A Machine Learning Approach to Determine Prognosis of Class III Malocclusion Patients

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Introduction

The conundrum of determining how to treat a skeletal Class III malocclusion is significant, creating a burden on the patient and a challenge for the orthodontist. The challenge behind this polygenic condition lies within it's etiologic diversity.[1] The skeletal Class III pattern is heritable due to the inheritance of disproportionate jaw relationships and can be due in part to excessive mandibular growth, deficient maxillary growth, or any combination. Generally accepted as the rarest of the malocclusion types, the prevalence ranges from 1% to 4% in the U.S. with rates of 12-23% in parts of Asia.[2]

Stability following Class III correction, whether treated orthopedic, orthodontic, or orthosurgically, continues to be a major concern.[3] Indications for early intervention include presence of a mild anterior crossbite in the mixed dentition phase.[4] The most widely studied and approved treatment protocol for the Class III malocclusion in children involves rapid maxillary expansion combined with facemask therapy.[5] Studies have found approximately 70% of patients who received early facemask therapy maintain positive overjet at three to four year follow-ups, thus it has been shown that up to 30% of Class III skeletal patterns experience relapse following early intervention.[5-8] Mandall et. al. reported 36% of patients who received early facemask therapy later required surgical intervention. Class III skeletal patterns exhibiting mandibular prognathism have been most associated with relapse due to subsequent growth.[6-8] Mackey et. al. found in a sample of 50 adults who subsequently required surgical correction, all showed some degree of mandibular prognathism.[10]

Past studies have investigated the skeletal types of the Class III malocclusion. Authors of this paper previously characterized the skeletal Class III malocclusion's convergences into phenotypic subtypes using cephalometric and principal component analyses. Five predominant

clusters of the Class III malocclusion were identified based on a preliminary cluster analysis of a large cohort using 67 normalized prescriptive cephalometric variables: 1) mandibular prognathic - long face; 2) maxillary deficient - short face; 3) maxillary deficient - long face; 4) mild mandibular prognathic; 5) combination mandibular prognathic and maxillary deficient.[8] Several studies have reported similar findings with Mackey et. al. and Uribe et. al. identifying five clusters, Abu Alhaija and Richardson identifying three clusters, and Hong and Yi identifying seven clusters.[12-15] The next logical step was to develop a systematic clinical tool that identifies a patient's Class III skeletal subtype to aid in reaching a more specific and reliable diagnosis.

This study reports a novel statistical prediction model (SPM3) for Class III patients, which classifies patients into one of the original five subtypes reported in Bui et. al. The rationale behind creating this formula is two-fold. It stems from the fact that most orthodontists agree several types of the skeletal Class III malocclusion exists, but agreement on what they are and how to diagnose them is less clear.[16] This machine learning approach addresses this gap by providing a detailed and objective characterization identifying the skeletal discrepancy. In addition, algorithms allowing for data-driven decision-making have shown to be beneficial for the field of orthodontics, especially with valuable diagnostic resources that lack objective validation such as cephalometry.[17] A recent study utilizing a patient's cephalometric x-rays for automated skeletal classification, reported over 90% sensitivity, specificity, and accuracy in both vertical and sagittal diagnosis.[18] Similarly, the SPM3 utilizes a systematic formula-based system involving cephalometric analysis to provide a diagnosis.

The objectives of this study are to employ the SPM3 which uses cephalometric data to classify 3 predominant subtypes of the skeletal Class III malocclusion and to determine if the Class III

subtype is valuable in predicting treatment modality and outcome. This study tests the hypothesis that Class III subtypes are associated with treatment modalities (e.g., surgical versus non-surgical), and treatment outcome. This study's findings can aid in future studies on Class III phenotypes, diagnosis, and treatment outcomes.

Materials and Methods

Sample and Inclusion Criteria

The study sample was derived from a random cohort of 1004 patients (ages 7–25 with an A.N.B. ≤ 0°) within the Orthodontic Program database using Dolphin Imaging Systems (Chatsworth, Calif), a database of patients treated at U.N.C. Orthodontics in the Dentofacial Program from 1985 to 2020. Subjects met one additional inclusion criterion and no exclusion criteria as listed in Table 1. The authors proposed an equal number of subjects would be obtained in all groups and expected the rate of surgery to be highest in Subtype 1 (60%) versus Subtypes 2,3 and 4,5 (25%) given mandibular prognathic phenotypes are those most likely to undergo surgical correction.[3,4,10] Assuming a sample size of at least 125 subjects, the power to reject the null hypothesis (the rate of surgery being equal among Subtype 1 versus Subtypes 2,3 and Subtype 1 versus Subtypes 4,5) is greater than .8. Table 2 summarizes the demographics of the final sample of 148 subjects.

To complete the analysis, treatment was classified as either surgical or non-surgical; treatment decisions were based on the treating orthodontists' clinical judgment. All treating orthodontists at UNC follow the rubric and envelope of discrepancy as described by Profitt and White when deciding between surgical versus nonsurgical approaches.[19] Comparisons between clinical pre- and post-treatment photos were used to determine extraction patterns. Treatment outcome

(success or failure) was defined as success when an orthognathic or convex facial profile was achieved, an overjet and overbite of ≥ 1mm, and an absence of posterior crossbite. These criteria were based on a composite of previous studies.[3-8] Treatment outcome was determined based on the result of active treatment using both soft and hard tissue records. Post-treatment photographs of the patient's dentition (in MIP or CR) were inspected comprising lateral and anterior views to assess overjet, overbite, and the absence of anterior or posterior crossbite. The facial profile was characterized by evaluating the patient's soft tissue profile using the line formed by the nose's bridge, the base of the nose, chin, and the relationship of soft tissue point A to soft tissue point B. Success and failure criteria are summarized in Table 3.

Reliability of Treatment Outcome Assessment and Subtype Assignment

On a random sample of 20 subjects, the kappa statistic for intra-examiner reliability on treatment outcome was found to be .8, indicating substantial agreement, and 1.0 for subtype assignment, indicating almost perfect agreement. One examiner performed the intra-examiner reliability tests.

Development of Statistical Prediction Model (SPM3) for Class III patients

Distance Weighted Discrimination (D.W.D.) method was used to reproducibly determine a Class III subtype classification for additional patients in this current study beyond the original training set of the Bui et. al. study.[20] D.W.D. is a margin-based binary classification method for multivariate data. Each D.W.D. classifier aims to distinguish data between two classes, which is denoted as the positive and negative classes. Classifier predictions are based on a linear function in the form of $r(x) = w1\ X1 + w2\ X2 + \ldots + w67\ X67 + b$, where each w is the coefficient for the jth measurement X j (j=1…, 67) and b is called the intercept term. This function is evaluated on each data point which outputs a real number. Data points with positive values for r(x) are

classified as the positive class, and those with negative values are classified as the other class. The coefficients and the intercept terms are obtained by solving a mathematical optimization problem to maximize separation between the two classes based on a set of training data. The binary version of the D.W.D. is used here to produce more robust results in the high-dimensional setting. D.W.D. classification methods are shown to be stable and perform well in the high-dimensional data analysis setting as this study.[21, 22]

Using the original training data set from the Bui et al. study, a pyramid (a hierarchy) of four D.W.D. classifiers was built to accommodate the scenario with more than two classes. For each D.W.D. classifier, the original 67 cephalometric variables was used to facilitate the prediction of one of three Class III subtypes for any given patient. On the top level, a D.W.D. classifies between the combined class of subtypes {2, 3} (positive class) and the combined class of subtypes 1, 4 (negative class). If a data point was classified to be {2, 3}, then it was also tested on two ancillary DWD classifiers which aimed to distinguish between {2,3} vs {5}, and {2,3} vs {1,4,5}, respectively, to reconfirm. If a data point was classified to be from {1,4} in the top D.W.D. classifier, then a lower-level D.W.D. was used to classify between {1} and {4}.

Cephalometric Analysis and Subtype Assignment

Pretreatment lateral cephalometric records (taken in natural head position with posterior teeth in maximum intercuspation) were digitized using a 67-point model for anteroposterior and vertical structures in Dolphin Imaging (Dolphin Imaging Systems, Chatsworth, Calif). 67 normalized cephalometric variables were used in this study, including 38 linear, 25 angular, four proportional measurements, and the measures adapted from the analyses of Steiner, Jacobson, Ricketts, and McNamara (Table S1).[23-26] Patient measurements were then applied to the statistical prediction model (SPM3) to assign a Class III subtype. Subtype assignments were {1}

for mandibular prognathic, {2,3} for maxillary deficient, or {4,5} for combination (mild maxillary deficient and mild mandibular prognathic).

Statistical Analysis of Treatment Modality and Treatment Outcomes

Binary outcome variables were the proportion of patients classified as having experienced treatment failure and the proportion receiving specific treatment modalities. For the univariate analysis, contingency table methods were used to compare proportions between three subtypes. We assessed relative risk to determine the correlation of subtypes and treatment modality and treatment outcome. Ratios of proportions (hereafter "risk ratios") were calculated between pairs of subtypes, and corresponding 95% confidence limits (95%CLs) were calculated using the exact method. Fisher exact test was used to determine the significance of the associations. The stratified analysis investigated potential variation in treatment failure risk ratios according to subtype. This analysis requires each group to have a certain number of subjects, and because Subtype 1 itself had too few subjects, it was combined with Subtypes 4,5. For the multivariable analysis, a log-binomial regression model estimated adjusted risk ratios and 95%CL for treatment failure. *P* values less than .05 were considered to indicate statistical significance. All statistical analysis was done using the S.A.S. version 9.4 software program.

Results

Utilization of the SPM3

Visualization of scatter plots of the original Bui et al. study revealed that Subtypes 2 and 3 were visually close from multiple spatial and angular perspectives. Also, subtypes 1 and 4 showed a more distinct separation from certain angles; hence we created a subsequent classifier to separate them. The nearest subtype to Subtype 4 was Subtype 5, and given their similar phenotypic

characteristics; we combined them into one group.[11] The result was three distinct subtype groupings (Subtype 1, Subtypes 2,3, and Subtypes 4,5), subsequently used to distinguish the Class III phenotype in this study.

Assessment of Surgical Risk with Subtype

The final sample of 148 Class III patients closely resembled the original study relative to racial and gender statistics. Over 50% of subjects were Caucasian, and there were slightly more female subjects than male. Analysis of the cohort revealed that differences exist in the likelihood of a surgical approach based on subtype. Subtype 1 (Mandibular prognathic) had a higher proportion (64%) of surgical treatment while Subtypes 2,3 (Maxillary deficient) and Subtypes 4,5 (Combination) had a higher proportion of orthodontic treatment (82% and 88%, respectively). The Fisher Exact Test revealed a statistically significant relationship ($P < .01$) exists between subtype and treatment modality: Subtype 1 (Mandibular prognathic) patients had 3.5x times the probability of surgical treatment than Subtypes 2,3 (Maxillary deficient) patients and 5.3x the probability as Subtypes 4,5 (Combination) patients (Figure 1).

Correlation of Treatment Outcome with Subtype

The analysis also showed that differences exist in the likelihood of treatment failure based on the Class III subtype. Fisher Exact Test revealed a statistically significant relationship ($P < .05$) exists between subtype and treatment outcome: Subtype 1 (Mandibular prognathic) patients had 1.5x higher risk of treatment failure compared to Subtypes 2,3 (Maxillary deficient) and 1.7x higher risk compared to Subtypes 4,5 (combination) (Figure 2).

Subtypes exhibiting mandibular prognathism were found to be at higher risk for treatment failure. A stratified analysis of failed treatment, done using exact contingency tests, compared failure rates within treatment modalities. Subtypes 1 (Mandibular prognathic) and 4,5 (Combination) exhibited around 1.7-1.8x the risk of treatment failure compared to Subtypes 2,3 (Maxillary deficient) alone, being statistically significant in the non-surgical group ($p<.05$) (Figure 3). In cases of non-surgical treatment, all subtypes were more likely to have undergone orthodontic camouflage without extractions (81% cases with no extractions compared to 19% with extractions).

Significant independent effects of both subtype and treatment modality were revealed upon a multivariable analysis of percent failed treatment. Subtype was shown to predict a greater risk of treatment failure independent of treatment modality, with Subtypes 1 (Mandibular prognathic), 4, and 5 (Combination) patients more likely to experience treatment failure across all treatments, a finding consistent with Figure 3 ($p<.05$). Treatment modality was shown to predict treatment outcome independent of subtype, with non-surgical treatment at a higher risk of treatment failure across all subtypes ($p<.01$) (Figure 4).

Discussion

This study found that treatment failure was more likely among subjects with a Class III subtype characterized by mandibular prognathism and who furthermore were treated non-surgically. These findings strongly suggest that this machine learning algorithm produces a classification system that can predict treatment prognosis independently.

One of this study's strengths is that the sample contained subjects with mild to severe cases, appropriately representing the wide range of variation in Class III phenotypes. Among the sample size of 148 subjects, Subtypes 4,5 (Combination) was most frequently assigned (50%), followed by Subtypes 2,3 (Maxillary deficient) (40.5%), and lastly, Subtype 1 (Mandibular prognathic) (9.5%). Subtype 1 (Mandibular prognathic) was also the minor subtype in the original cluster study reported by Bui et al. This suggests Subtype 1 to be a less prevalent and more severe phenotype, representing somewhat of a limitation in that it required a grouping with 4, 5, and subsequent stratified treatment analysis. This is primarily justified since Subtype 1 and Subtypes 4,5 were most similar phenotypically (both mandibular prognathic) and exhibited the most similar failure rates in each treatment modality.

The distribution of ethnicity in the study sample reflects the patient population treated at UNC's orthodontic clinic during the 35 year period studied. However, there were no inclusion or exclusion criteria based on ethnicity used when selecting participants for this study. Unfortunately, the Dolphin database did not have ethnicity listed for all patients so we could not include this data point for the sample as a whole. Hence, the extent to which ethnic groups might be under- or over-represented in this sample relative to people with Class III malocclusion in the U.S. population at large cannot be quantified. The study also cannot evaluate potential confounding that may be present due to our inability to adjust for ethnicity. Thus, ethnicity may be a potential confounder of the observed association between SPM classification and treatment outcomes.

The inclusion criteria features a wide range in order to capture Phase 1, Phase 2, and surgical treatment outcomes when indicated. However, we also performed a stratified age analysis dividing the sample into ages 7-16 and 16+ years. No statistically significant differences were found between the age groups with regard to subtype, treatment outcome, and treatment

modality. One explanation for the lack of age group differences is that certain Class III skeletal patterns (i.e. mandibular prognathic) have an unfavorable growth pattern and ultimately require surgical correction; thus, it is inconsequential when they are treated orthodontically as they are posed for an unfavorable outcome.[4] Future studies investigating early versus late treatment outcomes of subtypes can explore such opportunities to identify early surgical cases.

Moreover, this study did not further classify non-surgical treatment plans since the database did not contain information on the specific type of treatment rendered and the primary purpose of this study was not to assess clinical protocols, but rather assess clinical outcomes based on clinical parameters and subtype assignment. Given that there are several traditional and contemporary treatment options used today, each with varying success rates, future studies should capture the success rates of different treatment options for each subtype. Moreover, the cephalometric measurements required for the SPM3 are standard angular, linear, and proportional relationships, and most of the cephalometric landmarks used in this study reproduce real-world clinical scenarios. While there is the potential for error (landmark identification, image resolution, and observer expertise), none is greater than the error expected with any assessment tool. It is a benefit that the SPM3 relies on an objective measure (cephalometric values) therefore removing some of the clinician subjectivity that may depend on esthetic preferences. Thus, the model can serve as an additional objective diagnostic tool that is reliable, reproducible and complements the clinician's acumen.

The SPM3 revealed subtype 1 (mandibular prognathic) showed a higher likelihood for orthognathic surgery than Subtypes 2,3 (maxillary deficient) and Subtypes 4,5 (combination). This aligns the SPM3 finding reported here with other reports that have concluded the skeletal Class III malocclusion with a prognathic mandible is one of the most severe facial deformities

and most often requires surgical intervention.[3-9] This machine learning approach also revealed that Subtypes 1, 4, and 5 (exhibiting mandibular prognathism) who underwent non-surgical treatment were at higher risk for treatment failure than Subtypes 2,3 (exhibiting maxillary deficiency). The authors conclude from this finding that patients exhibiting maxillary deficiency fair a better prognosis when managed by non-surgically and early orthodontic intervention should be considered for such cases. For more severe mandibular prognathic subtypes, given previous findings and those of this study, the authors recommend cautioning parents and patients regarding the possible need for future surgery if orthodontic treatment is pursued.[3-9] Most of all, clinicians should adopt the approach of treating the Class III condition as one with various subtypes with diagnosis, treatment planning and timing focused on addressing the skeletal discrepancy.

By allowing an objective and detailed classification of clinical subtypes of skeletal Class III patients (beyond Angle's classification), this systematic tool can potentially improve our ability to diagnose and treat Class III malocclusions. Subtype assignment provides additional patient-specific criteria to further inform the diagnosis and prognosis of the orthodontist. It may be advantageous in scientific research areas requiring a high level of reproducibility or in borderline surgical versus non-surgical cases. This model holds the potential for improvement in the management of complex Class III patients by identifying early surgical cases and providing predictive power when considering treatment outcomes across different treatment modalities. While further work and ongoing studies will bolster the utility of the SPM3, clinicians must continue to navigate the complexity of the Class III skeletal malocclusion, balancing orthodontic-only and surgical treatment options to first *do no harm*. It can be confidently speculated that the field of orthodontics will continue to witness advances in diagnosis and

treatment planning and incorporate more accurate and reliable methodology based on a hybrid of machine learning and clinician acumen.

Conclusions

This assessment of a systematic method to characterize skeletal Class III patients into subtypes revealed subtype 1 (mandibular prognathic) proved effective in predicting surgical treatment and treatment outcome. The model also identified Class III subtypes exhibiting mandibular prognathism as more likely to experience non-surgical treatment failure than maxillary deficient only Class III subtypes. The model can potentially become a reliable tool that improves the diagnostic process of Class III patients and aids in better-predicting treatment outcomes and, therefore, patient management.

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Figures

- *See attached PDF*

Tables

Table I. Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
Ages 7-25	Congenital abnormalities
ANB ≤ 0°	Trauma
Overjet ≤ 0	Missing or nondiagnostic cephalogram
Concave profile	No post-treatment clinical photos
Anterior crossbite	Previous orthodontic treatment

Subjects, after meeting age and ANB criteria, were required to meet at least one additional inclusion criteria to be eligible for the study.

Table II. Descriptive Statistics of Study Group: n, number; N, total number of subjects; SD (Standard Deviation)

Characteristic	Statistic	
Number of patients	N	148
Age (years)	Mean; SD; Range	14.7 yrs; 3.23; 7-25
Male	n/N (%)	68/148 (45.95%)
Female	n/N (%)	80/148 (54.05%)

Supplementary Table IV. Sixty-seven cephalometric variables used in this study, with their respective abbreviations, descriptions, and norm values.

Abbreviation	Cephalometric Variable Name	Landmarks	Norms
1. Saddle	Saddle/sella angle (º)	(SN-Ar)	124° ± 5°
2. Gonang	Gonial/Jaw angle (º)	(Ar-Go-Me)	122.9° ± 6.7°
3. Acb	Length of ant cranial base (mm)	(SN)	75.3 ± 3mm
4. Pcb	Length of post cranial base (mm)	(S-Ar)	35 ± 4mm
5. Ramht	Ramus height (mm)	(Ar-Go)	48.5 ± 4.5mm
6. Mdlgth	Length of Mn base (mm)	(Go-Pg)	73 ± 3mm
7. Facang	Facial Angle (º)	N-Pg-FH	87.8° ± 3.6°
8. Convex	Convexity angle (º)	(NA-APg)	4.9° ± 3°
9. Abfp	A-B plane to facial plane angle (º)	(A-B to N-Po)	-3.5° ± 3°
10. Fpsn	Facial plane to SN (º)	(SN-NPg)	80.5° ± 4°
11. Factap	Facial Taper (º)	(Go-Gn-N)	70° ± 6°
12. Artang	Articular angle (º)	(S-Ar-Go)	140.3° ± 6°
13. Pafaceht	Postero-Anterior Face height (mm)	(S-Go/N-Me)	65% ± 4%
14. Yang	Y-Axis angle (º)	(SGn-SN)	60.3° ± 3.4°
15. Midface	Midface Length (mm)	(Co-A)	93.2 ± 4mm
16. SNA	Sella-Nasion-Point A Angle (º)		81.8° ± 3.5°
17. SNB	Sella-Nasion-Point B Angle (º)		78.9° ± 3.9°
18. ANB	Point A-Nasion-Pointb Angle (º)	(SNA - SNB)	2.9° ± 2.7°
19. Anperp	A-N Perpendicular (mm)		0.4 ± 2.3mm
20. Bnperp	B-N Perpendicular (mm)		-5.3 ± 6.7mm
21. Pgnperp	Pog-N Perpendicular (mm)		-1.8 ± 4.5mm
22. Mxul	Maxilarry Unit Length (mm)	(Co-ANS)	92.4 ± 2.7mm
23. Mdul	Mandibular Unit length (mm)	(Co-Gn)	119.5 ± 5mm
24. Unitdif	Maxillo-Mandibular Unit Length (mm)	(Co-ANS - Co-Gn)	27 ± 4.1mm
25. U1sndeg	Inclination of the upper incisor with SN plane (º)	(U1 - SN)	103.7° ± 7.1°
26. U1nadeg	Inclination of the upper incisor with NA plane (º)	(U1 - NA)	21.9° ± 7°
27. U1namm	U1 - NA (mm)	(U1 - NA)	3.9 ± 3.2mm
28. U1fhdeg	U1 - FH (º)	(U1 - FH)	111.3° ± 4.3°
29. IMPA	IMPA (º)	(L1-MP)	92° ± 6.4°
30. L1nbdeg	L1 - NB (º)	(L1 - NB)	23.3° ± 6.6°

31. L1nbmm	L1 - NB (mm)	(L1 - NB)	3.9 ± 2.8mm
32. Liprot	L1 Protrusion (º)	(L1-APo)	22.1° ± 1.2°
33. L1apo	L1 Protrusion (mm)	(L1-APo)	1.2 ± 2.5mm
34. Wits	Wits Appraisal (mm)	(AO/BO)	0.1 ± 1.8mm
35. Interang	Interincisal Angle (º)	(U1-L1)	131.9° ± 10.3°
36. Oj	Overjet (mm)	U1, L1	2 ± 1mm
37. Pgnbmm	Pog - NB (mm)		1.9 ± 1.4mm
38. Hold	Holdaway Ratio (%)	(L1-NB/Pg-NB)	1 ± 1.7mm
39. FMIA	FMIA (º)	(L1-FH)	61.5° ± 9.2°
40. Tfh	Total Anterior Face Ht (mm)	(N-Me)	122.7 ± 6.4mm
41. Ufh	Upper Anterior Face Height (mm)	(N-ANS)	55.3 ± 3.2mm
42. Lfh	Lower Anterior Face Height (mm)	(ANS-Me)	69.5 ± 5.3mm
43. Nasaht	Nasal Height (%)	(N-ANS/N-Me)	43%
44. Pfh	Post Facial Ht (mm)	(Co-Go)	58.9 ± 3.4mm
45. Pfhafh	PFH:AFH (%)	(Co-Go/N-Me)	60%
46. FMA	FMA (º)	(MP-FH)	24.6° ± 4.1°
47. Sngogn	Mandibular Plane Angle (º)	(SN - GoGn)	32.1° ± 5.5°
48. Opsn	Occ Plane to SN (º)		15.1° ± 4.1°
49. Opfh	Occ Plane to FH (º)		8.7° ± 2.4°
50. Fhsn	(º)	(FH – SN)	6° ± 2.5°
51. U1ppmm	U1 - PP (UADH) (mm)		29.1 ± 3.3mm
52. L1mpmm	L1 - MP (LADH) (mm)		42 ± 3.2mm
53. U6ppmm	U6 - PP (UPDH) (mm)		16.5 ± 2.2mm
54. L6mpmm	L6 - MP (LPDH) (mm)		32.7 ± 2.9mm
55. Obite	Overbite (mm)	U1, L1	2 ± 1mm
56. Uleplane	Upper Lip to E-Plane (mm)		-4 ± 2mm
57. Lleplane	Lower Lip to E-Plane (mm)		-2 ± 2mm
58. Softnpul	STissue N Vert (N Perp) to Upper Lip (mm)		1.6 ± 1mm
59. Softnpll	STissue N Vert (N Perp) to Lower Lip (mm)		0 ± 1mm
60. Softnppg	STissue N Vert (N Perp) to Pogonion (mm)		-3.5 ± 1mm
61. chinang	Chin angle (º)		
62. Softnvtul	STissue N Vert (N Perp) to Pogonion (mm)		
63. Softnvtll	Stissue N Vert (True Vert) to Lower Lip (mm)		

64. Softnvtpg	Soft tissue N Vert (True Vert) to Pogonion (mm)		
65. Anvt	A-N Vert (True Vert) (mm)		
66. Bnvt	B-N Vert (True Vert) (mm)		
67. Pgnv	Pg-N Vert (True Vert) (mm)		

Table III. Success and Failure Criteria for Treatment Outcome

Success Criteria	Failure Criteria*
Orthognathic or straight profile	Concave profile (soft tissue pt B ahead of A)
Overjet ≥ 1	Overjet ≤ 0
Overbite ≥ 1	Overbite ≤ 0
Absence of anterior or posterior crossbite	Anterior or posterior crossbite
	Relapse

*Any subject who had one or more of the failure criteria were classified as failure. Otherwise, for the purposes of this paper, they were labelled as success.