analysis of extrusion movement.

canines). This was likely influenced in part by the fact that clinicians tend to focus more on refining the anterior rather than the posterior sectors because the anteriors are of greater esthetic impact and importance to the patient. As for rotation, the premolars required the greatest amount of correction, likely because of their round coronal morphology, which made it difficult for the transmission of effective rotational forces.

The findings partially confirmed data in the literature that showed that rotation was the most difficult type of movement to achieve with aligners.[1,2,4,14] Rotational control was found to depend on both the coronal morphology and the amount of correction required.[1,3] In addition, the current study revealed a critical threshold value for the planned movement of about 17.5°, similar to that found by Simon et al. for premolars[3] and by Kravitz et al. for the upper canines.[1] Specifically, Simon et al. stated that the accuracy of premolar derotation decreased from 43.3% to 23.6% if the prescribed movement was greater than 15°.[3] Kravitz et al. reported a similar reduction from 35.8% to 18.8% for the upper canines.[1]

However, the data reported in the current study suggested that this threshold value pertained to all teeth and not only round-shaped teeth. In other words, overcorrection should be applied to all teeth, and it should be greater than that reported by Boyd.[18] In addition, although for the cases investigated in this study, the setup provided for positioning of grip points for planned derotation of greater than 10° for round-shaped teeth, it was evident that the extent of the corrective movements required depended mainly on the degree of rotation initially planned. The need for greater correction in the anterior sectors also extended to angulation, although this did not usually exceed 1°.

Analysis of intrusive movements revealed the need for correction of about 0.2 mm for planned intrusion of the incisors and lower canines greater than 0.9 mm. However, the amount of correction required decreased for smaller prescribed movements. With extrusion, on the other hand, the need for replanning was minimal and did not depend on either the type of tooth or the extent of the movement prescribed.

Although this study can be considered innovative, there were some methodological limitations that need to be highlighted. In particular, the study design was retrospective and was conducted using cases treated with CAT that were considered to be successful. Therefore, the study was not representative of all possible clinical conditions (eg, noncompliant patients, inexperienced operators, and/or use of auxiliaries). In addition, despite the large number of patients in the sample, some data reported were derived from only a few observations. Further studies with larger samples should resolve these issues. Others should incorporate overcorrection using amounts reported in the current study in the initial setup phase to validate the data presented. However, it should be considered that incorporation of overcorrection may not, in itself, necessarily lead to optimal results.

Other important factors for success of treatment include fit of the aligners and patient compliance, both of which might be affected negatively by intentionally programming overcorrection into the prescription. Further study of this topic is, therefore, recommended.

CONCLUSIONS

- To optimize CAT performance, overcorrection should be incorporated into the initial digital setup.
- Based on the study sample, approximately 20% (19.42%) overcorrection should be prescribed for challenging movements, particularly inclination and rotation. Other movements could benefit from smaller percentage overcorrection.
- For angular movements, both inclination and rotation overcorrection values appear to depend on both tooth type and the magnitude of the movement prescribed.
- For linear movements, intrusion accuracy depends on both tooth type and, to a lesser extent, the magnitude of the prescribed movement, whereas extrusion accuracy does not.
- Based on these findings, the null hypothesis is rejected.

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