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A comparative study of new Barcelona line and traditional method for 3D planning of orthognathic surgery

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Abstract

Background This retrospective study aims to compare the postoperative facial profiles of Class III orthognathic surgery patients planned according to the true vertical line (TVL) by comparing their positions with the Barcelona line (BL) reference specifically focusing on Class III patients with maxillary retrognathism and mandibular prognathism.

Methods A retrospective analysis was conducted on 43 skeletal Class III patients undergoing isolated maxillary LeFort I or bimaxillary surgery. Digital planning data were used for preoperative and postoperative (6 months) upper incisor (UI)-BL measurements. Patients were categorized into four groups based on the maxillary incisor position relative to BL: Group 1 (UI > 4 mm behind BL), Group 2 (UI 0–4 mm behind BL), Group 3 (UI 0–4 mm ahead of BL), and Group 4 (UI > 4 mm ahead of BL).

Results In total of 43 patients, those with maxillary retrognathia showed significant postoperative transitions towards a more protrusive position, while those with mandibular prognathism exhibited greater stability. *($p = 0.001$)*

Conclusion BL is a reliable reference in digital planning for skeletal Class III patients, particularly in cases of maxillary retrusion, leading to outcomes more aligned with contemporary aesthetic standards. These findings support incorporating BL into orthognathic surgery planning to optimize sagittal positioning and facial harmony.

Trial registration Baskent University Institutional Review Board approved this study (D-KA24/16). All participants provided informed consent prior to inclusion.

Keywords Barcelona line, Orthognathic surgery, 3D planning, Facial projection, Skeletal malocclusion

Introduction

Orthognathic surgery corrects skeletal deformities while optimizing facial aesthetics. Postoperative profile assessment ensures desired aesthetic and functional outcomes. Despite the increasing use of digital planning techniques, there remains a lack of consensus on the most reliable reference line for sagittal positioning. TVL, proposed by Arnett, is widely used [1, 2]. The Barcelona Line (BL), developed in 2010 and validated in 2022, BL, aligns the upper incisor with a vertical plane through the soft tissue nasion, remaining unaffected by skeletal movements [3, 4].

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This study examines Class III patients with maxillary retrognathism and mandibular prognathism, requiring significant skeletal adjustments for facial projection. The Barcelona Line (BL) is key for maxillary positioning, guiding surgery for optimal maxillo-mandibular balance and facial harmony. Assessing BL's impact on the postoperative profile is crucial to determine whether it provides superior aesthetic outcomes compared to TVL. Additionally, BL's potential advantages over TVL, such as greater stability and improved predictability of soft tissue adaptation, warrant further investigation.

The objective of this study is to assess the effectiveness of BL as a reference for 3D planning in orthognathic surgery and compare postoperative profile outcomes with those based on TVL. Additionally, it seeks to address prior reference line limitations and determine if BL offers a more precise, aesthetically favorable result.

Materials and methods

This retrospective study analyzed preoperative digital planning data from Class III orthognathic cases. Patient data were sourced from Baskent University's Oral and Maxillofacial Surgery Department and DENTALAG Digital Planning Partner (METUM, Ankara, Turkey). A consecutive case series method minimized selection bias while ensuring a sufficient sample size for detecting group differences. Patients with skeletal Class III malocclusion who underwent either isolated maxillary LeFort I surgery or bimaxillary orthognathic surgery were included. Cases with Class II deformities, isolated mandibular corrections, syndromic conditions, and cleft lip and palate were excluded. Additionally, patients with significant facial asymmetry were excluded to maintain homogeneity in the sample. All participants underwent comprehensive preoperative orthodontic treatment to ensure the alignment and leveling of the dentition. Additional postoperative alignment or leveling were not necessary in all included patients. Preoperative photographs were taken after finalizing dental movements for optimal surgical alignment. Postoperative photographs were obtained six months post-surgery to ensure soft tissue adaptation and surgical outcome stabilization. Arnett's soft tissue analysis guided orthognathic surgery planning using the True Vertical Line (TVL) through Subnasale (Sn') in the neutral head position (NHP). Following distances specified by Arnett were used to project the position of maxilla: The distance between the nasal tip (NT) and TVL (NT-TVL), the distance between the nasal base and TVL (NB-TVL), the distance between the soft tissue A point (A') and TVL (A'-TVL), the distance between the incisal edge of the maxillary incisor and TVL (Mx1–TVL), the distance between the anterior part of the upper lip (ULA) and TVL (ULA-TVL), the upper lip angle (Sn'-ULA-TVL: The angle between the line extending from the anterior upper lip to subnasale and TVL) and the nasolabial angle (Columella-Sn'-ULA: the angle between the columella, subnasale, and anterior upper lip) [5]. Preoperative and 6-month postoperative profile photos were taken by the same operator for consistency. Photos captured maximum interdigitation and smile in NHP. To prevent perspective distortion, patients adjusted NHP by nodding while viewing a mirror 2 m away. A pendulum system with a millimetric scale (DentalAG TVL) standardized measurements in preoperative images. Preoperative peri-oral photos were taken at rest and maximum smile to assess incisal and gingival display. A Canon R10 APS-C mirrorless camera with a 100 mm macro lens (Canon R10, Canon U.S.A., Inc.) and studio strobe flash ensured high-quality images. A professional image-processing computer software (Adobe Photoshop (Adobe Ps 25.5.0 20240214.r.375, San Jose, California, USA)) was used for image superimpositions and measurements. Preoperative and smile photos were scaled using the pendulum's millimetric guides, then rotated until the pendulum was perpendicular. Images were superimposed via best-fit on Soft Tissue Nasion (N'), Glabella (G'), Orbitale (Or'), and Tragus points. Following superimposition of pre and post operative photographs, perpendicular UI distances were measured from TVL and BL. Calibration used the pendulum system as a reference for UI-BL measurements (Fig. 1). All measurements were performed on digital images. Intra- and inter-rater reliability was

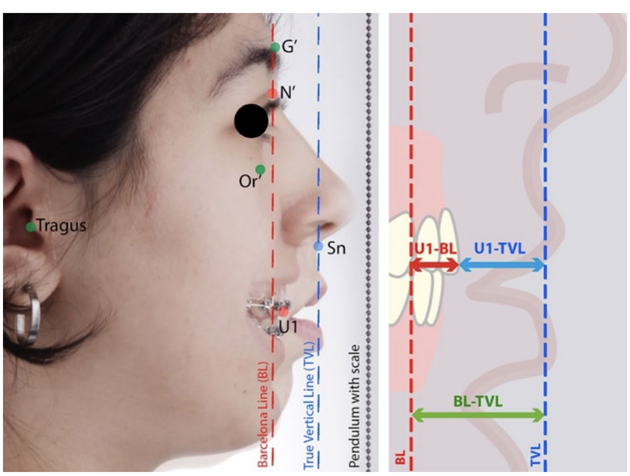

Fig. 1 Pendulum System and Photographic Superimposition. This figure also illustrates the clinical relevance of each measurement, where U1–BL indicates sagittal maxillary position relative to BL, and U1–TVL indicates the same relative to TVL. A pendulum was used as both a scale and as a reference plane perpendicular to ground. Profile photos at maximum interdigitation and maximum smile were superimposed using soft tissue Glabella (G'), soft tissue Nasion (N'), soft tissue Orbitale (Or') and soft tissue Tragus. True Vertical Line (TVL) and Barcelona Line (BL) were drawn parallel to pendulum line and placed on Subnasale (Sn) and soft tissue Nasion (N') points (Left side). Distances from upper incisor (U1) to Barcelona Line (U1-BL), Upper incisor to True Vertical Line (U1-TVL) and Barcelona Line to True Vertical Line (BL-TVL) were measured (Right side)

assessed using the Intraclass Correlation Coefficient (ICC), exceeding 0.90. Measurement repeatability was tested on 10 patients by two independent raters. The ICC values exceeded 0.90, confirming high reliability. A standardized calibration process, using the pendulum system and software corrections, minimized scaling and alignment errors.

Patients were categorized into four groups based on the UI-BL measurements [4](Fig. 2);

- Group 1: Postoperatively, the upper incisor was located more than 4 mm behind BL.
- Group 2: Postoperatively, the upper incisor was located between 0 and 4 mm behind BL.
- Group 3: Postoperatively, the upper incisor was located between 0 and 4 mm ahead of BL.
- Group 4: Postoperatively, the upper incisor was located more than 4 mm ahead of BL.

Statistical analysis

Statistical analysis was conducted using IBM SPSS Statistics 25 (IBM Corp., Armonk, NY, USA). Test selection was based on data distribution and variable type. The Chi-Square test analyzed categorical variables, while non-normally distributed continuous variables were assessed using the Mann-Whitney U test (two-group) and Kruskal-Wallis test (multiple-group). Normally distributed variables were analyzed with ANOVA, followed by Tukey's post-hoc test. Multivariate regression controlled for confounders (age, gender, malocclusion severity). A 4 mm UI-BL cut-off, based on prior research [4], ensured consistency in facial aesthetics and skeletal positioning analysis. Planned vs. achieved surgical movements were compared using a paired t-test. Though differences were not statistically significant, intraoperative constraints and postoperative healing factors were discussed.

Results

A total of 43 patients with skeletal Class III deformity who underwent either isolated maxillary LeFort I surgery or bimaxillary orthognathic surgery were included in the study. Among 43 patients, 19 (44.2%) had maxillary retrognathia, and 24 (55.8%) had mandibular prognathism.

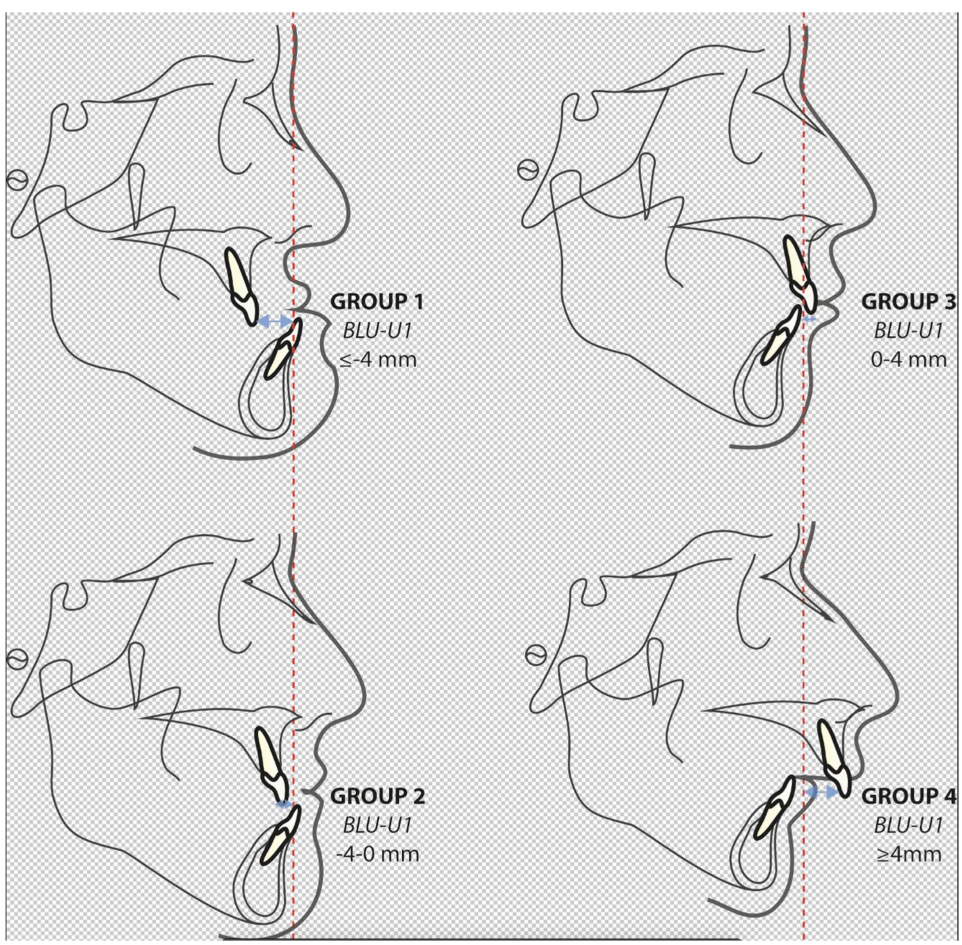

Fig. 2 Classification of patient groups was based on the distance of upper incisor to Barcelona Line

Table 1 Demographic data chart

	PRE-OP PLANNED GROUP DISTRIBUTION			POST-OP GROUP DISTRIBUTION		
GROUPS	***n***	**SKELETAL CLASS III OCCLUSION CAUSE**		***n***	**SKELETAL CLASS III OCCLUSION CAUSE**	
		Maxillary Retrognathia	**Mandibular Prognathia**		**Maxillary Retrognathia**	**Mandibular Prognathia**
GROUP 1	6	5	1	2	1	1
GROUP 2	7	3	4	11	**7**	4
GROUP 3	12	**7**	5	17	**7**	**10**
GROUP 4	18	4	**14**	13	4	**9**
TOTAL	43	19	24	43	19	24

(Group 1 = UI > 4 mm behind BL; Group 2 = UI 0–4 mm behind BL; Group 3 = UI 0–4 mm ahead of BL; Group 4 = UI > 4 mm ahead of BL)

Table 2 Postoperative positional changes of groups relative to the BL based on preoperative measurements

CHANGES OF GROUPS RELATIVE TO THE BL-ANTERIOR OR POSTERIOR LOCALISATION						
			POSTOP DISTRIBUTION		**TOTAL**	***P* VALUE**
			NEGATIVE	**POSITIVE**		
PREOP GROUP DISTRIBUTION	UI Position Behind the BL (Negative) (GROUP 1 and GROUP 2-TOTAL)	Patient Count	**8**	**5**	**13**	$P = 0.99$
		% within Preop Group	61,5%	38,5%	100,0%	
		% within Postop Group	66,7%	16,1%	30,2%	
	UI Position Forward the BL (Positive) (GROUP 3 and GROUP 4-TOTAL)	Patient Count	**4**	**26**	**30**	
		% within Preop Group	13,3%	86,7%	100,0%	
		% within Postop Group	33,3%	83,9%	69,8%	
Total		Patient Count	**12**	**31**	**43**	
		% within Preop Group	27,9%	72,1%	100,0%	
		% within Postop Group	100,0%	100,0%	100,0%	

Preoperative measurements determined patient group distribution as follows:

- Group 1: 6 patients (14%).
- Group 2: 7 patients (16.3%).
- Group 3: 12 patients (27.9%).
- Group 4: 18 patients (41.9%).

At the 6-month follow-up, upper incisor-Barcelona line measurements showed patient redistribution:

- Group 1: 2 patients (4.7%).
- Group 2: 11 patients (25.6%).
- Group 3: 17 patients (39.5%).
- Group 4: 13 patients (30.2%).

Preoperatively, most maxillary retrognathic patients were classified in Group 2, while postoperatively, they were primarily distributed across Groups 2 and 3. Mandibular prognathic patients were mostly in Group 4 before surgery, whereas postoperatively, they were mainly classified in Groups 3 and 4. The inter group transitions and detailed distribution of these patients are shown in Table 1. The most common LeFort I movement was advancement with down fracture ($n = 18$, 41.9%), followed by advancement with impaction ($n = 9$, 20.9%) and isolated advancement ($n = 8$, 18.7%). The planned maxillary movement averaged 4.59 ± 2.11 mm, while the achieved movement averaged 3.47 ± 3.18 mm. Statistical analysis ($p = 0.055$) showed no significant difference. The changes in the positioning of patients in Group 1 and Group 2 (located behind the BL) and Group 3 and Group 4 (located in front of the BL) relative to the BL in the preoperative period, based on whether they remained anterior or posterior to the BL in the postoperative period is presented in the Table 2. An examination of transitions between groups revealed that patients initially classified in Groups 1 and 2 based on the UI position relative to BL in preoperative planning shifted postoperatively to groups with more protrusive UI positioning. In contrast, patients in Groups 3 and 4 generally remained in the same group as their preoperative measurements. The Chi-Square test between the groups resulted in a p-value of 0.001, indicating that there was significant difference (Table 3). Among patients with a change in grouping based on preoperative and postoperative measurements, it was observed that the majority of those with a more retrusive position than planned had a mandibular prognathic relationship (6 out of 9 patients). Conversely, among those with a more protrusive position than planned, the majority had a maxillary retrognathic relationship (5 out of 7 patients) (Fig. 3).

Discussion

To facilitate direct linkage between the findings and literature, the main numerical outcomes are briefly restated here. Among 43 patients, preoperative distribution showed 14% in Group 1, 16.3% in Group 2, 27.9%

Table 3 Analysis of group transitions and statistical significance of postoperative UI positional changes

TRANSITIONS BETWEEN GROUPS

			Postop Group					**P VALUE**
			Group 1	**Group 2**	**Group 3**	**Group 4**	**Total**	
PREOP GROUP DISTRIBUTION	UI Position Behind the BL (GROUP 1 and GROUP 2)	Patient Count	**2**	**1**	**3**	**1**	13	P = 0.001
		% within Preop Group	15,4%	7,7%	23,1%	7,7%	100,0%	
		% within Postop Group	100,0%	7,7%	17,6%	7,7%	30,2%	
	UI Position Forward the BL (GROUP 3 and GROUP 4)	Patient Count	**0**	**12**	**14**	**12**	30	
		% within Preop Group	0,0%	40,0%	46,7%	40,0%	100,0%	
		% within Postop Group	0,0%	92,3%	82,4%	92,3%	69,8%	
Total		Total Patient Count	**2**	**11**	**13**	**13**	43	
		% within Preop Group	4,7%	25,6%	30,2%	30,2%	100,0%	
		% within Postop Group	100,0%	100,0%	100,0%	100,0%	100,0%	

(Group 1 = UI > 4 mm behind BL; Group 2 = UI 0–4 mm behind BL; Group 3 = UI 0–4 mm ahead of BL; Group 4 = UI > 4 mm ahead of BL)

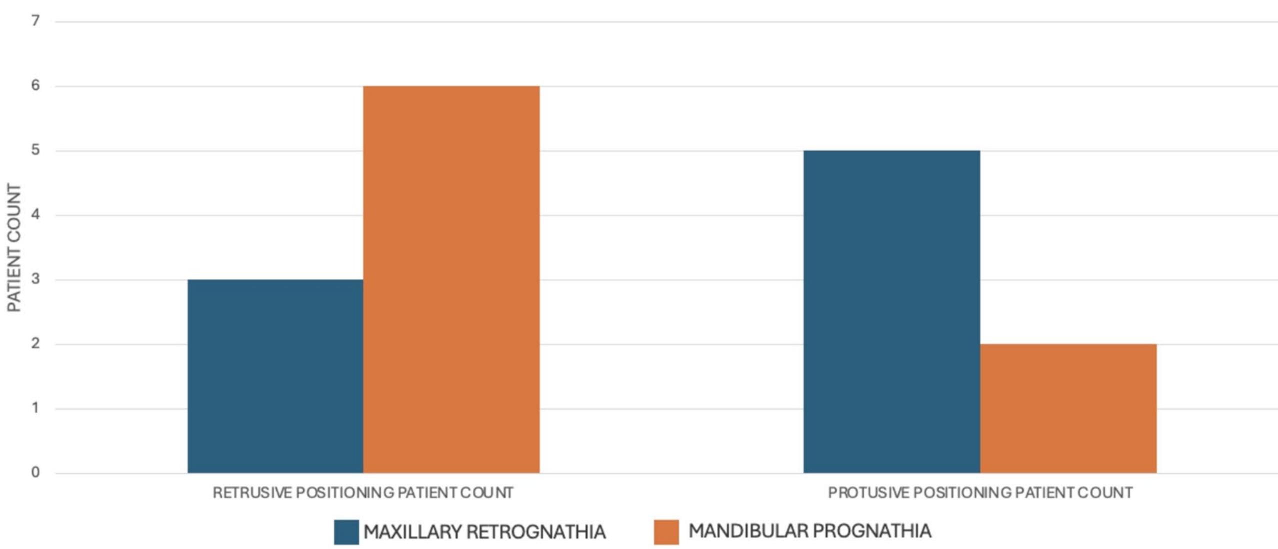

Fig. 3 Distribution of patients with group transitions

in Group 3, and 41.9% in Group 4. Postoperatively, the distribution shifted to 4.7% in Group 1, 25.6% in Group 2, 39.5% in Group 3, and 30.2% in Group 4. Notably, patients in preoperative Groups 1 and 2 (behind BL) frequently transitioned to Groups 3 and 4 (ahead of BL) postoperatively, reflecting a tendency towards greater anterior projection, especially in maxillary retrognathia cases ($p = 0.001$).

Soft tissue changes reflect skeletal movements in orthognathic surgery, making accurate analysis essential for optimal aesthetics. Despite ongoing debate, no universal guidelines exist for maxillomandibular sagittal positioning in dentofacial deformities. Treatment combines occlusal correction with surgeon aesthetic judgment. Mansour et al. [6] have emphasized that the soft tissue response to maxillomandibular movements can be quantitatively assessed. This study evaluated the preoperative and 6-month postoperative UI-BL position in patients with Class III skeletal deformities who underwent maxillary advancement or bimaxillary surgery, focusing on maxillary sagittal alignment. The primary aim was to assess profile changes relative to the BL following maxillary repositioning in Class III patients with retrusive and protrusive facial profiles.

Sachin et al. (2019) compared TVL projection norms in Himachali and Caucasian females. Digital tracings of 50 Himachali women (18–25) showed lower TVL values, with significant differences in orbital rim, cheekbone, nasal base, and maxillary incisor projections. The study emphasized that TVL norms vary across ethnic groups, suggesting that a single normative standard may not be universally applicable [7]. Lee et al. [8] emphasized ethnic differences in aesthetic jaw positioning in Asians. Arnett [9] studying Caucasian Americans, noted that maxillary retrusion shifts the upper lip posteriorly, complicating soft tissue prediction. He suggested placing TVL 1–3 mm anterior to Sn' but acknowledged its limitation as a precise reference. However, this adjustment does not provide clinicians with a clear reference point for achieving a predictable soft tissue contour. The soft tissue cephalometric analysis by Arnett and Bergman [9] takes the soft tissue subnasale (Sn') to TVL as a reference instead of cranial base bones. However, with the inclusion of 3D analyses in orthognathic surgery planning, it has been observed that the traditional 2D-based TVL is insufficient [10–14]. Therefore, various researchers have proposed alternative references for maxillary positioning. For instance, Adams et al. used the forehead-face axis for maxillary positioning [15]. Hernandez et al. introduced the reference line from the soft tissue Nasion (Na'), known as the "Barcelona Line" [4, 16]. In a 2024 study by Chen et al. [17], compared maxillary sagittal positioning methods in the Southern Chinese population, including Steiner, Barcelona Line, Glabella Vertical, and Andrews analyses. Findings showed the Barcelona Line was the most aesthetically preferred reference.

This study adopts the BL reference line defined by Hernandez et al.'s recent study [4] with the assumption that aesthetic and practical preferences are similar. It was suggested that a protrusive maxillary position was perceived as more aesthetically pleasing, associated with a youthful appearance [4]. Surgeons favored slightly protrusive skeletal positioning for optimal aesthetics, aligning with our findings as most patients were classified in Group 3 postoperatively. In this study, patients in preoperative Groups 1 and 2 generally shifted to more protrusive positions (Groups 3 and 4) postoperatively, indicating an improvement in the UI position following surgery for those with a retrusive maxillary position. Conversely, patients in Groups 3 and 4 largely maintained their preoperative classifications after surgery. This consistency further suggests that aesthetic preferences align with a more protrusive maxillary position, and the consistent classification of postoperative groups along the BL supports its utility as a reference for aesthetic predictability, providing surgeons with an objective tool for planning. Our findings align with these perspectives, reinforcing the BL's utility for both surgical planning and outcome assessment. The observed stability in Groups 3 and 4, alongside the postoperative improvements in Groups 1 and 2, suggests that BL-guided planning promotes results consistent with current aesthetic ideals while accommodating individual variation. These findings suggest that incorporating BL into preoperative planning may assist surgeons in achieving targeted sagittal positions more consistently, improving predictability of postoperative aesthetics and potentially reducing the need for secondary revisions.

Patients were classified as mandibular prognathic or maxillary retrognathic. Cases with a more protrusive initial UI position showed greater stability in preoperative, postoperative measurements, and group transitions, consistent with studies on maxillary protrusion stability [18]. There were 16 patients whose postoperative group, differed from their preoperative planned UI position group. Analyzing the patients whose group changed between preoperative and postoperative measurements revealed that patients with mandibular prognathism tended to result in a more retrusive position (6 out of 9 patients). This finding suggests that postoperative adaptation of the mandible needs to be managed more effectively. In contrast, the majority of patients who resulted in a more protrusive position than planned preoperatively were found to have maxillary retrognathia (5 out of 7 patients). This indicates that a retrusive maxilla requires more pronounced corrections and that surgical outcomes in these patients tend to be more dynamic. In addition, TVL may not always be reliable, especially for maxillary retrusive patients [4, 19]. Recent literature indicates that traditional reference lines like the true vertical line may not fully meet modern aesthetic goals, and Hernández-Alfaro's 2022 study [20] highlights that greater anterior facial projection more readily achievable with the BL is essential for optimal harmony and youthfulness. Also, the postoperative adaptation process might contribute to this variation. The mean planned maxillary movement preoperatively was 4.59 ± 2.11 mm, while the mean achieved maxillary movement postoperatively was 3.47 ± 3.18 mm. Although this difference was not statistically significant ($p = 0.055$) it indicates that intraoperative constraints, tissue resistance, and postoperative healing may influence surgical outcomes. This emphasizes the importance of surgical planning, intraoperative flexibility, and postoperative follow-up in optimizing results [18, 21].

This study has several limitations that should be acknowledged. The sample size of 43 patients, although informative, may limit the generalizability of the findings to broader populations with Class III skeletal deformities. While the BL was used as a reference for sagittal alignment, individual anatomical variations and ethnic differences could influence the perception of ideal maxillary positioning, warranting further multicenter studies across diverse populations. The study primarily focused on linear maxillary movement without assessing rotational changes, which may also affect postoperative outcomes and aesthetic perceptions. Furthermore, the study did not include the use of three-dimensional (3D) analysis and preoperative and postoperative CBCT evaluations, which could provide a more comprehensive assessment of aesthetic and skeletal parameters.

Conclusion

The BL serves as a reliable reference point that may offering clear predictions for postoperative profile outcomes. Based on the current evaluation, it can be concluded that surgical planning for skeletal Class III patients, particularly those with preoperative maxillary retrognathia, leads to more prominent facial features, aligning with contemporary aesthetic standards. Postoperatively, patients with both maxillary retrusion and mandibular prognathism display a upper incisor located 0–4 mm anterior to the BL (Group 3).

Future studies incorporating long-term follow-up and diverse populations are essential to validate these findings and refine surgical protocols further.

Abbreviations

TVL	True Vertical Line
BL	Barcelona Line
UI	Upper Incisal Tip
Mx1	Maxillary Incisor
NB	Nasal Base
3D	Three-Dimensional
2D	Two-Dimensional
NHP	Neutral Head Position
NT	Nasal Tip
ULA	Anterior Part of the Upper Lip
A′	Soft Tissue A Point
N′	Soft Tissue Nasion
G′	Soft Tissue Glabella
Or′	Soft Tissue Orbitale
Sn'	Soft Tissue Subnasale
mm	Millimeters

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Authors' contributions
Berat Serdar Akdeniz: Conceptualization, Project Administration, Software, Resources, Writing- Review & Editing. Ezgi Ergezen Arık: Formal Analysis, Investigation, Resources, Writing- Review & Editing. Seda Öz: Formal Analysis, Investigation, Resources, Writing- Review & Editing, Writing-Original Draft. Nur Altıparmak: Software, Formal Analysis, Investigation.Sıdıka Sinem Akdeniz: Conceptualization, Methodology, Validation, Project Administration, Supervision.

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Data availability
The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
This study was conducted in accordance with the ethical principles of the Declaration of Helsinki. The study protocol was approved by the Baskent University Institutional Review Board (Approval number: D-KA24/16). Written informed consent was obtained from all participants prior to their inclusion in the study.

Consent for publication
Written informed consent was obtained from the participant for the publication of the clinical image included in this manuscript. The patient's identity is anonymized and no identifiable personal information is presented.

Competing interests
The authors declare no competing interests.

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