Utility of Automated Digital Setup for Orthodontic Treatment Planning

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Abstract

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Digital setups (also known as treatment simulations) allow orthodontists to visualize predicted outcomes of various treatment plans. Recent integration of artificial intelligence in the treatment simulation software packages has improved the efficiency of digital setups. However, little is known about the utility of automated simulations in assisting orthodontists with treatment planning. The purpose of this study was to assess the utility of automatically generated digital setups in helping orthodontists make informed treatment decisions and to identify the strengths and shortcomings of automated setups. The perception of orthodontists towards digital treatment simulations was also analyzed to identify barriers in their implementation in the daily practice of orthodontics.

This study had two parts. Part I involved an online survey sent to approximately 18,000 orthodontists through Facebook® and the American Association of Orthodontists®. The survey

collected information to help understand the purpose, frequency, and modality of orthodontic treatment simulation for fixed appliances cases. The second part of this study involved orthodontist evaluation of automated treatment simulations generated for 5 patient cases using uLab® uDesign®. Orthodontists answered questions regarding the need for a diagnostic setup for each case, the helpfulness of each setup, and the quality of automated setups.

From the 145 completed surveys collected, it was shown that up to 71% of orthodontists perform some setups to assist with treatment planning of patients treated with fixed appliances. The most common simulated plan was single mandibular incisor extraction. Time, cost, and effort were identified as primary barriers to creating a diagnostic treatment simulation. Evaluation of automated treatment simulations by orthodontists in Part II revealed that digital setups were helpful in 68% of treatment decision-making incidences. The parameters needing the most improvements were alignment and spacing as well as tip and torque of teeth. Significant associations were observed between helpfulness of automated setups and when there is perceived need for a setup, when the case is more difficult, when the quality of the automated setup is high, and for a single mandibular incisor extraction plan.

The orthodontists judged the setups in this study as less than ideal on several parameters, and as the quality of automated setups improves, they should become even more useful. Future studies should focus on quantifying improvements in setup efficiency through automation and comparing the utility of different automated treatment simulation systems. In addition, more research is needed to determine the threshold of accuracy in automated digital setups in the decision-making process of treatment planning.

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INTRODUCTION:

Orthodontic Treatment Simulation

Orthodontic setups, also known as orthodontic treatment simulations, traditionally involved sectioning and rearranging plaster teeth in wax to represent their final positions after treatment. Originally developed for the fabrication of the Tooth Positioning Appliance, this technique was described by Kesling in 1945[1,2] and has since allowed orthodontists to make more informed decisions about treatment options[3–5]. Because each patient presents a unique set of skeletal and dental relationships, treatment simulations allow the orthodontist to assess the viability of plans tailored to each patient. They provide insights on the need for extractions, anchorage requirements, and specific mechanics to obtain optimal alignment and occlusion[4]. Ideally, each patient's case would be analyzed with one or more setups to allow visualization of viable plans. However, the challenge with plaster setups is the time and effort needed to perform them. Advancements in digital dentistry since the 1980's paved the way for what is now known as digital orthodontic setup and virtual treatment planning[6]. The application of computer-aided design and manufacturing (CAD/CAM) dramatically improved the process of orthodontic treatment simulation.

Digital Orthodontic Setup

The paradigm shift in clear aligner therapy with the Invisalign® appliance (Align™ Technology, Tempe, Arizona) in 1997 revolutionized the landscape of orthodontics and the way we leverage technology in treatment planning. By simulating outcomes using digital models, a novel way of treating malocclusion emerged. However, to digitize the orthodontic setup process several key problems needed to be resolved. These problems included accurate capturing of complex tooth geometry, identification and sectioning of teeth, and the virtual staging of tooth movement to a clinically, aesthetically, and biologically acceptable final position[7]. Align™ Technology overcame these challenges and reimagined Dr. Kesling's technique as a computer-based manufacturing process. With input and specifications from the practitioner, patient records are submitted to Invisalign® and transformed into digital setups by technicians using computer programs. This customized process gives the provider the ability to forecast treatment outcomes and lays the foundation for the series of aligners to be fabricated.

Digital orthodontic setups are a resource efficient and user-friendly alternative to analog setups. With digital setups, tooth movement can be measured precisely, and tooth position at any stage can be superimposed on the original model. A study on the effect of digital setups on orthodontic treatment planning suggested that using digital setups to assess multiple treatment options increases the overall confidence level of practitioners, especially for challenging cases and for less experienced practitioners[3]. Whether setups are used to fabricate clear aligners, to design customized brackets and arch wires, or to facilitate consultation with new patients, orthodontic setups have become ubiquitous in clinical practice. Orthodontists can outsource digital setups to commercial laboratories such as Align™ and 3M™ (Saint Paul, Minnesota) and receive a digital setup within days. A major downside of the Invisalign® method, however, is that it still relies heavily on technicians to move teeth to their desired locations. Thus, many companies are developing new methods to make setups more efficient by automating various required tasks. This will allow quick and efficient digital treatment simulations.

Automation of Digital Setups

A recent application of artificial intelligence (AI) in orthodontics is the automation of digital treatment simulations. Software developers seek to improve the accuracy of teeth segmentation - a critical step within the digital setup framework - through convolutional neural network[8]. Computer programs are being "trained", through deep learning, to recognize patterns in malocclusion and suggest the most appropriate treatment options[9]. Depending on the preference and workflow of the practitioner, digital setups can now be constructed in three ways, giving the practitioner varying levels of control and input: (1) manually with programs such as Maestro 3D Dental Studio (Maestro 3D, Pisa, Italy), where parameters are reviewed by the users and alignment of teeth are performed manually; (2) semi-automatically with programs such as Autolign (Diorco, Gyeonggi-do, Korea), where teeth alignment is performed automatically after user review of dental and occlusal parameters; (3) fully automatically with programs such as iTero Outcome Simulator Pro (Align™ Technology, Tempe, Arizona) and Medit Ortho Simulation (Medit, Seoul, Korea) without any user input, both of which are integrated with corresponding intraoral scanners.

uLab® Systems' uDesign® software (Memphis, Tennessee) is another example of an orthodontic simulation platform that leverages the expertise of orthodontists to create realistic digital setups. They are also developing an automated setup feature to be released with a future update. The mission of uLab® is to equip orthodontists with tools to construct diagnostic and therapeutic orthodontic setups in a short amount of time, stating that users of uLab® can treatment plan a case in minutes.

While this advancement in digital orthodontic treatment simulation seems promising, a 2023 study examining the accuracy of automated setup concluded that manual adjustment to the final simulation is still needed for the fabrication of aligners and in-direct bonding templates[10]. The challenge with full automation of digital orthodontic setups is that mistakes in pertinent tasks such as definition of clinical crown axes and orientation of the occlusal plane can still be made by the software. And although teeth segmentation has become increasingly sophisticated, most software programs continue to require the user to confirm that the complete tooth morphology is captured, and machine errors are reconciled. Digital orthodontic setups can be as reliable as analog setups for answering key questions in treatment planning[11]. However, there is a lack of research data to show whether automated orthodontic simulation technology can create accurate and realistic diagnostic setups that help orthodontists make treatment decisions.

Purpose of Study

The purpose of this study was twofold. First, we examined the current application of digital setups for fixed appliances cases in clinical orthodontics. We wished to better understand the perception of orthodontists towards digital setups and identify barriers in implementing digital treatment simulation in the daily practice of orthodontics. Second, we assessed the utility of automatically generated digital diagnostic setups for five cases of varying complexity. We aimed to identify the strengths and shortcomings of automated setups in the simulation of orthodontic treatment outcomes.

MATERIALS & METHODS:

This study was reviewed and approved by the University of Washington (UW) Institutional Review Board and was supported by the UW Orthodontic Alumni Association.

uLab® Systems provided access to software, technical support, and facilitated practitioner interview sessions for the evaluation of automated setups but did not provide any direct funding.

This study had two parts: Part I, a survey to collect information on the perception of orthodontists towards digital treatment simulation (digital setup); Part II, one-on-one interviews with orthodontists to evaluate automated digital treatment simulations of five patients with various orthodontic treatment needs.

Part I: Digital Setup Survey

The first part of this study was an online survey to help understand the purpose, frequency, and modality of performing orthodontic treatment simulation for fixed appliances cases in clinical practices. To maximize representation of the orthodontic profession, an invitation to participate in the survey was distributed to the American Association of Orthodontists® Partners in Research program (AAO) and all members of the Orthodontic Pearls and OrthoPreneurs Facebook® groups (FB). In addition, the same questionnaire was given to all participants in Part II (*Automated Setup Evaluation: Practitioner Interview*) of this study (P2). Participation was voluntary and each participant could complete the survey only once. Informed consent and researchers' contact information were included in the invitation.

The anonymous survey was created with Typeform® (Barcelona, Spain) and included 14 multiple choice questions (Appendix I). The first part of the survey collected basic demographic information such as age, sex, and clinical experience (years in clinical practice). Participants were then asked questions relating to use of digital setups for treatment planning, including number of fixed appliance cases treated in the last 12 months, number of clear aligner cases treated in the last 12 months, modality and frequency of orthodontic setups for **fixed appliances**

cases performed in the last 12 months, case types for which orthodontic setups are typically constructed for, and experiences with various orthodontic simulation software. The survey was available from March to December of 2023.

Part 2: Utility of Automated Digital Setup for Orthodontic Treatment Planning

To assess the utility of automated digital setups for orthodontic treatment planning, automated setups were created using uLab® Systems uDesign® and were reviewed by participating orthodontists during one-on-one interview sessions. The utility of automated digital setups was determined by comparing the perceived need for treatment simulation for each of the five different patients with the helpfulness of the corresponding automated simulations. The quality of an automated setup was assessed by asking the orthodontist to identify areas of the simulation needing improvement. A sample size target of 30 orthodontists was selected based on a previous study on the effect of digital orthodontic setups on orthodontic treatment planning[3].

Patient Case Selection

Patient cases (Appendix II) were selected from the UW Department of Orthodontics clinical archive based on the following inclusion criteria: full permanent dentition with minimal restorations, Angle's Class I molar classification, complete records available (facial and intraoral photographs, intraoral scan, panoramic radiograph and lateral cephalometric radiograph tracing and measurements, Bolton tooth-size analysis), and were selected by a panel of three orthodontists to meet the following case descriptions: (1) deep bite and minor spacing, (2) deep bite and moderate crowding, (3) anterior open bite, (4) moderate crowding with significant anterior tooth-size discrepancy, (5) severe maxillary and mandibular crowding. The five case types represented a range of treatment difficulty levels commonly encountered in orthodontic practices. Each case was scored using the Peer Assessment Rating (PAR) Index to represent pre-treatment complexity. The panel reviewed all five cases and, for each case, decided on one treatment plan that was determined to be most appropriate in obtaining a desired final treatment simulation. Automated setups were generated according to the prescribed treatment plan.

Automated Setup

The digital models were imported into uLab® Systems uDesign® (V8.0 *Beta*), and tooth segmentation, occlusal plane orientation, vertical and mesiodistal axes orientation of clinical crowns, and tooth numbering were completed by the software without user input (Appendix III-A). Digital removal of teeth in treatment plans that included extractions were performed (Appendix III-A). Next, the “Auto Setup” feature was selected, treating all teeth in both arches (Appendix III-B). The times needed to prepare the models and to complete the “Auto Setup” feature for each case were recorded. No additional adjustments or revisions were made to the setup once completed.

Automated Setup Evaluation: Practitioner Interview

To participate, practitioners must have graduated from an orthodontic residency program. The evaluation sessions were conducted by one of two calibrated interviewers (AC and CS) either through Zoom (Zoom Video Communications, San Jose, California) or in-person. Each participant received de-identified patient records (Appendix II) for all cases prior to the interview session, so they could familiarize themselves with the cases. During the session, the records were briefly reviewed, the proposed treatment plan was described, and participants were asked the following questions to assess the perceived level of orthodontic treatment difficulty and the perceived level of need to perform a setup prior to treatment for each case: (1) on a scale of one to five, what is the orthodontic treatment difficulty level of this case; and, (2) is this a case you would typically perform a setup for to determine the feasibility of the treatment plan, and why. Participants subsequently evaluated the automatically generated orthodontic setup according to the proposed treatment plan from various views (Appendix IV-A to E.) and were asked to assess the quality of the setup based on the following parameters: (1) overjet and overbite, (2) canine and molar relationships, (3) tip and torque of teeth, (4) gingival contours, (5) alignment and spacing, (6) arch form and arch width, (7) anchorage management, and (8) occlusal contacts. Participants were prompted to select the parameters that could be improved. The participants were then asked about the helpfulness of the automated setup for treatment planning with the question – "Was this setup helpful in assessing the feasibility of the proposed treatment plan, and why?" Responses to all questions were manually recorded during the interview and recordings of both in-person and virtual evaluation sessions were obtained through Zoom with participant consent.

Statistical Analysis

The collected survey data were downloaded from Typeform® and stored on an encrypted web-based cloud storage platform. Information collected from the participants and answers to each question were described by frequency and percentage overall and by survey group. Information relating to participant demographics and answers to orthodontic setup related questions were calculated and described in frequencies and percentages. Practitioner demographic data was compared between the 3 survey groups using Fisher's exact test and

Pearson's Chi-square test, and post-hoc testing using Holm's method to account for the multiple testing.

To assess the utility of automated digital setups, quantitative outcomes (perceived difficulty level and number of improvements needed) were summarized by the mean and standard deviation for each case, and comparisons between cases were done using repeated measures ANOVA and post-hoc pairwise testing using paired t-tests. For categorical outcomes (perceived need for a setup and helpfulness) frequency and percentage were reported, and comparisons between cases were done using Cochran's Q test and post-hoc pairwise testing using McNemar's test[12]. Log-linear regression was used to test for associations with the need for setup and for helpfulness, and linear regression was used to test for associations with the number of needed improvements. The regression methods were performed using generalized estimating equations (GEE) to account for the repeated measures[13]. Holm's method was used to adjust the p-values for the multiple testing in the post-hoc comparisons[14]. All analyses were performed using R statistical software Version 4.3.0 (R Core Team, 2023) with significance level set at $\alpha = .05$[15].

RESULTS:

Part 1: Digital Setup Survey

The survey was distributed to 2,300 AAO® members through the Partners in Research program (AAO) and approximately 15,752 combined members in the Orthodontic Pearls and OrthoPreneurs Facebook® groups (FB). The survey was also completed by all 41 participants from Part II of this study (P2). A total of 145 surveys out of 18,093 potential participants were collected for an estimated completion rate of 0.8%. A summary of survey responder demographics is found in Table I. The survey sample comprised of 57% male and 43% female, with a varied age distribution of 2% under 25 years old, 28% between 25-34 years old, 23% between 35-44 years old, 25% between 45-54 years old, 15% between 55-65 years old, and 7% that are above 65 years old. Orthodontists with more than 15 years of experience (46%) were in the majority when compared to between 5-15 years (22%) and less than 5 years (32%). Most responders treated less than 200 cases using full fixed appliances (59%) and less than 75 cases using clear aligners (62%) in the past 12 months. Inferential analysis showed no major differences between the three groups of survey participants except for the number of aligner cases treated in the past 12 months ($p < .001$). The FB group treated fewer aligner cases in the past 12 months as compared to the AAO and P2 groups. While there was some evidence of a significant difference between the three groups for years in practice ($p = .034$) and the number of fixed appliances cases treated in the past 12 months ($p = .048$), post-hoc testing did not identify any significant differences between groups (adjusted $p > .05$). It is pertinent to note that there may be inherent differences in demographics between the three groups that were not captured by our survey questions, such as geographic location of residency training, the location of clinical practice, and accessibility to technology and software. To the author's knowledge, AAO members included orthodontists that completed an ADA/CDA-accredited orthodontic program in the U.S. or Canada, while members of the Facebook groups included residents and orthodontists worldwide. All samples in the P2 group were graduates of a U.S. orthodontic residency program and at least 18 were uLab® users.

Table II summarizes responses to questions regarding the use of orthodontic setups for fixed appliances cases. 71% of responders utilize orthodontic setup in their clinical practice, with the most frequently chosen reason being that it helps them make decisions regarding a treatment plan (80%). Reasons for why the other 29% of practitioners do not utilize orthodontic setups included the burden of time (31%), money (29%), and effort (29%), and that it does not help with treatment planning (29%). The most common case type that practitioners perform orthodontic setups for is single mandibular incisor extraction, with a 70% selection rate, followed by interdisciplinary treatment (68%) and unusual extraction patterns (59%). Most practitioners perform setups digitally on a computer (98%), 48% of which use in-office software exclusively. uLab® Systems was shown to be the leading program among 15 other orthodontic simulation software for both the AAO and the P2 groups, which was significantly more than the FB group ($p < .0001$). The 3Shape software is the most used simulation platform for the FB group, with a significantly higher selection rate when compared to the other two groups ($p = .00011$). If responses from the P2 group were excluded as many of the participants were known to be uLab® users, we found that uLab® Systems and 3Shape have equal representation (31%). The top reasons for outsourcing digital orthodontic setups to a commercial laboratory technician, such as through Align™ Technology, are the amount of time required to perform a setup (53%) and the lack of a subscription to a digital setup software (45%). Only two responders performed only analog setups with plaster and wax, citing three reasonings: (1) the lack of digital model acquisition, (2) the lack of a subscription to an orthodontic software, and (3) that plaster setups are more helpful than digital setups.

Table I. Digital Setup Survey Practitioner Demographics.

	Overall, N = 145	AAO, N = 31	FB, N = 73	P2, N = 41	p-value
Age, N (%)					**0.457[1]**
Under 25	3 (2)	0 (0)	3 (4)	0 (0)	
25-34	41 (28)	10 (32)	23 (32)	8 (20)	
35-44	33 (23)	8 (26)	13 (18)	12 (29)	
45-54	36 (25)	8 (26)	16 (22)	12 (29)	
55-64	22 (15)	3 (10)	11 (15)	8 (20)	
65+	10 (7)	2 (7)	7 (10)	1 (2)	
Sex, N (%)					**0.367[1]**
Female	62 (43)	15 (48)	27 (37)	20 (49)	
Male	83 (57)	16 (52)	46 (63)	21 (51)	
Years in practice, N (%)					**0.0342[1]**
Less than 5 years	46 (32)	8 (26)	30 (41)	8 (20)	
5-15 years	32 (22)	11 (36)	10 (14)	11 (27)	
More than 15 years	67 (46)	12 (39)	33 (45)	22 (54)	
No. fixed appliances (past 12m), N (%)					**0.048[2]**
Less than 200 cases	85 (59)	14 (45)	47 (64)	24 (59)	
200-400 cases	44 (30)	12 (39)	16 (22)	16 (39)	
More than 400 cases	16 (11)	5 (16)	10 (14)	1 (2)	
No. clear aligners (past 12m), N (%)					**<0.001[2]**
Less than 75 cases	90 (62)	13 (42)	58 (80)	19 (46)	
75-150 cases	41 (28)	11 (36)	13 (18)	17 (42)	
More than 150 cases	14 (10)	7 (23)	2 (3)	5 (12)	
% orthodontic setups for fixed appliances cases, N (%)					**0.491[2]**
0%	42 (29)	12 (39)	19 (26)	11 (27)	
1%-5%	56 (39)	9 (29)	30 (41)	17 (42)	
6%-20%	27 (19)	5 (16)	14 (19)	8 (20)	
More than 20%	20 (14)	5 (16)	10 (14)	5 (12)	

[1]Fisher's exact test; [2]Pearson's Chi-squared test

Table II. Digital Setup Survey Responses. Survey responses indicating modality, frequency, and purpose of orthodontic treatment simulation. Values are presented as frequency and percentage.

Survey Question					
What are your reasons for performing a setup when treatment planning a case that will undergo fixed appliances? N (%)					
	Overall, N = 103	**AAO, N = 19**	**FB, N = 54**	**P2, N = 30**	**p-value**
It helps me make decisions regarding a treatment plan	82 (80)	15 (79)	40 (74)	27 (90)	0.22[1]
It helps me communicate better with my patient	62 (60)	10 (53)	34 (63)	18 (60)	0.73[2]
It helps me communicate better with other providers	31 (30)	6 (32)	13 (24)	12 (40)	0.31[2]
Other	7 (67)	1 (5.3)	3 (6)	3 (10)	-
What type of fixed appliances patients do you routinely perform a setup for? N (%)					
	Overall, N = 103	**AAO, N = 19**	**FB, N = 54**	**P2, N = 30**	**p-value**
Single lower incisor extraction	72 (70)	14 (74)	30 (55.6)	28 (93)	**0.0013[2]**
Interdisciplinary cases	70 (68)	11 (58)	37 (68.5)	22 (73)	0.52[2]
Unusual extraction patterns	61 (59)	10 (53)	25 (46.3)	26 (87)	**0.0012[2]**
Significant tooth size discrepancy	50 (40)	9 (47)	22 (40.7)	19 (63)	0.14[2]
Orthognathic surgical treatment	43 (42)	6 (32)	28 (51.9)	9 (30)	0.092[2]
Moderate to severe crowding – non-extraction	23 (22)	5 (26)	11 (20.4)	7 (23)	0.86[2]
When you perform orthodontic setup for fixed appliances patients, which format do you use? N (%)					
	Overall, N = 103	**AAO, N = 19**	**FB, N = 54**	**P2, N = 30**	**p-value**
I use both plaster and digital setups	11 (11)	1 (5)	9 (16.7)	1 (3)	0.15[1]
Setups only with digital models on a computer	90 (87)	18 (95)	44 (81.5)	28 (93)	0.26[1]
Setups only with plaster models and wax	2 (2)	0 (0.0)	1 (1.9)	1 (3)	1.0[1]
What are your reasons for performing a plaster setup instead of a digital setup when treatment planning for a fixed appliances patient? N (%)					
	Overall, N = 2	**AAO, N = 0**	**FB, N = 1**	**P2, N = 1**	**p-value**
I do not acquire digital models	1 (50)	0 (0)	1 (100)	0 (0)	-
I do not subscribe to a digital software	1 (50)	0 (0.0)	1 (100)	0 (0)	-
A digital setup is not as helpful as a plaster setup	1 (50)	0 (0.0)	0 (0)	1 (100)	-
It takes too long for digital setups to be performed by a third-party technician	0 (0)	0 (0.0)	0 (0)	0 (0)	-
Other	0 (0)	0 (0.0)	0 (0)	0 (0)	-
For your digital setups for fixed appliances patients, how are they performed? N (%)					
	Overall, N = 101	**AAO, N = 19**	**FB, N = 53**	**P2, N = 29**	**p-value**
In-office with an orthodontic software	48 (48)	7 (36.8)	24 (45)	17 (59)	0.30[2]
Outsourced to a third-party technician such as Invisalign®	38 (38)	9 (47.4)	21 (40)	8 (28)	0.35[2]
Both	15 (15)	3 (15.8)	8 (15)	4 (14)	1.0[1]
If you perform digital setups in-office, which software do you use? N (%)					
	Overall, N = 63	**AAO, N = 10**	**FB, N = 32**	**P2, N = 21**	**p-value**
uLab® System	29 (46)	7 (70)	6 (19)	16 (76)	**<0.0001[1]**

3Shape	13 (21)	0 (0)	13 (41)	0 (0)	**0.00011**[1]
SureSmile	7 (11)	1 (10)	1 (3)	5 (24)	0.052[1]
OrthoSelect DIBS AI	6 (10)	3 (30)	2 (6)	1 (5)	0.077[1]
ArchForm	3 (5)	1 (10)	2 (6)	0 (0)	0.40[1]
Orchestrate 3D	1 (1)	0 (0)	1 (3)	0 (0)	1.0[1]
Diorco Autolign	0 (0)	0 (0)	0 (0)	0 (0)	-
Maestro 3D Dental Studio	0 (0)	0 (0)	0 (0)	0 (0)	-
Other	12 (19)	2 (20)	9 (28)	1 (5)	-
OnyxCeph	*6 (10)*	*1 (10)*	*5 (16)*	*0 (0)*	0.23[1]
Ormco Insignia	*1 (2)*	*0 (0)*	*1 (3)*	*0 (0)*	0.66[1]
iTero Outcome Simulator	*1 (2)*	*0 (0)*	*0 (0)*	*1 (5)*	0.49[1]
LightForce	*1 (2)*	*1 (10)*	*0 (0)*	*0 (0)*	0.16[1]
Planmeca Romexis	*1 (2)*	*0 (0)*	*1 (3)*	*0 (0)*	1.0[1]
Medit	*1 (2)*	*0 (0)*	*1 (3)*	*0 (0)*	1.0[1]
NemoCast	*1 (2)*	*0 (0)*	*1 (3)*	*0 (0)*	1.0[1]

Reasons for not performing setups: N (%)

	Overall, N = 42	**AAO, N = 12**	**FB, N = 19**	**P2, N = 11**	**p-value**
It takes too much time	13 (31)	5 (42)	4 (21)	4 (36)	-
It costs too much money	12 (29)	4 (33)	6 (32)	2 (18)	-
It takes too much effort	12 (29)	3 (25)	7 (37)	2 (18)	-
It does not help with treatment planning	12 (29)	2 (17)	8 (42)	2 (18)	-
Other	11 (26)	3 (25)	4 (21)	4 (36)	-

Reasons for not performing in-office digital setups: N (%)

	Overall, N = 38	**AAO, N = 9**	**FB, N = 21**	**P2, N = 8**	**p-value**
It takes too long to perform a digital setup by myself or my staff	20 (53)	5 (56)	9 (43)	6 (75)	-
I do not subscribe to a digital setup software	17 (45)	4 (44)	11 (52)	2 (25)	-
The setups do not simulate treatment realistically	8 (21)	2 (22)	4 (19)	2 (25)	-
The software costs too much money	5 (13)	1 (11)	4 (19)	0 (0)	-
The software is difficult to learn and/or operate	5 (13)	1 (11)	1 (5)	3 (38)	-
Other	2 (5)	0 (0)	2 (10)	0 (0)	-

[1]Fisher's exact test; [2]Pearson's Chi-squared test

Part 2: Utility of Automated Digital Setup in Orthodontic Treatment Planning

Practitioner Demographics

Forty-one practitioners participated in the interview portion of this study. Of the participants there was a near equal sex representation of 21 male and 20 female. 22 of the 41 participants had more than 15 years of practice experience, while 11 had between 5-15 years and 8 had less than 5 years. The age of practitioners ranged between 25 years old and over 65 years old, with over 58% either in the 35-44 or 45-54 age groups. When compared to the basic demographics of the survey sample, no significant differences were observed for practitioner age or sex.

Patient Case Description

All five selected cases had Angle's Class I molar classification pre-treatment and represented different commonly diagnosed malocclusions with a variety of orthodontic complexities. PAR scores ranged from 14 (Case 1) to 52 (Case 5) with average perceived case difficulty ranging from 2.15 (Case 1) to 3.95 (Case 4) out of 5. The case types, proposed treatment plans, PAR scores, and average perceived level of difficulty for each case are described in Table III. There were significant differences between the 5 cases in the perceived difficulty level ($p < .001$). Post-hoc testing using paired t-test and Holm's method to adjust for the multiple testing showed that Case 1 was significantly lower in difficulty level than Cases 2-5, and Case 2 was significantly lower in difficulty level than Cases 3-5 (adjusted $p < .05$). No other significant differences were observed. Automated setups constructed according to the proposed treatment plan were completed by uLab® uDesign® without alteration. On average, the preparation phase including occlusal plane orientation, tooth segmentation, tooth number, and axes definition took 2.5 minutes to complete, while the "Auto Setup" feature took less than 55 seconds to complete.

Table III. Automated Setup Case Description. Case type, proposed treatment plan, pre-simulation PAR score, and averaged perceived difficulty level as determined by practitioner interview.

Case	Case Type (Angle's Class I)	Proposed Treatment Plan	PAR Score	Participant Perceived Difficulty Level (1 to 5), mean (SD)[1]
1	Deep bite, minor spacing	Non-extraction	14	2.15 (0.82)[a]
2	Deep bite, moderate crowding	Non-extraction	30	2.80 (0.71)[b]
3	Anterior open bite	Non-extraction	16	3.88 (0.75)[c]
4	Significant anterior Bolton discrepancy	Single lower incisor extraction	34	3.95 (0.74)[c]
5	Severe crowding	Four first premolar extraction	52	3.88 (0.87)[c]

[1]There were significances differences between the 5 cases (repeated measures ANOVA, p-value < .0001). [a, b, c] Cases with different subscript letters are significantly different (Paired t-test, Holm's adjusted p-value < .05).

Automated Setup Evaluation – Perceived Setup Need

When asked whether the practitioner would typically perform a setup for each case to determine the feasibility of the treatment plan, one practitioner (2%) answered yes to Case 1, 10% replied yes for Case 2, 41% for Case 3, 90% for Case 4, and 44% for Case 5 (Table IV). There were significant differences between the 5 cases ($p < .001$). Post-hoc testing using McNemar's test and Holm's method to adjust for multiple testing revealed that setups were judged less needed for Cases 1 and 2 compared to Cases 3, 4, and 5; and setups were judged less needed for Cases 3 and 5 compared to Case 4 (adjusted $p < .05$). The primary reasons practitioners would set-up a case include visualizing the outcome of the proposed plan, determining amount and direction of teeth movement, helping patients visualize the proposed treatment plan, and evaluating different treatment plans. Common reasons not to perform a setup included that the case was too simple/straightforward/predictable, and that orthodontic setups are not a part of their clinical workflow. A summary of commonly stated reasons whether to perform a setup for each case can be found in Table VI.

When examining the variables that influenced the perceived need for a setup, we found significant positive association with case difficulty level ($p = .002$), PAR score ($p < .001$), extraction ($p < .001$), and clinical experience ($p = .011$) (Fig. 1-A through D).

Table IV. Automated Setup Evaluation Questions and Responses. The first question was asked prior to viewing the automated setup to assess the perceived need for a setup for each case. The second question was asked after viewing the automated setup to assess the helpfulness of the setup and its utility for treatment planning.

	Would you typically set up this case? N (%)[1]	**Was the setup helpful? N (%)**[1]
Case	Yes	Yes
1	1 (2%)[a]	23 (56%)[a]
2	4 (10%)[a]	24 (59%)[a]
3	17 (41%)[b]	29 (71%)[a]
4	37 (90%)[c]	41 (100%)[b]
5	18 (44%)[b]	22 (54%)[a]

[1]There were significances differences between the 5 cases (Cochran's Q test, p-values < .0001). *[a, b, c] Cases with different subscript letters are significantly different (McNemar's test, Holm's adjusted p-value < .05).*

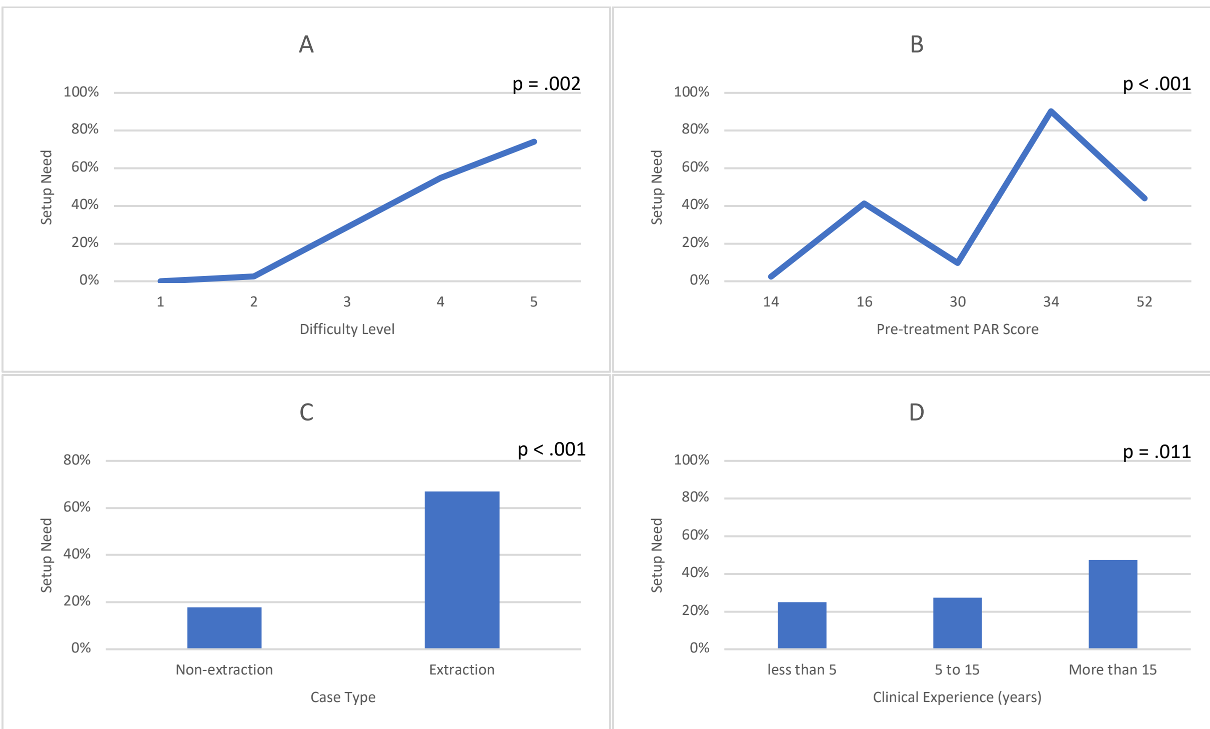

Figure I. Perceived Need for Orthodontic Setup. Represented by the percentage of participants finding a patient case to need a setup to facilitate treatment planning. Stratified by (A) case difficulty level, (B) pre-treatment PAR score. (C) case type: extraction vs. non-extraction, (D) practitioner clinical experience**.**

Automated Setup Evaluation – Quality

The quality of automated setups was assessed by asking the practitioners to identify areas needing improvement from a list of 8 parameters. The quality of setup for each case was determined by the average number of selected parameters needing improvement per practitioner, per case. The total and average frequency of selection for each parameter needing improvement in each case is summarized in Table V. Case 5 was perceived to have the poorest setup quality, with an average of 5.8±1.3 improvements identified, which was significantly higher than Cases 1-4. Case 3 performed the best, with 3.0±1.3 parameters selected per practitioner (Table V). Alignment and spacing were the most frequently selected and thus categorized as the parameter most commonly needing improvement, followed closely by tip and torque of teeth. Canine and molar relationships were the least frequently selected parameter (Fig. II).

There was a marginally significant positive association with case difficulty ($p = .074$) (Fig. III-A). Significant positive associations between number of improvements needed with PAR score ($p < .0001$) and with extraction cases ($p < .001$) were shown (Fig. III-B, C). Practitioners' experience was not found to be a significant factor ($p = .74$) (Fig. III-D).

Table V. Quality of Automated Setup. Determined by selection frequency of parameters needing improvement.

Case	**1**	**2**	**3**	**4**	**5**	
Parameter						**Total per parameter**
Alignment/Spacing	39	31	35	38	35	178
Tip/Torque	40	31	26	36	40	173
Gingival Contour	10	14	9	27	35	95
OJ/OB	20	15	8	9	39	91
Occlusal Contacts	19	14	17	15	21	86
Arch Form/Width	7	11	16	14	25	73
Anchorage	8	9	4	11	27	59
Canine Molar	2	7	7	14	15	45
Total per case	145	132	122	164	237	
No. of improvements needed. Mean (SD)	$3.54\ (1.1)^{a,c}$	$3.22\ (1.4)^{a,b}$	$2.98\ (1.3)^{b}$	$4.00\ (1.5)^{c}$	$5.78\ (1.2)^{d}$	**p-value**[1] <.001

[1]There were significances differences between the 5 cases (repeated measures ANOVA, p-value < .0001). a, b, c. Cases with different subscript letters are significantly different (Paired t-test, Holm's adjusted p-value < .05).

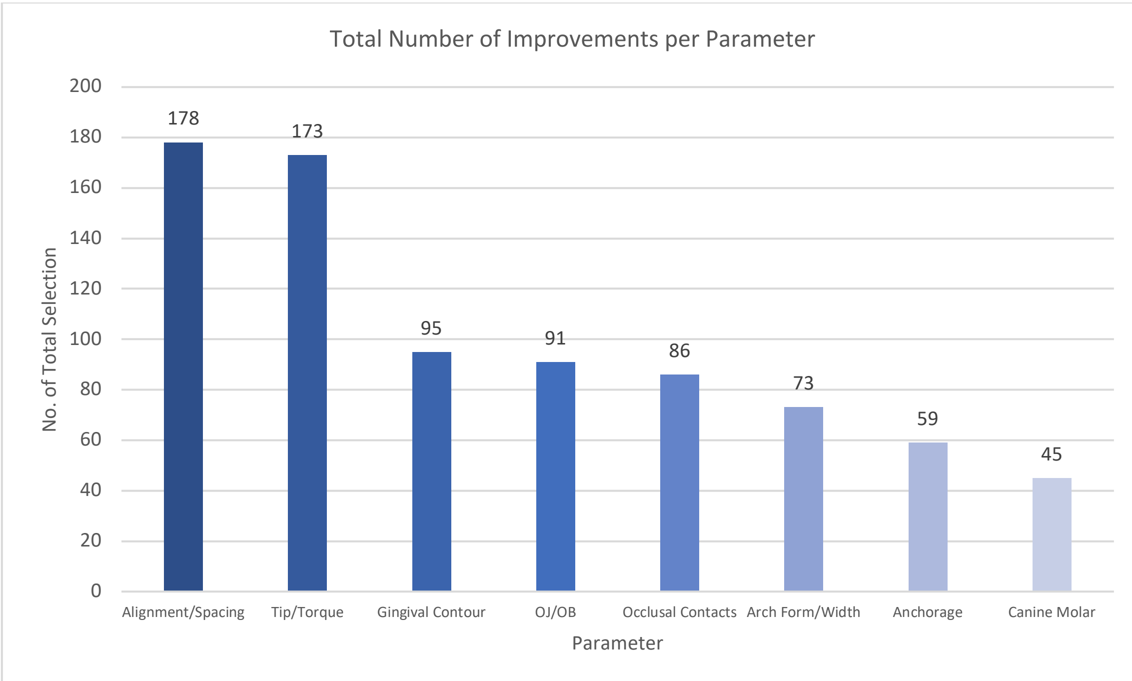

Figure II. Total Count of Improvements Identified. Alignment and spacing were the most selected parameter needing improvement, followed closely by tip and torque of teeth. Canine and molar relationships were the least selected parameter.

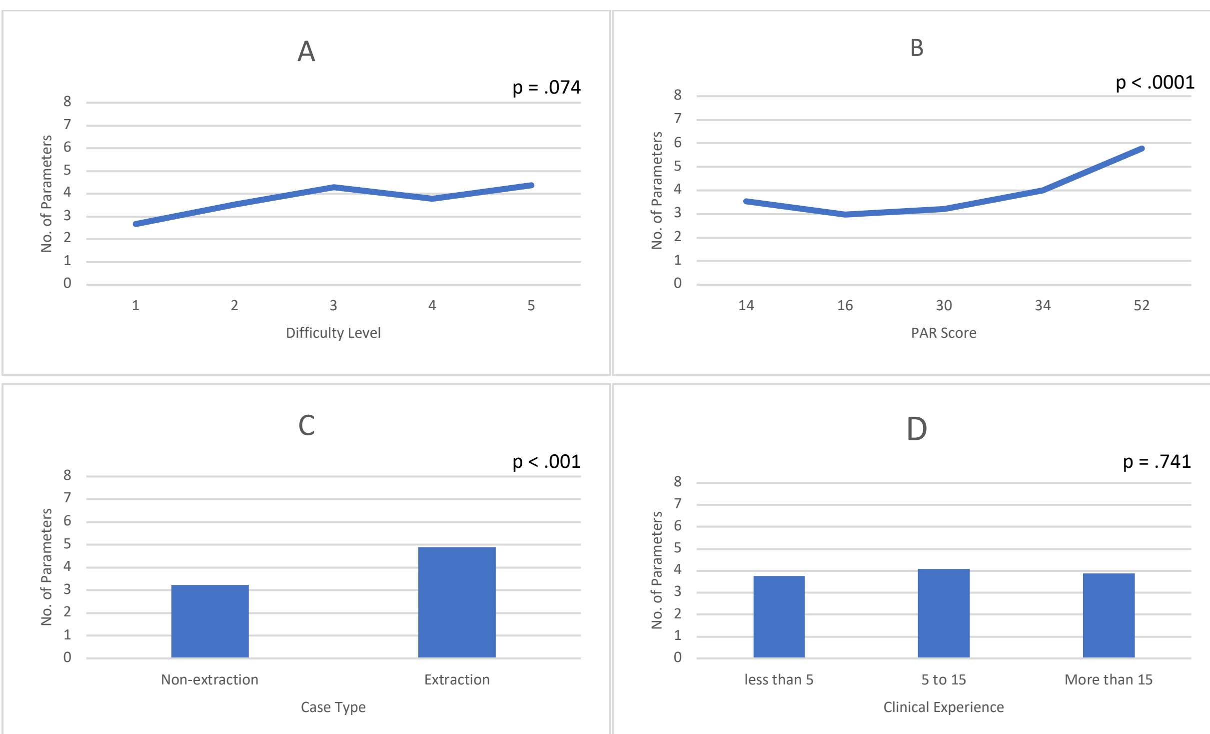

Figure III. Quality of Automated Setup. Determined by number of improvements needed identified by practitioners. Stratified by (A) case difficulty level, (B) pre-treatment PAR score, (C) case type: extraction vs. non-extraction, (D) practitioner clinical experience.

Automated Setup Evaluation – Setup Utility

After evaluating the automated setups, over half of the practitioners thought that setups were helpful regardless of the case type or treatment plan, with 100% of participants finding the automated setup for a single incisor extraction (Case 4) was helpful for determining the feasibility of the plan (Table IV). The setup for Case 4 was significantly more helpful than Cases 1, 2, 3, 5 (adjusted $p < .05$). The relationships between utility of automated setups and various factors can be visualized in Figure IV. It was found that as perceived difficulty level increase, utility of the setup also increases significantly ($p = 0.002$). However, no association was found between PAR scores and utility of setup ($p = .16$). With respect to the proposed treatment plan, automated setups for extraction cases were more helpful than for non-extraction cases ($p < .001$), though this difference was mostly due to single lower extraction (100% helpful). In terms of quality of automated setups, there was a negative and significant association between number of improvements needed selected for a case and the utility of the automated setup ($p = .014$), suggesting that the better the quality of an automated setup the more helpful it is for orthodontic treatment planning. Practitioners with between 5 to 15 years of experience found setups to be less helpful than those with more or less experiences ($p < .001$). Lastly, the higher the perceived need for a setup, the more helpful they found the corresponding automated setup to be ($p < .001$). A summary of commonly stated reasons whether a setup for each case was helpful is described in Table VI. The top reasons for finding an automated setup helpful were visualization of the proposed treatment plan, information on amount and location of interproximal reduction (IPR), information on teeth movement, and communication with patients. The top reasons for not finding an automated setup helpful were that the case was not complex enough to warrant a setup, and that the setup was not ideal/realistic.

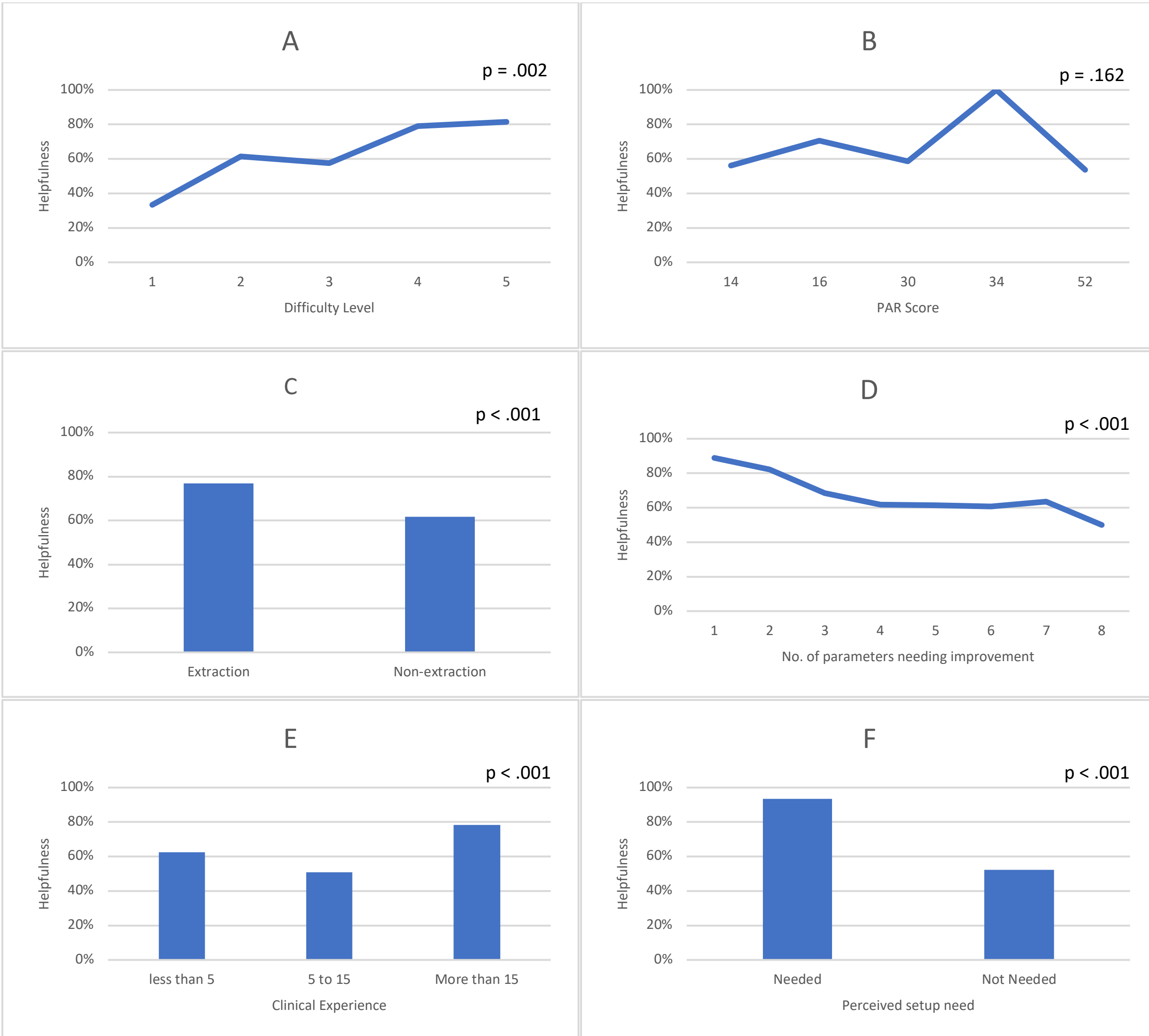

Figure IV. Helpfulness of Automated Setups. Represented through the percentage of participants finding a setup to be helpful, stratified by (A) case difficulty Level, (B) pre-treatment PAR score, (C) case type: extraction vs. non-extraction, (D) number of improvements needed, (E) practitioner clinical experience, (F) perceived need for a setup.

Table VI. Automated Setup Evaluation Questions and Responses – Reasoning. Summary of reasoning to support answers to questions regarding perceived need for setup and helpfulness of setup. Verbal reasoning given by each practitioner was recorded, analyzed, tabulated, and summarized. Values are presented as N (%).

Case 1 - Deep bite, mild spacing	
Would you typically set-up this case?	
Yes (n = 1)	
It is a part of my clinical workflow; to assist with anchorage determination	1 (100%)
No (n = 40)	
A setup is not needed; the case is simple, straightforward, predictable	35 (88%)
No Bolton tooth-size discrepancy or IPR needed; not an interdisciplinary case	10 (25%)
Do not typically do setups; not in workflow; no time	8 (20%)
Was the setup helpful?	

Yes (n = 23)	
It is always good to visualize the outcome of a proposed plan	14 (61%)
It gave information on IPR and/or restorations due to residual spacing	7 (30%)
The setup exposed a potential Bolton discrepancy	4 (17%)
It would help with patient communication	2 (9%)
No (n = 18)	
The case is not complex enough to warrant a setup	11 (61%)
The setup was not accurate/realistic	7 (39%)
Case 2 - Deep bite, moderate crowding	
Would you typically set-up this case?	
Yes (n = 4)	
To determine direction and amount of teeth movement	3 (75%)
It is a part of my clinical workflow	1 (25%)
No (n = 37)	
A setup is not needed; the case is simple, straightforward, predictable	28 (76%)
Do not typically do setups; not in workflow; no time	5 (14%)
No Bolton tooth-size discrepancy, non-extraction, no specific anchorage requirement	4 (11%)
Was the setup helpful?	
Yes (n = 24)	
It is always good to visualize the outcome of a proposed plan	7 (29%)
It gave information on the direction and amount of teeth movement – expansion vs. proclination	6 (25%)
It gave information on IPR amount and location	4 (17%)
It would help with patient communication	4 (17%)
It confirmed the proposed non-extraction plan	3 (13%)
It gave information on anchorage requirements; elastics may be needed	2 (8%)
No (n = 17)	
The case is not complex enough to warrant a setup	11 (65%)
The setup was not accurate/realistic	7 (41%)
Case 3 – Anterior open bite	
Would you typically set-up this case?	
Yes (n = 17)	
To determine direction and amount of teeth movement – intrusion vs. extrusion	8 (47%)
To visualize the outcome of the proposed plan	7 (41%)
To determine amount/location of IPR needed	3 (18%)
To evaluate different treatment plans including non-extraction vs. extraction vs. surgery	2 (12%)
To help patients visualize the proposed treatment plan	1 (6%)
No (n = 24)	
A setup is not needed; the case is simple, straightforward, predictable	20 (83%)
Do not typically do setups; not in workflow; no time	3 (13%)
AOB cases are highly compliance dependent; vertical correction unpredictable	1 (4%)
Was the setup helpful?	
Yes (n = 29)	
It is always good to visualize the outcome of a proposed plan	15 (52%)
It gave information on IPR amount and location	12 (41%)
It showed that posterior intrusion is needed to close AOB	4 (14%)

It showed that anterior extrusion proposed may not be biologically feasible	3 (10%)
No (n = 12)	
The case is not complex enough to warrant a setup	9 (75%)
The setup did not give information on how to properly address AOB	2 (17%)
The setup was not accurate/realistic	1 (8%)
IPR location and distribution was no ideal	1 (8%)
Case 4 - Significant anterior Bolton discrepancy	
Would you typically set-up this case?	
Yes (n = 37)	
I always perform a setup for single incisor extraction plans	37 (100%)
To evaluate different treatment plans: single incisor vs. 4 premolars vs. non-extraction	17 (46%)
To visualize the outcome of a proposed plan	3 (8%)
To help patients visualize the proposed treatment plan	2 (5%)
No (n = 4)	
A setup is not needed; the case is simple, straightforward, predictable	2 (50%)
Do not typically do setups; not in workflow; no time	2 (50%)
Was the setup helpful?	
Yes (n = 41)	
It confirmed the feasibility of the proposed treatment plan	39 (95%)
I would do more setups to evaluate other treatment plans	6 (15%)
It would help with patient communication	4 (10%)
It gave information on IPR amount needed to achieve anterior coupling	3 (7%)
No (n = 0)	
n/a	n/a
Case 5 - Severe crowding	
Would you typically set-up this case?	
Yes (n = 18)	
To evaluate extraction vs. non-extraction plans	15 (83%)
To evaluate different extraction patterns	3 (17%)
Because there is Bolton tooth-size discrepancy	2 (11%)
To help patients visualize the proposed treatment plan	1 (6%)
No (n = 23)	
A setup is not needed; the case is simple, straightforward, predictable	19 (83%)
Do not typically do setups; not in workflow; no time	3 (13%)
I do not agree with the proposed treatment plan	2 (9%)
Was the setup helpful?	
Yes (n = 22)	
It is always good to visualize the outcome of a proposed plan	16 (73%)
It gave information on the direction and amount of teeth movement	4 (18%)
It gave information on IPR amount and location	3 (14%)
It would help with patient communication	2 (9%)
It helped me decide on an alternative treatment plan	2 (9%)
No (n = 19)	
The setup was not accurate/realistic	13 (68%)
The case is not complex enough to warrant a setup	11 (58%)

DISCUSSION:

Digital treatment simulation transformed the practice of orthodontics by allowing practitioners to virtually diagnose, plan, and treat patients. It is always used when fabricating aligners and customized fixed appliances and can be combined with cone-beam computed tomography (CBCT) to simulate root and periodontal changes. However, digital setups for fixed appliance treatments are not required with stock brackets - the most common treatment option in orthodontic practices - and may not be performed routinely for treatment planning due to inefficiency. This prompted us to explore the utility of automated digital setups for patients planned to be treated with non-custom fixed appliances.

Integration of AI in the simulation software packages continues to push the boundaries of efficiency, directly addressing concerns with the increase in non-clinical doctor time spent on digital treatment planning[17]. A significant reduction in time to construct a digital setup through automation was documented in a study by Woo et al[10]. They reported that fully automated systems took 1.1-3.1 minutes to perform a simulation, and semi-automated setups, which included some manual tasks such as axis identification took 12 minutes to complete. Regardless of the level of user input, both automated and semi-automated setups were generated faster when compared to the 19.8 minutes to 2 hours needed for manual digital setup construction as found in previous studies [10,11], a drastic improvement in efficiency. Our study supported their results, finding that automated digital setups constructed using uLab® uDesign® took an overall average of 3.5 minutes.

Despite an unequivocal improvement in efficiency, however, the question of whether automated setups can realistically reflect practitioners' treatment objectives remains. Our study sought to answer this question by examining the utility of automated setups for treatment planning. Through one-on-one interviews, orthodontists reviewed automated treatment simulations of five patients with various complexity of treatment needs and found them to be helpful an average of 68% of the time. We found that automated setups are most useful when: (1) the orthodontic treatment difficulty level is high; (2) the perceived need for a setup prior to initiating treatment is high; (3) extraction of teeth is planned; (4) the quality of the automated setup is high. According to our data, 93% of the practitioners found automated setups to be helpful when there was a need to perform treatment simulations for a case, and over half of them found automated setups to be helpful even if they initially felt a setup was unnecessary. The results of this study highlighted the utility of digital setups in treatment planning and demonstrated that automated simulations can assist orthodontists in their treatment decision making process.

An important finding of our study was the relationship between treatment needs, complexity, and the helpfulness of automated setups. The survey data revealed that evaluating a single mandibular incisor extraction plan was the most common reason practitioners perform a simulation for fixed appliances cases. This was supported by our finding where 100% of the practitioners found the automated simulation for a single mandibular extraction plan (Case #4) to be helpful. Single mandibular incisor extraction is a reasonable alternative when treating lower incisor irregularity, yet it is a relatively uncommon approach due to challenges in obtaining proper occlusion and mitigating risks for black triangles [18,19]. Not only could an automated setup quickly render the proposed final occlusion, but it could also specify locations and amounts of IPR to achieve ideal anterior coupling. It also provides a visual aid for patients to better understand the planned outcome. All of these were reasons cited by practitioners for the utility of automated setups for mandibular incisor extraction plans.

Moreover, it was shown in both parts of this study that digital setups are helpful for evaluating extraction plans, including symmetric extraction of four premolars and unusual extraction patterns. This finding highlights the complexity in recommending extraction as a part of orthodontic treatment, as both subjective and objective variables play significant roles when choosing to remove natural tooth structure to assist with treatment[20,21]. In Case #5 where the amount of crowding was categorized as severe in both arches, most of the participants (56%) did not think a setup was needed, with many practitioners describing it as a "textbook" four premolar extraction case. After viewing the setup, over 50% of the practitioners reported that the setup was helpful because it modeled the extraction outcome and predicted teeth movement. While an automated setup cannot directly provide a numerical value to dental crowding in its pre-treatment analysis, it provides immediate visual feedback to help the practitioner evaluate the consequences of extraction. This is especially helpful when there is ambiguity in the severity of crowding (i.e., borderline extraction cases), such as in Case #4, which can heavily influence the extraction decision. It appears that not only is it more common for practitioners to perform setups in extraction cases, but the automated setups are found to be more valuable in helping practitioners make treatment decisions (77%) when compared to non-extraction plans (62%).

Although automated setups seem to be effective as a diagnostic tool, deficiencies in their quality were still identified by the interviewed orthodontists. More specifically, automated setups for cases with planned extraction (Cases #4 and #5) were reportedly lower quality than non-extraction simulations. Case #5 had the highest number of improvements needed, with an average of 5.8 out of 8 errors identified per evaluator. According to participants, the final overjet in the four premolar extraction simulation (Case #5) was excessive, and the anchorage allocation for space closure was unrealistic. Gingival contours at the extraction site after space closure were inadequately simulated in both extraction cases, resulting in the formation of a “gingival cleft”. Several practitioners identified this as an issue if presented to patients, though it had minimal impact on treatment decision making. Final canine and molar relationships were another parameter that was more difficult for the software to simulate in extraction cases. These challenges could be attributed to the increase in the range of tooth movement when compared to non-extraction treatment simulations. Of course, companies will continue to improve their setup software/algorithms, and these deficiencies will likely be corrected over time.

Overall, alignment and spacing as well as the tip and torque of teeth were the most selected parameters needing improvement. A review of the setups revealed that spacings remained in various interproximal contacts and were not recognized by the Space Interferences indicator tool (Fig. V-A). Minor misalignments were identified, particularly at incisors and premolars (Fig. V-B), a pattern observed in all five patient cases. Tip and torque of incisors were not ideal in several renderings and the maxillary first molars in all setups displayed excess distal root tip. One explanation for these deficiencies could be the lack of user input during tooth segmentation and axes definition in our setup procedure, which was intentionally omitted to simulate a fully automated workflow. Any errors in defining the mesiodistal and vertical long axes could result in misalignment and non-ideal tooth angulation, as accurate and precise tooth orientation is foundational to ideal simulations. Furthermore, several studies have described the challenges tooth segmentation poses in the digitization of dental and soft tissue models[8,22–24]. Complexity and variation in tooth morphology make it difficult to develop a one-size-fits-all algorithm for tooth segmentation. There can be ambiguity in gingival margins and the boundaries between teeth, especially when crowding, restorations, and soft tissue defects are present. Interproximal surface data cannot be fully acquired through intraoral scanning and has to be reconstructed with intricate image completion methods; the spacing issue seen in uLab®'s automated setups could be a direct consequence of incomplete and inadequate surface reconstruction. Many researchers have strived to improve accuracy in tooth segmentation, proposing methods such as generative adversarial network to predict and reconstruct missing interproximal surface data[22]. However, when investigating various automated tooth segmentation methods, Im et al. found significant differences in the accuracy of 3D object segmentation and reconstruction, depending on the software used[23]. While no gross errors were identified in the preparation phase when we retrospectively evaluated the automated setups used in this study, our findings suggest that the algorithm employed in the software can heavily influence simulation outcomes, and that teeth segmentation is critical to and continues to be challenging in the construction of aesthetic, accurate, and realistic orthodontic simulations. Again, these algorithms and processes are expected to improve over time.

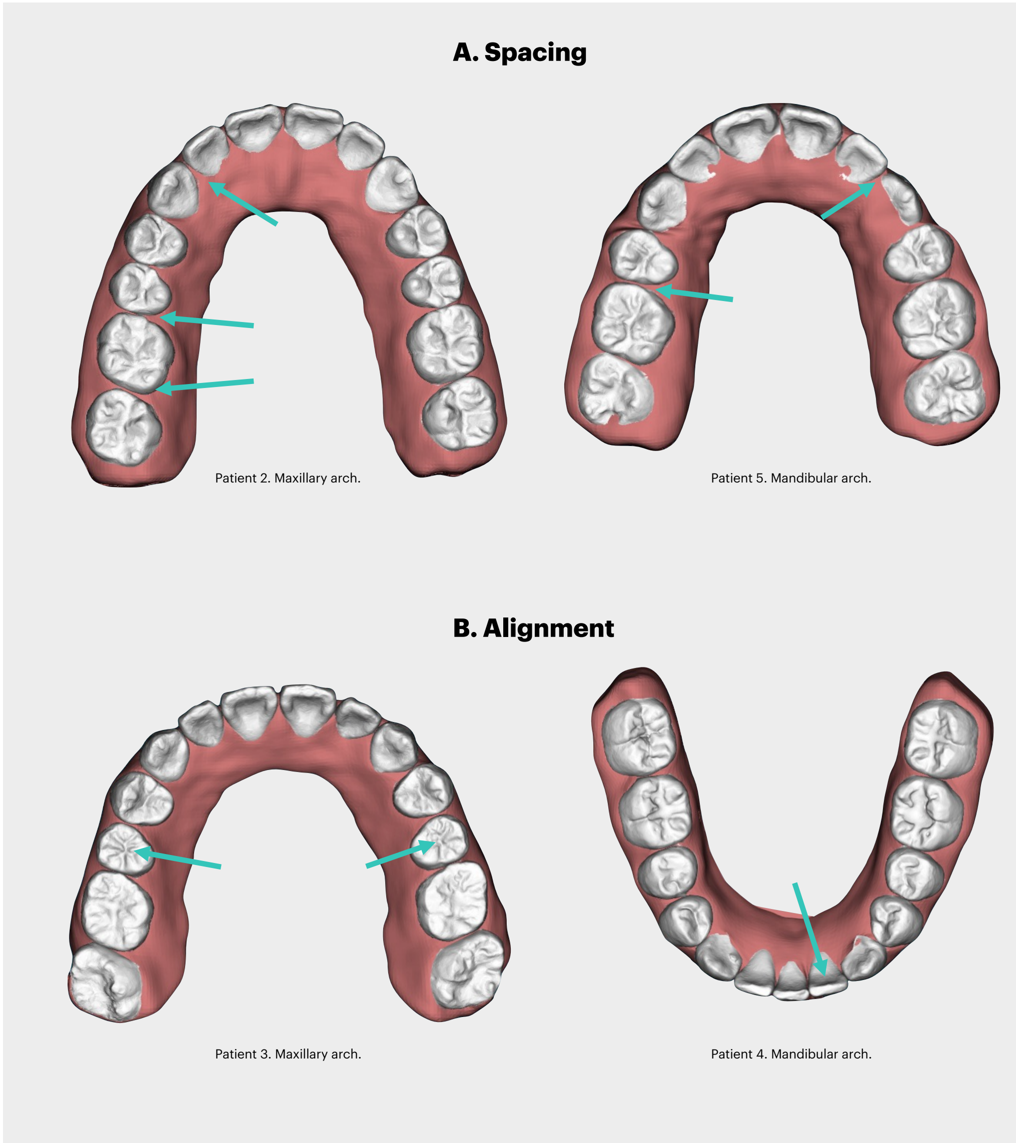

Figure V. Examples of Parameters Commonly Needing Improvement as Identified by the Orthodontists. (A) Spacing, identified visually by evaluation participants but were not indicated by the Space Interreferences indicator tool in uDesign® (B) Alignment, another commonly identified parameter that needed improvement.

Another explanation for teeth angulation as a commonly selected parameter needing improvement could be the preferences of the practitioner, which is made apparent by the variety of bracket prescriptions and treatment philosophies prevalent within orthodontics. Many practitioners pointed out the excess distal root tip in the maxillary first molars while others favored this angulation as it followed molar stolarization as described in Andrew's six keys to normal occlusion[25]. Some practitioners desired more maxillary canine offset, and some asked for increased palatal crown torque in the same teeth to accentuate canine root prominences. For parameters where there is agreement on what ideal is, such as overjet, overbite, and molar classification, there seems to be consensus on the adequacy of the algorithm's performance. Inversely, there is less consensus on the quality of automated setups when freedom of artistic expression is allowed within what is considered "ideal". While our profession has endeavored to establish quantifiable standards to measure treatment success by developing systems such as the American Board of Orthodontics Objective Grading System[26], a successful orthodontic treatment still depends on the patient needs, the experience and artistic preferences of the practitioner, and current industry best practices. These same considerations must be accounted for in the virtual simulation of orthodontic treatment, which can then be customized by the practitioner in preset protocols for different types of malocclusions.

Moreover, the practitioner's purpose for constructing a digital setup could influence their perception of utility and quality. Differentiation between diagnostic and therapeutic setup should be made when evaluating treatment simulations. During our practitioner interviews, we defined digital setup as a diagnostic simulation to aid in decision making when treatment planning and is not tailored to the fabrication of customized appliances (therapeutic digital setup). Yet, many practitioners expressed a desire to program overcorrection in specific types of malocclusions, such as deep bite and anterior open bite. Overcorrection up to 20% of an ideal setup when staging for clear aligner therapy has been proposed to achieve higher efficiency in movements, such as inclination (20.5%), angulation (14.5%), rotation (28.4%), extrusion (11.7%), and intrusion (22%)[27]. Digital therapeutic setups incorporating overcorrection, however, could look drastically different than a diagnostic setup meant to simulate a final ideal occlusion. A recent systematic review found digital setups to be clinically acceptable in their accuracy for simulating orthodontic treatment outcomes, especially for cases with less complex tooth movement. But when looking specifically at automated digital setups, they concluded that further manual adjustments to automated setups were needed for clinical use, regardless of the software used[16]. A diagnostic setup should simulate the desired outcome of a proposed treatment plan and reflect the objectives set forth by the orthodontist and patient. It could expose potential burdens of treatment such as restorative needs due to tooth-size discrepancy, or specific anchorage demands such as the use of temporary anchorage devices. On the other hand, a therapeutic setup represents an active force system designed by the orthodontist to achieve the intended orthodontic movements effectively. It requires knowledge in the properties of plastic aligners and force exertion on teeth depending on the size, shape, and direction of composite attachments. Most importantly, it requires expertise in the anatomy of teeth and the limitations of tooth movement. Future iterations of orthodontic simulation software should allow designated protocols for diagnostic and therapeutic setups.

Regardless of the purpose of digital setups, the findings in this study can provide a roadmap for orthodontists and software developers to improve the efficiency, quality, and utility of automated treatment simulations. Currently, digital setups can be easily transferred to our medical and dental colleagues as images, video-recordings, or as 3D STL (stereolithography) files for further manipulation. Fully automated setup platforms such as the Invisalign® Outcome Simulator Pro provides real-time illustration of a predicted outcome within minutes after a patient's teeth have been digitized with the iTero™ scanner, which can subsequently be used in patient consultation. It is exciting to imagine the future of digital orthodontics, where automated digital setups could be customizable based on individualized preferences, and treatment recommendations could be made by the software depending on the type and severity of malocclusion. Extraoral and CBCT scans could be integrated with setups to create virtual digital patients, and more realistically predict the dental, periodontal, and facial changes as a result of orthodontic treatment. This would enable a holistic approach to orthodontic treatment, placing the focus beyond the teeth and tissues that surround them. As technology continues to progress and engineers resolve shortcomings in the automated setup framework, the utility of automated setups will undoubtedly improve with time.

There were a number of limitations in this study. First, the participants represented a small sample of orthodontic practitioners and cannot fully capture the scope of experiences, characteristics, and preferences of providers in the field of orthodontics. Second, there is an inherent sampling bias as many of the practitioners who completed the survey are current uLab® users. Their specific experience with the uDesign® software could have had an influence on the interview outcomes, introducing bias to our dataset. Inclusion of the P2 group in the survey analyses skewed the response for the modality of digital treatment simulation (in-office software vs. third-party technician) and for the most commonly used in-office simulation software toward the use of in-office systems and uLab® uDesign®. Therefore, the true representation of modality of digital treatment simulation and the specific software used amongst orthodontists could be significantly different than what was described in this study. Third, only five cases were selected for the evaluation of automated setup, all of which were of Class I molar classification pre-treatment. While they represented a variety of case types and complexity as measured by PAR scores, they were certainly not all encompassing. Exploring a larger range of malocclusions and treatment plans could help identify additional deficiencies in automated setup software and clarify its value in many different types of cases. Fourth, digital tools are ever evolving, and the present study can only represent the performance of an unreleased version of one automated digital simulation software - the uLab® Systems uDesign®. Newer versions of different software with additional setup features are released regularly, changing the accuracy, efficiency, and reliability of the technology. The digital orthodontics space is crowded and competitive, with many companies marketing various digital products that facilitate efficient treatment planning. While this study is the first to investigate the utility of automated digital setups for treatment planning, only one specific product was tested, and the findings cannot be generalized to the functionality and performance of all digital orthodontic setup systems.

Revisiting our research objectives, we have found that automated orthodontic setups can be an efficient and useful diagnostic tool for treatment planning, especially for more difficult cases and those involving the extraction of teeth. It can also be used to facilitate conversations with patients and other practitioners. While efficiency of automated setups is important, increasing the quality of automated setups may be the most important area for improvement. Barriers to performing digital setups were identified as time, money, and effort. As more commercially available automated orthodontic setup software emerges, future studies should compare and investigate their efficiency, utility, and accuracy in helping practitioners arrive at the most ideal treatment plans.

CONCLUSION:

This study suggests the following conclusions:

1. Most orthodontists perform digital orthodontic setups to help with treatment decision making, either through an in-office simulation software or outsourced to a commercial laboratory.

2. The most common applications for setups are for extraction plans, especially single incisor extractions.
3. Barriers to implementing digital treatment simulation include time, money, and the effort required to perform a setup.
4. Automated treatment simulations are useful in helping practitioners make informed decisions in treatment planning regardless of the case type or the perceived need for a setup.
5. Automated setups are most helpful when the orthodontic treatment difficulty level is high, when there is perceived need for a setup, and when the quality of the automated setup is high.
6. The quality of automated setups appears to be adequate for orthodontic treatment planning but may be variable depending on the case complexity and case type.

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Appendix I

Orthodontic Treatment Simulation Survey Questions

Demographic Questions

1. What is your age?
    a. Under 25
    b. 25-34
    c. 35-44
    d. 45-54
    e. 55-64
    f. Over 65

2. What is your sex?
    a. Male
    b. Female
    c. Non-binary
    d. Prefers not to answer

3. For how many years have you practiced orthodontics?
    a. Less than 5 years
    b. 5-15 years
    c. More than 15 years

4. In the past 12 months, how many cases did you treat with fixed appliances?
    a. Less than 200 cases
    b. 200-400 cases
    c. More than 400 cases

5. In the past 12 months, how many cases did you treat with clear aligners?
    a. Less than 75 cases
    b. 75-150 cases
    c. More than 150 cases

6. For how many cases do you perform diagnostic orthodontic setups (physical or digital) prior to starting treatment for a patient with fixed appliances (brackets)? This includes digital setup via treatment simulation by a third-party technician (i.e., Invisalign® technicians)
    a. 0%
    b. 1-5% (skip to Question #8)
    c. 6-10% (skip to Question #8)
    d. 11-20% (skip to Question #8)
    e. >20% (skip to Question #8)

7. What are your reasons for not performing a setup when treatment planning for a case that will undergo fixed appliances? (Select all that apply)

a. It does not help with treatment planning
b. It takes too much time
c. It takes too much effort
d. It costs too much money
e. Other: _____

(Stop if answered Question #7)

8. What are your reasons for performing a setup when treatment planning a case that will undergo fixed appliances? (Select all that apply)
    a. It helps me make decisions regarding a treatment plan
    b. It helps me communicate better with my patients
    c. It helps me communicate better with other providers
    d. Other: _____

9. What type of fixed appliances patients do you routinely perform a setup for? (Select all that apply)
    a. Single lower incisor extraction
    b. Significant tooth size discrepancy based on Bolton analysis
    c. Interdisciplinary cases needing prosthetic replacement of teeth
    d. Unusual extraction patterns
    e. Moderate to severe crowding needing significant expansion (non-extraction)
    f. Orthognathic surgical treatment
    g. Other: _____

10. When you perform orthodontic setup for fixed appliances patients, which format do you use?
    a. Setups only with plaster models and wax
    b. Setups only with digital models on a computer (skip to Question #12)
    c. I use both plaster and digital setups (skip to Question #12)

11. What are your reasons for performing a plaster setup instead of a digital setup when treatment planning for a fixed appliances patient?
    a. I do not acquire digital models
    b. I do not subscribe to digital setup software
    c. It takes too long for digital setups to be performed by a third-party technician
    d. It takes too long to perform a digital setup by myself or my staff
    e. A digital setup is not as helpful as a plaster setup
    f. Other: _____

(STOP if answered Question #11)

12. For your digital setups for fixed appliances patients, how are they performed?
    a. Outsourced to a third-party technician such as Invisalign® or 3M® Clarity
    b. In-office with an orthodontic software (Jump to Question #14)
    c. Both (skip to Question #14)

13. What are your reasons for not performing an in-office digital setup when treatment planning for a fixed appliances patient? (Select all that apply)
    a. I do not subscribe to a digital setup software
    b. It takes too long to perform a digital setup by myself or my staff
    c. The software costs too much money
    d. The software is difficult to learn/operate
    e. The setups do not simulate treatment realistically
    f. Other: _____

(STOP if answered Question #13)

14. If you perform digital setups in-office (i.e., not through a third party such as an Invisalign® technician), which software do you use?
    a. uLab® Systems
    b. SureSmile
    c. 3Shape Clear Aligner Studio
    d. OrthoSelect DIB AI
    e. Orchestrate 3D
    f. Diorco Autolign
    g. CareStream CS Model+
    h. Maestro3D
    i. ArchForm
    j. Other: ______

(STOP if answered Question #14)

Appendix II

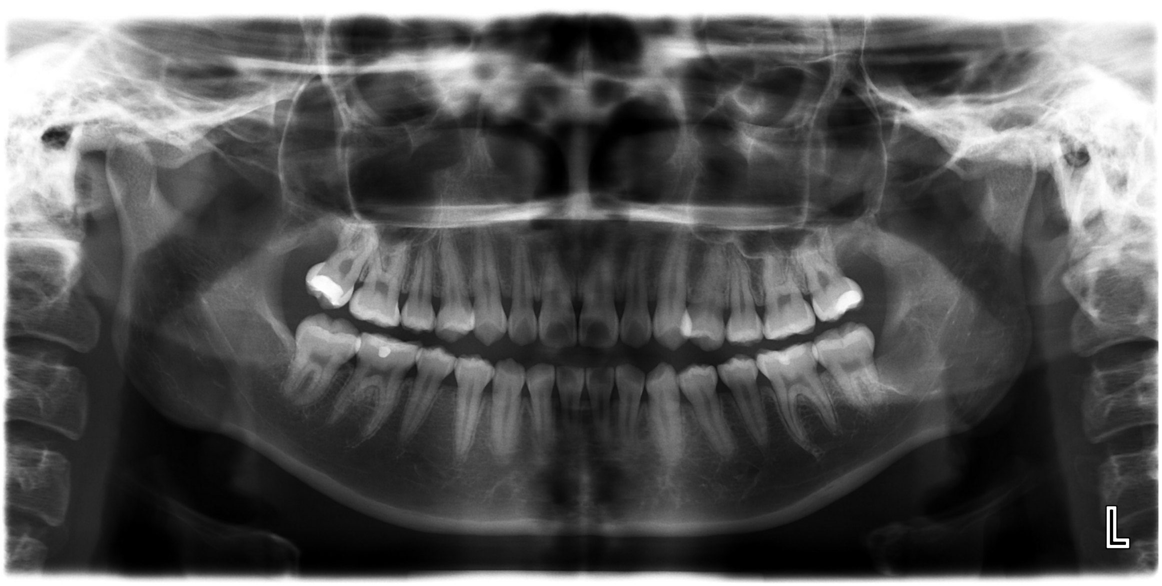
Patient Records: Patient 1

	Value	Norm	Std Dev	Dev Nor	
Maxilla to Cranium					
SNA (°)	81.1	82.0	3.5	-0.2	
A - N-Perp (mm)	2.8	0.0	3.1	0.9	
Mandible to Cranium					
SNB (°)	75.4	80.9	3.4	-1.6	*
Pog - N-Perp (mm)	-4.3	-4.0	5.3	-0.1	
A-P relationship					
ANB (°)	5.7	1.6	1.5	2.8	**
Wits Appraisal (mm)	1.9	-1.0	1.0	2.9	**
Harvold (CoPog)-(CoANS)	27.0	20.0	3.0	2.3	**
Mx Unit Length (Co-ANS)	82.9	90.0	5.0	-1.4	*
Md Unit Length (Co-Pog)	109.8	113.0	8.0	-0.4	
Inter-incisal relationship					
Interincisal Angle (U1-L1) (°)	138.1	130.0	6.0	1.4	*
Overjet (mm)	5.0	2.5	2.5	1.0	*
Overbite (mm)	6.0	2.5	2.0	1.8	*
Upper incisors					
U1 - NA (°)	11.2	22.8	5.7	-2.0	**
U1 - NA (mm)	2.0	4.3	2.7	-0.8	
U1 - Palatal Plane (°)	102.0	112.0	6.0	-1.7	*
Lower incisors					
L1 to Mn Plane (IMPA) (°)	95.4	95.0	7.0	0.1	
L1 - NB (°)	24.9	25.3	6.0	-0.1	
L1 - NB (mm)	6.0	4.0	1.8	1.1	*
Vertical Measures					
Mandibular Plane - FH (°)	22.4	23.6	4.5	-0.3	
Mandibular Plane - SN (°)	34.1	33.0	6.0	0.2	
Y-Axis -- Downs (SGn-FH) (°)	60.9	60.2	3.4	0.2	
Y-Axis (SGn-SN) (°)	72.6	67.0	5.5	1.0	*
Nasal Height (%)	42.8	43.0	100.0	0.0	
Lower Face Height (ANS-Gn) (mm)	72.2	60.0	4.5	2.7	**
Palatal plane - FH (°)	2.0	-3.0	3.7	1.4	*
Occlusal Plane - FH (°)	8.1	6.3	5.0	0.4	
Chin Button					
Pog - NB (mm)	1.5	2.6	1.7	-0.6	
Holdaway Ratio (%)	0.3	1.0	0.5	-1.5	*
Facial Pattern					
Upper Lip to E-Plane (mm)	-1.5	-6.5	2.0	2.5	**
Lower Lip to E-Plane (mm)	2.6	-2.0	2.0	2.3	**
Zero Meridian (FH-soft tissue NPo) (	88.4	91.7	7.0	-0.5	
Facial Angle (FH-NPo) (°)	87.9	88.9	3.0	-0.3	
A-B to Facial Plane (°)	-8.5	-3.1	3.0	-1.8	*
Angle of Convexity (N-A-Pog) (°)	9.9	4.3	3.0	1.9	*

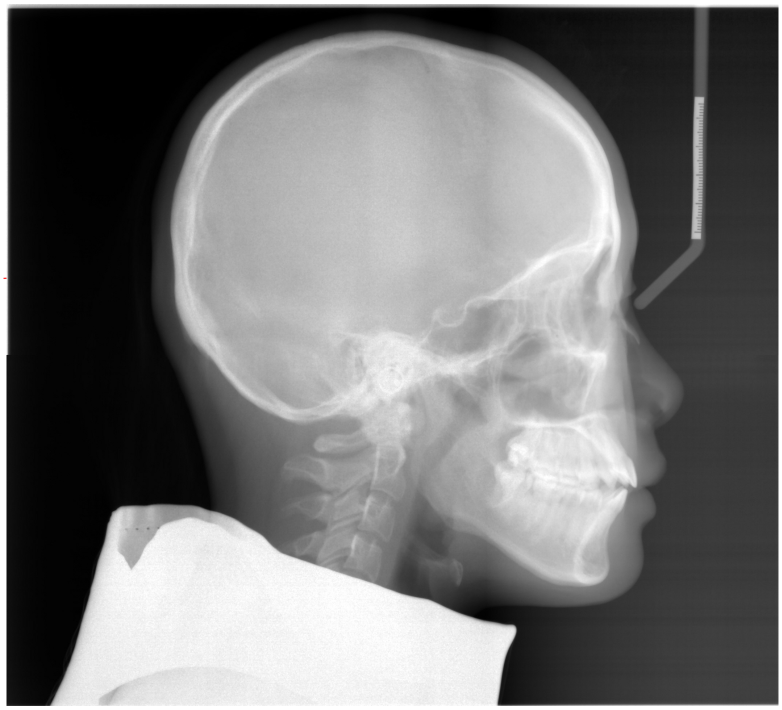
Patient Records: Patient 2

	Value	Norm	Std Dev	Dev Nor	
Maxilla to Cranium					
SNA (°)	87.4	82.0	3.5	1.5	*
A - N-Perp (mm)	12.5	0.0	3.1	4.0	****
Mandible to Cranium					
SNB (°)	81.7	80.9	3.4	0.2	
Pog - N-Perp (mm)	15.4	-4.0	5.3	3.7	***
A-P relationship					
ANB (°)	5.7	1.6	1.5	2.8	**
Wits Appraisal (mm)	0.9	-1.0	1.0	1.9	*
Harvold (CoPog)-(CoANS)	25.8	20.0	3.0	1.9	*
Mx Unit Length (Co-ANS)	86.2	90.0	5.0	-0.8	
Md Unit Length (Co-Pog)	111.9	113.0	8.0	-0.1	
Inter-incisal relationship					
Interincisal Angle (U1-L1) (°)	141.7	130.0	6.0	2.0	**
Overjet (mm)	5.0	2.5	2.5	1.0	*
Overbite (mm)	5.4	2.5	2.0	1.5	*
Upper incisors					
U1 - NA (°)	9.4	22.8	5.7	-2.3	**
U1 - NA (mm)	1.2	4.3	2.7	-1.1	*
U1 - Palatal Plane (°)	97.9	112.0	6.0	-2.3	**
Lower incisors					
L1 to Mn Plane (IMPA) (°)	95.7	95.0	7.0	0.1	
L1 - NB (°)	23.1	25.3	6.0	-0.4	
L1 - NB (mm)	4.9	4.0	1.8	0.5	
Vertical Measures					
Mandibular Plane - FH (°)	10.4	23.9	4.5	-3.0	***
Mandibular Plane - SN (°)	25.8	33.0	6.0	-1.2	*
Y-Axis -- Downs (SGn-FH) (°)	50.8	60.3	3.4	-2.8	**
Y-Axis (SGn-SN) (°)	66.2	67.0	5.5	-0.1	
Nasal Height (%)	41.3	43.0	100.0	0.0	
Lower Face Height (ANS-Gn) (mm)	70.9	65.0	4.5	1.3	*
Palatal plane - FH (°)	14.3	-2.4	3.7	4.5	****
Occlusal Plane - FH (°)	0.2	6.8	5.0	-1.3	*
Chin Button					
Pog - NB (mm)	2.4	2.4	1.7	0.0	
Holdaway Ratio (%)	0.5	1.0	0.5	-1.0	*
Facial Pattern					
Upper Lip to E-Plane (mm)	-5.1	-6.0	2.0	0.5	
Lower Lip to E-Plane (mm)	-3.2	-2.0	2.0	-0.6	
Zero Meridian (FH-soft tissue NPo) (	101.9	91.6	7.0	1.5	*
Facial Angle (FH-NPo) (°)	98.4	88.6	3.0	3.2	***
A-B to Facial Plane (°)	-9.9	-3.5	3.0	-2.1	**
Angle of Convexity (N-A-Pog) (°)	9.5	4.9	3.0	1.5	*

Patient Records: Patient 3

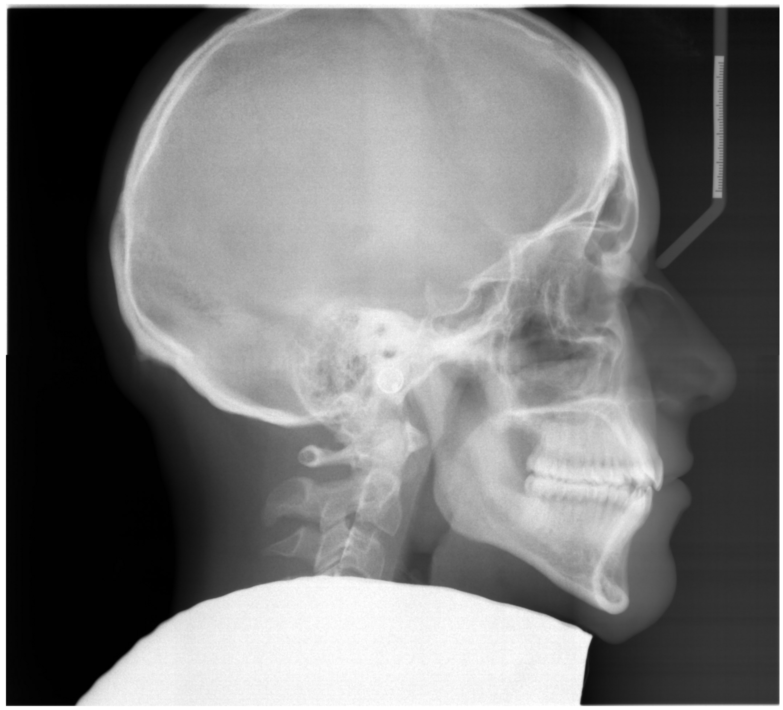


	Value	Norm	Std Dev	Dev Norm
Maxilla to Cranium				
SNA (°)	76.7	82.0	3.5	-1.5 *
A - N-Perp (mm)	-1.0	0.0	3.1	-0.3
Mandible to Cranium				
SNB (°)	74.1	80.9	3.4	-2.0 **
Pog - N-Perp (mm)	-5.9	-4.0	5.3	-0.4
A-P relationship				
ANB (°)	2.5	1.6	1.5	0.6
Wits Appraisal (mm)	-1.8	-1.0	1.0	-0.8
Harvold (CoPog)-(CoANS)	24.6	20.0	3.0	1.5 *
Mx Unit Length (Co-ANS)	72.8	90.0	5.0	-3.4 ***
Md Unit Length (Co-Pog)	97.3	113.0	8.0	-2.0 **
Inter-incisal relationship				
Interincisal Angle (U1-L1) (°)	119.0	130.0	6.0	-1.8 *
Overjet (mm)	2.9	2.5	2.5	0.2
Overbite (mm)	-1.0	2.5	2.0	-1.8 *
Upper incisors				
U1 - NA (°)	26.3	22.8	5.7	0.6
U1 - NA (mm)	5.9	4.3	2.7	0.6
U1 - Palatal Plane (°)	113.6	112.0	6.0	0.3
Lower incisors				
L1 - MP (gonion-menton)	98.4	95.0	7.0	0.5
L1 - NB (°)	32.2	25.3	6.0	1.2 *
L1 - NB (mm)	6.2	4.0	1.8	1.2 *
Vertical Measures				
Mandibular Inclination (FH - Me-Go)	27.3	23.9	4.5	0.8
SN/MnP (°)	39.7	33.0	6.0	1.1 *
Y-Axis -- Downs (SGn-FH) (°)	62.6	60.3	3.4	0.7
Y-Axis (SGn-SN) (°)	75.0	67.0	5.5	1.5 *
Nasal Height (%)	46.2	43.0	100.0	0.0
Lower Face Height (ANS-Gn) (mm)	62.3	65.0	4.5	-0.6
Palatal plane - FH (°)	1.6	-2.4	3.7	1.1 *
Occlusal Plane (°)	10.5	6.8	5.0	0.7
Chin Button				
Pog - NB (mm)	0.5	2.4	1.7	-1.1 *
Holdaway Ratio (%)	0.1	1.0	0.5	-1.8 *
Facial Pattern				
Upper Lip to E-Plane (mm)	0.7	-6.0	2.0	3.3 ***
Lower Lip to E-Plane (mm)	0.4	-2.0	2.0	1.2 *
S.T. Facial Angle (FH-N'Pg') (°)	90.1	91.6	7.0	-0.2
Facial Angle (FH-NPo) (°)	86.8	88.6	3.0	-0.6
A-B to Facial Plane (°)	-4.4	-3.5	3.0	-0.3
Angle of Convexity (N-A-Pog) (°)	4.9	4.9	3.0	0.0

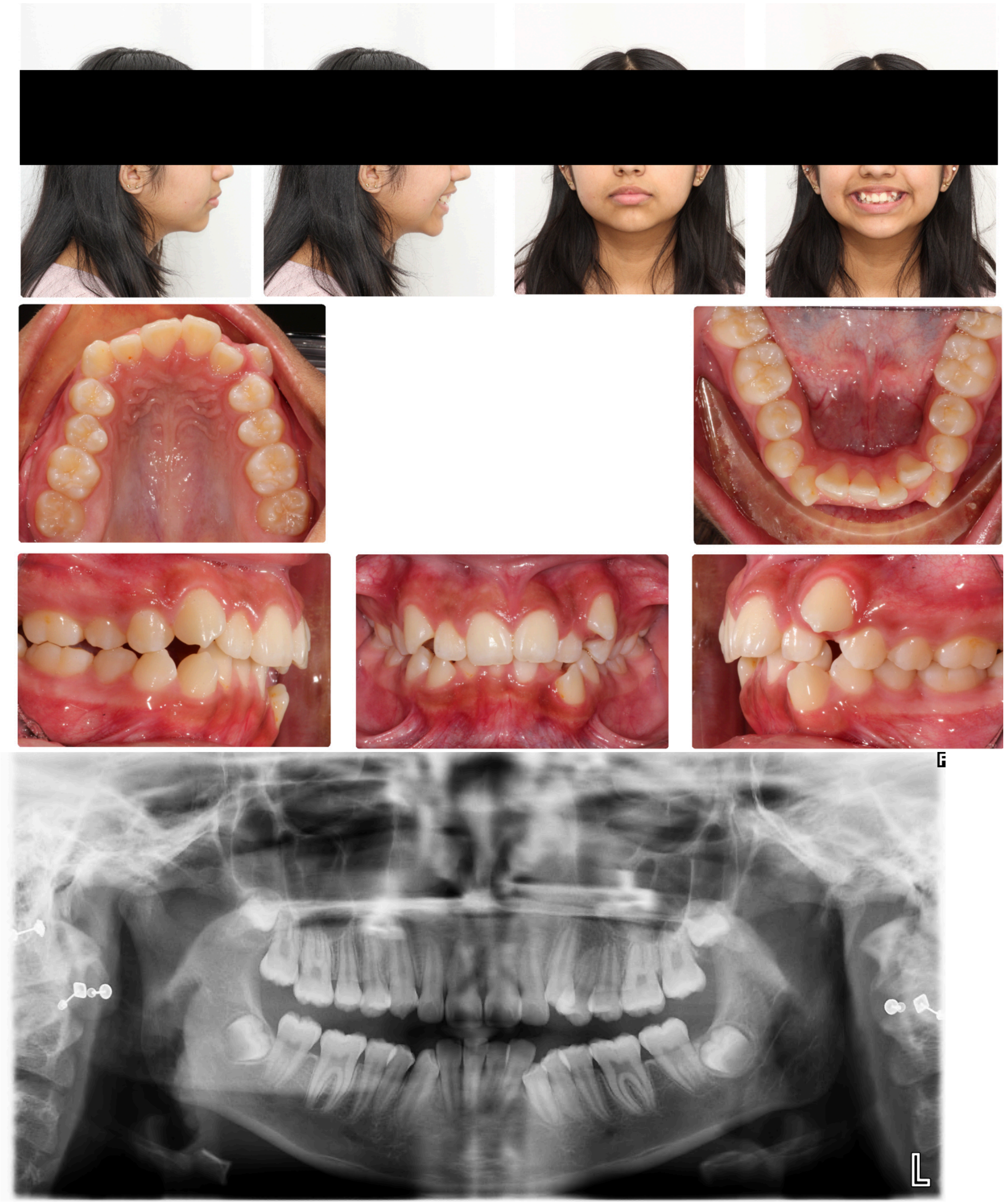


<u>Patient Records: Patient 4</u>

	Value	Norm	Std Dev	Dev Nor	
Maxilla to Cranium					
SNA (°)	81.8	82.0	3.5	-0.1	
A - N-Perp (mm)	4.1	0.0	3.1	1.3	*
Mandible to Cranium					
SNB (°)	76.1	80.9	3.4	-1.4	*
Pog - N-Perp (mm)	-5.4	-4.0	5.3	-0.3	
A-P relationship					
ANB (°)	5.7	1.6	1.5	2.8	**
Wits Appraisal (mm)	1.6	-1.0	1.0	2.6	**
Harvold (CoPog)-(CoANS)	24.5	20.0	3.0	1.5	*
Mx Unit Length (Co-ANS)	86.0	90.0	5.0	-0.8	
Md Unit Length (Co-Pog)	110.5	113.0	8.0	-0.3	
Inter-incisal relationship					
Interincisal Angle (U1-L1) (°)	144.6	130.0	6.0	2.4	**
Overjet (mm)	2.9	2.5	2.5	0.2	
Overbite (mm)	1.4	2.5	2.0	-0.5	
Upper incisors					
U1 - NA (°)	6.1	22.8	5.7	-2.9	**
U1 - NA (mm)	1.1	4.3	2.7	-1.2	*
U1 - Palatal Plane (°)	96.2	112.0	6.0	-2.6	**
Lower incisors					
L1 to Mn Plane (IMPA) (°)	84.7	95.0	7.0	-1.5	*
L1 - NB (°)	23.5	25.3	6.0	-0.3	
L1 - NB (mm)	6.9	4.0	1.8	1.6	*
Vertical Measures					
Mandibular Plane - FH (°)	30.7	22.9	4.5	1.7	*
Mandibular Plane - SN (°)	42.8	33.0	6.0	1.6	*
Y-Axis -- Downs (SGn-FH) (°)	64.0	60.0	3.4	1.2	*
Y-Axis (SGn-SN) (°)	76.1	67.0	5.5	1.7	*
Nasal Height (%)	41.7	43.0	100.0	0.0	
Lower Face Height (ANS-Gn) (mm)	80.2	60.0	4.5	4.5	****
Palatal plane - FH (°)	3.8	-3.2	5.8	1.2	*
Occlusal Plane - FH (°)	8.0	4.7	5.0	0.7	
Chin Button					
Pog - NB (mm)	-1.3	3.0	1.7	-2.6	**
Holdaway Ratio (%)	-0.2	1.0	0.5	-2.4	**
Facial Pattern					
Upper Lip to E-Plane (mm)	-6.1	-8.0	2.0	0.9	
Lower Lip to E-Plane (mm)	-2.9	-2.0	2.0	-0.4	
Zero Meridian (FH-soft tissue NPo) (	91.1	92.0	7.0	-0.1	
Facial Angle (FH-NPo) (°)	87.5	89.6	3.0	-0.7	
A-B to Facial Plane (°)	-7.7	-2.0	3.0	-1.9	*
Angle of Convexity (N-A-Pog) (°)	12.5	2.5	3.0	3.3	***



Patient Records: Patient 5



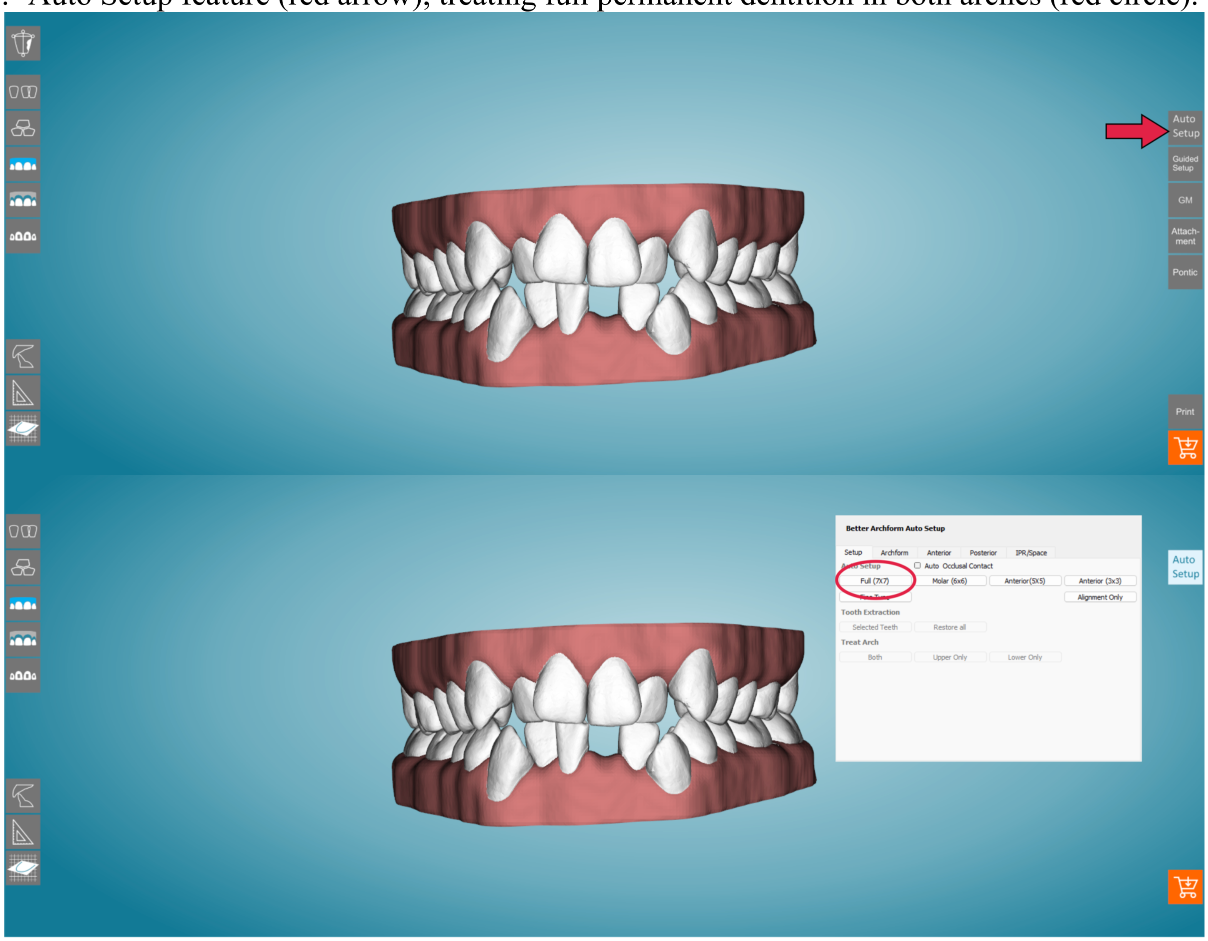
	Value	Norm	Std Dev	Dev Nor	
Maxilla to Cranium					
SNA (°)	73.9	82.0	3.5	-2.3	**
A - N-Perp (mm)	-0.5	0.0	3.1	-0.1	
Mandible to Cranium					
SNB (°)	67.0	80.9	3.4	-4.1	****
Pog - N-Perp (mm)	-13.0	-4.0	5.3	-1.7	*
A-P relationship					
ANB (°)	6.9	1.6	1.5	3.5	***
Wits Appraisal (mm)	2.5	-1.0	1.0	3.5	***
Harvold (CoPog)-(CoANS)	14.2	20.0	3.0	-1.9	*
Mx Unit Length (Co-ANS)	80.5	90.0	5.0	-1.9	*
Md Unit Length (Co-Pog)	94.7	113.0	8.0	-2.3	**
Inter-incisal relationship					
Interincisal Angle (U1-L1) (°)	134.1	130.0	6.0	0.7	
Overjet (mm)	6.5	2.5	2.5	1.6	*
Overbite (mm)	4.7	2.5	2.0	1.1	*
Upper incisors					
U1 - NA (°)	13.4	22.8	5.7	-1.6	*
U1 - NA (mm)	3.0	4.3	2.7	-0.5	
U1 - Palatal Plane (°)	104.5	112.0	6.0	-1.3	*
Lower incisors					
L1 to Mn Plane (IMPA) (°)	95.4	95.0	7.0	0.1	
L1 - NB (°)	25.5	25.3	6.0	0.0	
L1 - NB (mm)	7.2	4.0	1.8	1.8	*
Vertical Measures					
Mandibular Plane - FH (°)	27.4	24.8	4.5	0.6	
Mandibular Plane - SN (°)	43.1	33.0	6.0	1.7	*
Y-Axis -- Downs (SGn-FH) (°)	65.8	60.6	3.4	1.5	*
Y-Axis (SGn-SN) (°)	81.4	67.0	5.5	2.6	**
Nasal Height (%)	47.5	43.0	100.0	0.0	
Lower Face Height (ANS-Gn) (mm)	65.9	65.0	4.5	0.2	
Palatal plane - FH (°)	-1.5	-1.4	3.9	0.0	
Occlusal Plane - FH (°)	14.6	8.7	5.0	1.2	*
Chin Button					
Pog - NB (mm)	1.0	1.9	1.7	-0.5	
Holdaway Ratio (%)	0.1	1.0	0.5	-1.7	*
Facial Pattern					
Upper Lip to E-Plane (mm)	-1.0	-4.2	2.0	1.6	*
Lower Lip to E-Plane (mm)	1.2	-2.0	2.0	1.6	*
Zero Meridian (FH-soft tissue NPo) (	84.4	91.1	7.0	-1.0	*
Facial Angle (FH-NPo) (°)	83.2	87.7	3.0	-1.5	*
A-B to Facial Plane (°)	-11.5	-4.9	3.0	-2.2	**
Angle of Convexity (N-A-Pog) (°)	14.8	7.1	3.0	2.6	**

Appendix III

uLab® uDesign® Automated Digital Setup: Setup Procedure

A. Occlusal plane, tooth segmentation, tooth numbering, medio-distal axis, vertical long axis, and digital extraction of teeth.

B. Auto Setup feature (red arrow), treating full permanent dentition in both arches (red circle).

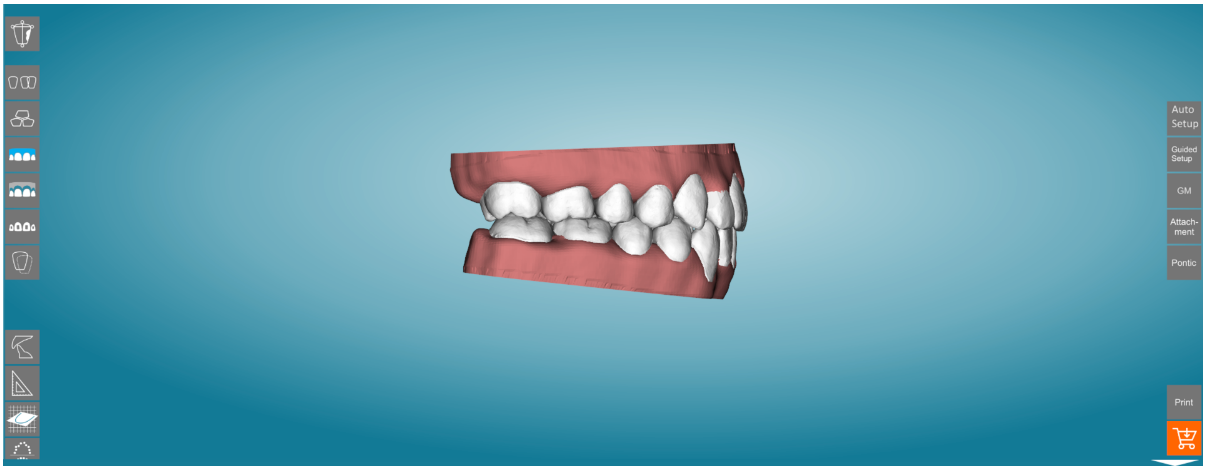


Appendix IV

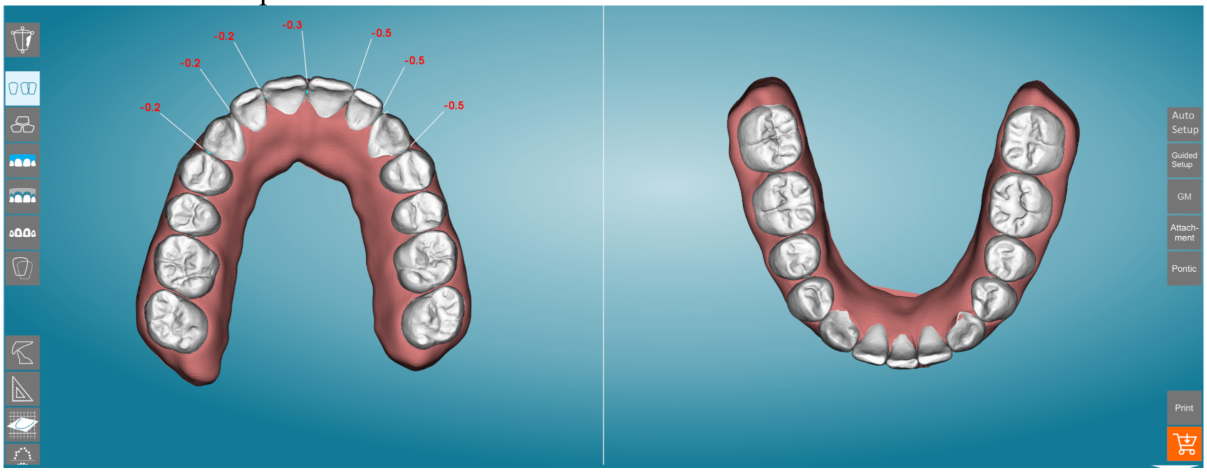
uLab® uDesign® Automated Digital Setup: Evaluator Views

A. Frontal view

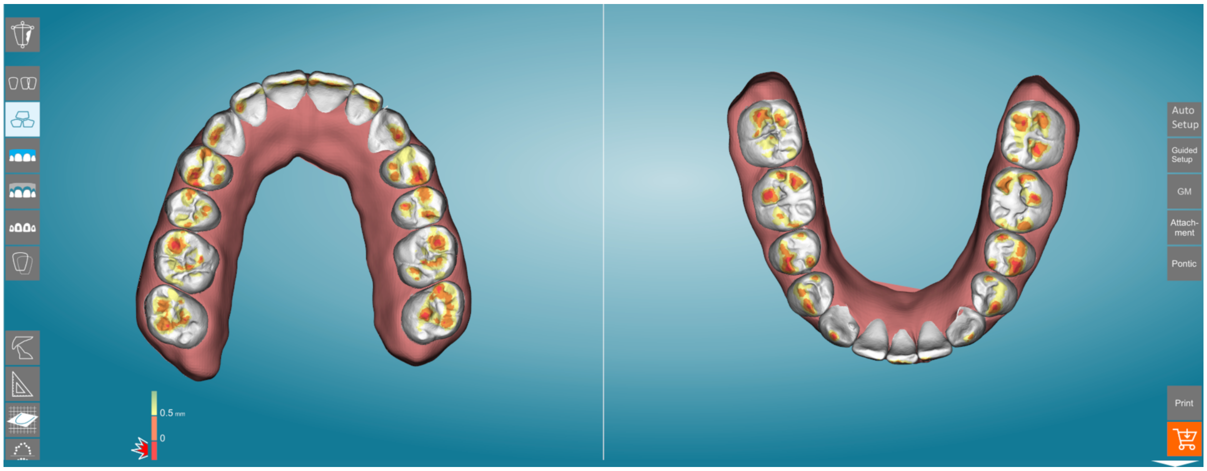
B. Buccal view



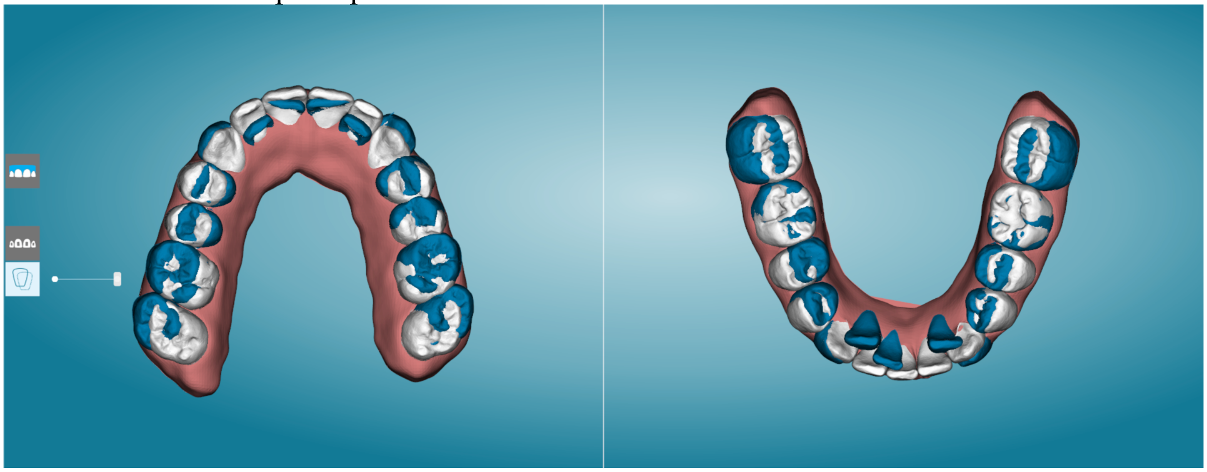
C. Occlusal view – Space Interferences



D. Occlusal view – Occlusal Contacts



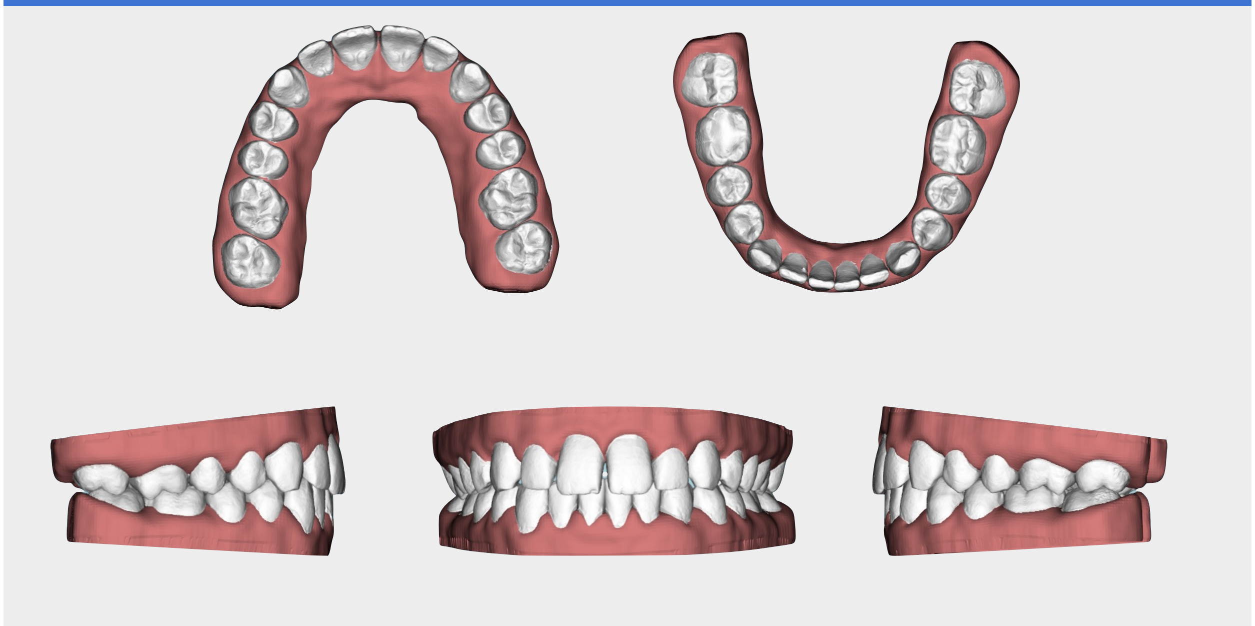
E. Occlusal view – Superimposition



Appendix V

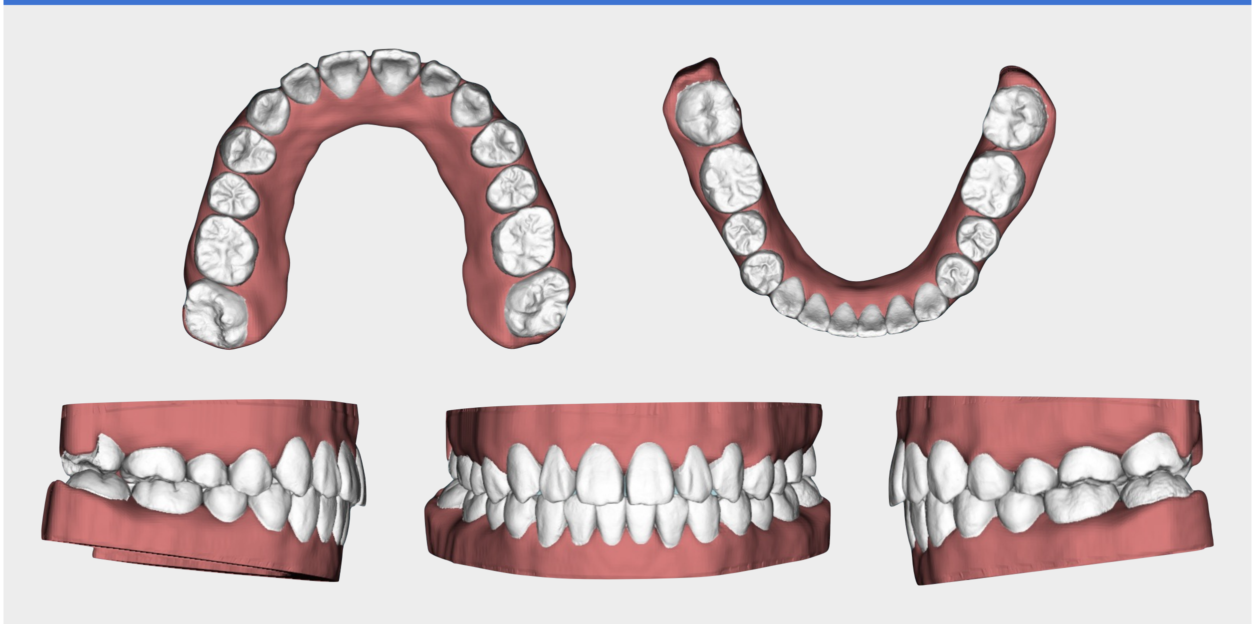
uLab® uDesign® Automated Digital Setup: Final Treatment Simulation

Patient 1: Automated Setup

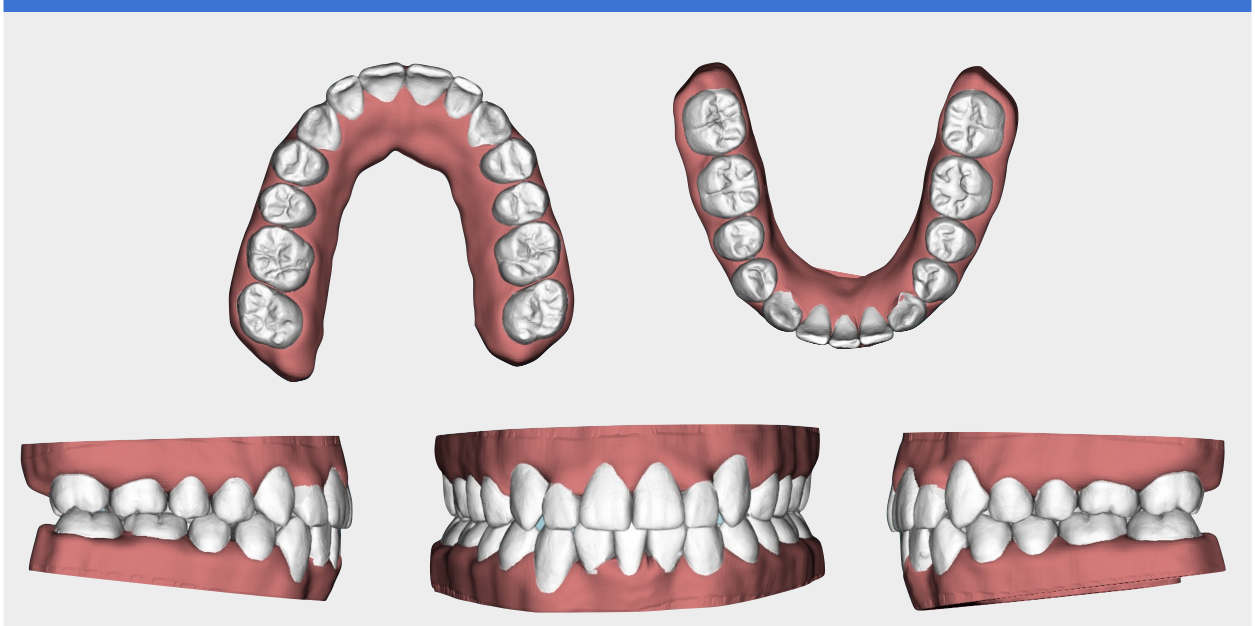


Patient 2: Automated Setup

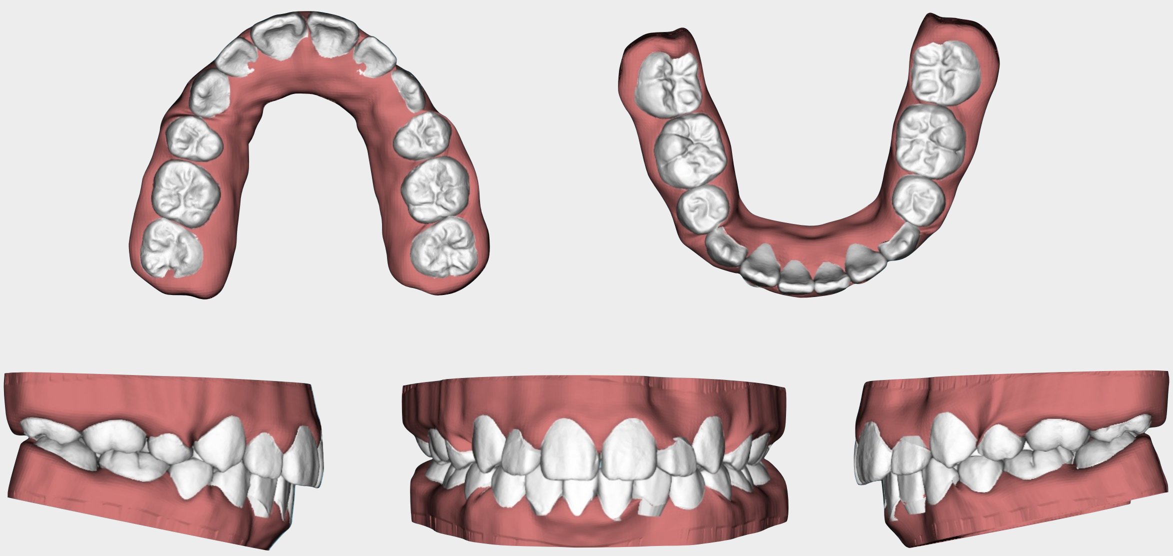
Patient 3: Automated Setup



Patient 4: Automated Setup



Patient 5: Automated Setup



Appendix VI

Automated Setup Evaluation Interview Questions

1. On a scale of 1 to 5, what is the orthodontic treatment difficulty level of this case?

   Not difficult 1 2 3 4 5 Very difficult

2. Is this a case you would typically perform a setup to determine the feasibility of the treatment plan? Please state the reason for your answer.
   a. Yes
   b. No

3. Which of the following parameters could be improved? Select all that apply.
   (1) Overjet and overbite
   (2) Canine and molar relationships
   (3) Tip and torque of teeth
   (4) Gingival contours
   (5) Alignment and spacing
   (6) Arch form and arch-width
   (7) Anchorage management
   (8) Occlusal contacts

4. Is this setup helpful for assessing the feasibility of the treatment plan? Please state the reason for your answer.
   a. Yes
   b. No

Appendix VII

Association between Perceived Setup Need, Quality of Setup, Perceived Helpfulness of Setup, Case Type, and Clinical Experience.

Perceived Setup Need

GEE log-linear regression showed a significant positive correlation between need for setup and case difficulty level (p-value = .002). The perceived need for a setup was higher for cases that were rated as more difficult.

Perceived Setup Need	**Yes**, N = 77	**No**, N = 128
Difficulty, N (%)		
1	0 (0)	9 (100)
2	1 (3)	38 (97)
3	17 (29)	42 (71)
4	39 (55)	32 (45)
5	20 (74)	7 (26)

GEE log-linear regression showed a significant positive correlation between need for setup initial PAR score (p-value < .001). The perceived need for a setup was higher for cases with higher initial PAR scores.

Perceived Setup Need	**Yes**, N = 77	**No**, N = 128
PAR score, N (%)		
14	1 (2)	40 (98)
16	17 (41)	24 (59)
30	4 (10)	37 (90)
34	37 (90)	4 (10)
52	18 (44)	23 (56)

GEE log-linear regression showed a significant difference in need for setup between case types (non-extraction vs. four first premolar extraction vs. single lower incisor extraction) (p-value < .001). Perceived need for a setup was higher for both types of extractions plans than for non-extraction plans (p-value < .05).

Perceived Setup Need	**Yes**, N = 77	**No**, N = 128
Case type, N (%)		
Non-extraction	22 (18)	101 (82)
Four first premolar extraction	18 (44)	23 (56)
Single lower incisor extraction	37 (90)	4 (10)

Perceived Setup Need	**Yes**, N = 77	**No**, N = 128
Case type, N (%)		
Non-extraction	22 (18)	101 (82)
Extraction	55 (67)	27 (33)

GEE logistic regression showed a significant association between perceived need for setup and clinical experience (p-value = .011). Although overall there was a significant association, no two groups were significantly different from each other (e.g., 15+ vs <5, p-value = .051 and 5-15 vs <5, p-value = .52).

Clinical Experience	**Less than 5 years**, N = 40	**5-15 years**, N = 55	**More than 15 years**, N = 110
Would you typically set up this case? N (%)			
y	9 (23)	16 (29)	52 (47)
n	31 (78)	39 (71)	58 (53)

Quality of Setup: Number of Improvements Needed

Post-hoc testing using paired t-test and Holm's method to adjust for the multiple testing showed that Case 5 had significantly more improvements needed than Cases 1-4, Case 4 had significantly more improvements needed than Cases 2 and 3, and Case 1 had significantly more improvements needed than Case 3 (adjusted p-values < .05).

Case	**1**, N = 41	**2**, N = 41	**3**, N = 41	**4**, N = 41	**5**, N = 41
No. improvements					
Mean (SD)	3.54 (1.10)	3.22 (1.44)	2.98 (1.29)	4.00 (1.52)	5.78 (1.29)

GEE linear regression based on Spearman rank correlation coefficient of 0.12 showed that there was a marginally significant association between number of parameters needing improvement and case difficulty level (p-value = .074).

Difficulty Level	**1**, N = 9	**2**, N = 39	**3**, N = 59	**4**, N = 71	**5**, N = 27
No. improvements					
Mean (SD)	2.67 (0.87)	3.51 (1.27)	4.29 (1.72)	3.77 (1.67)	4.37 (1.88)

GEE linear regression based on Spearman rank correlation coefficient of 0.45 showed that there was a significant association between number of parameters needing improvement and PAR score (p-value < .0001).

PAR Score	**14**, N = 41	**16**, N = 41	**30**, N = 41	**34**, N = 41	**52**, N = 41
No. improvements					
Mean (SD)	3.54 (1.10)	2.98 (1.29)	3.22 (1.44)	4.00 (1.52)	5.78 (1.29)

GEE linear showed that there was a significant association between number of parameters needing improvement and cases with planned extraction (p-value < .001).

Case Type	**Non-extraction**, N = 123	**Extraction**, N = 82	**p-value** (GEE linear regression)
No. improvements			<0.001
Mean (SD)	3.24 (1.30)	4.89 (1.66)	

GEE linear showed that there was no significant association between number of parameters needing improvement and practitioner clinical experience (p-value = .741).

Clinical Experience	**Less than 5 years**, N = 40	**5-15 years**, N = 55	**More than 15 years**, N = 110	**p-value** (GEE linear regression)
No. improvements				
Mean (SD)	3.78 (1.69)	4.07 (1.63)	3.86 (1.67)	0.741

Perceived Helpfulness of Setup

GEE log-linear regression showed that there was a significant positive association between perceived difficulty and helpfulness (p-value = .002). The helpfulness of the setup increased as the case difficulty level increased.

Helpfulness	**Yes**, N = 139	**No**, N = 66
Difficulty, n (%)		
1	3 (33)	6 (67)
2	24 (62)	15 (38)
3	34 (58)	25 (42)
4	56 (79)	15 (21)
5	22 (81)	5 (19)

GEE log-linear regression showed that the association between PAR score and helpfulness was not significant (p-value = .162).

Helpfulness	**Yes**, N = 139	**No**, N = 66
PAR score, N (%)		
14	23 (56)	18 (44)
16	29 (71)	12 (29)
30	24 (59)	17 (41)
34	41 (100)	0 (0)
52	22 (54)	19 (46)

GEE log-linear regression showed that only the difference between single lower incisor extraction and non-extraction was significant (p-value < .001). The setup for the single lower incisor extraction plan was significantly more helpful than the non-extraction plans and the four first premolar extraction plans.

Helpfulness	**Yes**, N = 139	**No**, N = 66	**p-value**
Case type, N (%)			<.001
Non-extraction	76 (62)	47 (38)	
Four first premolar extraction	22 (54)	19 (46)	
Single lower incisor extraction	41 (100)	0 (0)	

Helpfulness	**Yes**, N = 139	**No**, N = 66	**p-value**
Case type, N (%)			<.001
Non-extraction	76 (62)	47 (38)	
Extraction	63 (77)	19 (23)	

GEE log-linear regression showed that there was a significant association between increased number of improvements needed and decreased helpfulness (p-value = .014). As the number of improvements needed increased (i.e., the quality of the setup decreases), the helpfulness of the setup decreases.

Helpfulness	**Yes**, N = 139	**No**, N = 66
No. improvements, n (%)		
1	8 (89)	1 (11)
2	32 (82)	7 (18)
3	28 (68)	13 (32)
4	29 (62)	18 (38)
5	19 (61)	12 (39)
6	14 (61)	9 (39)
7	7 (64)	4 (36)
8	2 (50)	2 (50)

GEE log-linear regression showed that there was a significant difference between practitioners with 5-15 years of experience and practitioners with either less than 5 years or more than 15 years of experience (p-value < .001). Practitioners with 5-15 years of experience found the setups to be less helpful than the other two groups.

Helpfulness	**Yes**, N = 66	**No**, N = 66	p-value
Experience, n (%)			<.001
Less than 5 years	28 (70)	12 (30)	
5-15 years	25 (45)	30 (55)	
More than 15 years	86 (78)	24 (22)	

GEE log-linear regression showed that there was a significant association between increased need for a setup and increased helpfulness of the automated setup (p-value < .001). Setups were more helpful for cases where the perceived need for a setup was high.

Characteristic	**n**, N = 66	**y**, N = 139	p-value
Need for setup, n (%)			<.001
y	5 (6.5)	72 (94)	
n	61 (48)	67 (52)	