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Review

Barcelona line. A multicentre validation study of a facial projection reference in orthognathic surgery

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Abstract

The purpose of this study was to validate an already published facial anteroposterior reference: upper incisor (UI) to soft tissue plane or so-called Barcelona line (BL) to trace the most aesthetic sagittal position of the maxilla. A cross-sectional multicentre evaluation of Caucasian patients from Spain and Brazil with different anteroposterior maxillary positions was designed. Sagittal images in natural head orientation of grouped patients according to the horizontal distance from the UI to BL were ranked by healthcare professionals and non-professional Caucasian raters according to the aesthetic perception of each profile, using a digital survey. Seventy-four raters (50 laypeople, 12 orthodontists, and 12 maxillofacial surgeons) rated 40 profiles. The best-rated profile corresponded to group 3 (0–4 mm UI-BL) with 61.8% of positive evaluations, followed by group 4 ($\geq$ 4 mm UI-BL): with 61.1%. On the other hand, group 1 (≤ -4 mm UI-BL) was the worst-ranked profile with 71.8% of negative evaluations, followed by group 2 (-4–0 mm UI-BL): with 59.6% of negative evaluations. The correlation between the mean assessment score and UI-BL showed a moderately-strong association ($r = 0.68$, $p < 0.001$). The inter-rater reliability of assessment (74 evaluators) was moderate ($k = 0.49$, 95% CI: 0.39 to 0.59). The results suggest that protrusive middle-third facial profiles are preferable. The BL is proposed as a simple, individualised, and reproducible tool to trace an aesthetic sagittal position of the maxilla in orthognathic surgery.
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Keywords: Aesthetics; Orthognathic surgery; Maxillofacial surgery; Minimally invasive surgery; Imaging; Three-dimensional

Introduction

Beauty is a perception conditioned by individual preferences. However, objectivity in aesthetic ideals is helpful when planning orthognathic surgery (OS).[1] The contemporarily attractive face entails protrusive, angled, and defined lines.[2] Conversely, poor skeletal support of soft tissue (ST) manifests as premature facial aging.[3]

Throughout history, cephalometry has directed the diagnosis and surgical planning in patients with dentofacial deformity (DFD) [4–9] Most of them focused on the presumption that occlusion correction will result in ideal profiles. However, the centripetal facial concept[10] where the ST mask follows skeletal movement[11] found that attractive faces were more protrusive than the cephalometric standards would like to accept. Moreover, the aesthetic outcomes can be worsened due to errors of analysis related to skull variations or incorrect head postures.[12] The analysis of Arnett et al[13] guided the maxillary sagittally, based on a true vertical line (TVL) drawn through subnasale (Sn). However, Sn is a mistaken reference in maxillary hypoplasia, and is modified by surgery.[14]

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The 'upper incisor to soft tissue plane (UI-STP)',[15] renamed in the present paper as the 'Barcelona line' (BL) for establishing an easier and practical term, seek the most aesthetic sagittal maxillomandibular positioning in the diagnosis and planning of DFD; the published article analysed a series of extremely attractive people and most of them had their upper incisor (UI) at or in front of the 'STP' (so-called BL); defined as a ST nasion vertical line tangent, perpendicular to the natural head orientation (NHO)[16] (BL protocol described in Fig. 1). In the same setting, Marianetti et al[14] reported their TVL passing through ST-glabella, positioning the maxilla in front of the TVL. Adams et al[17] reported the forehead facial axis as a reference for maxillary positioning.

In this context, facial beauty has been discussed historically, but no rules have been accepted regarding the maxillomandibular sagittal position to resolve aesthetically and functionally DFD, becoming a mix of occlusal correction and subjective surgeon aesthetic preferences. The present study aimed to validate the BL to determine an aesthetic maxillary sagittal positioning in the DFD diagnosis and surgical planning based on a simple protocol.

Material and methods

A multicentre aesthetic evaluation of lateral images of patients from the Institute of Maxillofacial Surgery (Teknon Medical Centre, Barcelona, Spain) and São Lucas Hospital (Pontifical Catholic University of Porto Alegre, Brazil) - centres with extensive experience in OS - was conducted.

The images included preoperative or postoperative records with different distances from UI to BL, aesthetically evaluated by raters, were compiled according to the following inclusion criteria: Caucasians, over 18 years of age, with photographic and radiographic records based on BL protocol (Fig. 1). Patients were excluded if they had congenital craniofacial anomalies; facial trauma; chemotherapy or radiotherapy; any condition altering ST quality; facial cosmetic procedures; or nasal disharmonies.

The sample was selected based on a literature review and 40 profiles and six qualifiers were needed to secure a kappa value = 0.975, and a statistical power of 80%. Marginal frequencies for positive and negative results with a 95% confidence interval (CI) were assumed; the significance level was 5% ($\alpha = 0.05$). The sample was categorised into four groups,

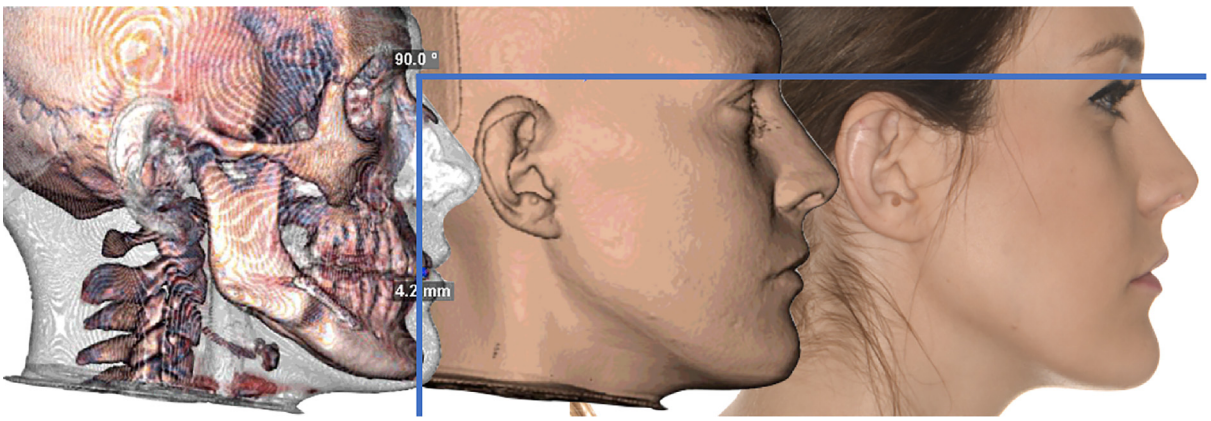

Fig. 1. Barcelona line protocol on cone beam computed tomography (CBCT) scan (Dolphin 3D software). CBCT - 3D software image of a postoperative bimaxillary OS case, the blue line represents the BL. Note that in this case the upper incisor lies in front of the BL by 4.2 mm, and the pogonion lies on the BL. The BL protocol comprises a sequence of reproducible steps:

1) A 3D set-up is applied for DICOM positioning.
2) The photography is oriented in NHO matching up the (CBCT) 'virtual patient' ('ST layer'), in which a true horizontal line (THL) is drawn on the photograph, passing through the eye and at a determined point of the helix or over it; this photographic THL is transferred to the same point at the CBCT 'soft tissue virtual patient' in NHO, resulting in a re-oriented CBCT 'virtual patient'.[16]
3) On the DICOM, the BL is traced perpendicular to the THL, crossing ST-Nasion.
4) Independently of the DFD, the cases are positioned in Class I occlusion.
5) The UI is translated (in bimaxillary cases the complex is moved as a block) virtually in or in front of the BL. The UI must have an appropriate angulation or a well-orthodontically planned position with the maxillary plane. The Pogonion must be in or ahead of the BL.
6) The dental and facial midline must be coincidental.
7) The yaw must be symmetrically corrected.
8) The vertical maxillary positioning is defined intraoperatively according to the clinical internal cantus/lateral incisor or orthodontic arch vertical measures, applying 2–3 mm of UI exposure with a relaxed upper lip (UL).

Abbreviations: CBCT = cone beam computed tomography; OS = orthognathic surgery; BL = Barcelona line; NHO = natural head orientation; ST layer = soft tissue layer; THL = true horizontal line. Images published with the patient's consent.

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exposing 40 intercontinental Caucasian profiles to 74 intercontinental Caucasian evaluators: Twenty-four healthcare professionals (12 from each country: six orthodontists and six surgeons), while laypeople raters were doubled to 50 (to attenuate the fatigue in answering), ensuring a ratio of one healthcare professional for every two laypeople (2:1). The Shapiro-Wilk test confirmed normal data distribution for most of the variables. However, due to the awareness of the low power caused by the subgroups, deviations were explored using Q-Q plots - with approximation to normal distribution in all cases, except for distance in group 1, due to the presence of two outliers.

The study was approved by the Institutional Review Board of Teknon Medical Centre (Ref. 2020/90-MAX-CMT), and by the 'Parecer Consubstanciado Do CEP ¨ (Ref. 661.499). Likewise, all participants gave written informed consent. The study was carried out in accordance with the ethics standards of the Declaration of Helsinki (1964 and later amendments).

Data collection methods

Photographic records

Preoperative or postoperative right profile images were compiled:

a) adjusted to the same size
b) head orientation according to NHO
c) with original colour (white background, standard flash-light setting)
d) Although the facial proportions are essential in aesthetic evaluation, the mandible was removed to avoid influencing the mid-face analysis (Table 1).

Tomographic BL-UI measurements

CBCTs were saved in DICOM format using 3-dimensional (3D) software (version 11.8; Dolphin Imaging). Patient virtual heads were oriented by J.S.V.C. and O.L.H.J according to the patients' NHO. BL was traced and the perpendicular distance to UI was measured (Fig. 1). Lateral images were classified into four groups according to the distance BL to UI (Table 1) in:

Group 1: UI-BL distance ≤- 4mm
Group 2: UI-BL distance – 4 to 0 mm
Group 3: UI-BL distance 0 to 4 mm
Group 4: UI-BL distance ≥4 mm

Each group was composed of 10 patients (five Spanish and five Brazilian); 40 subjects were included in the study.

Digital survey

We invited 120 raters to answer an online survey via e-mail using Google Forms (Google develop Web application. Collaborative Software Web Survey. Docs.google.com/forms); 74 evaluators: the first 50 non-healthcare raters', 12 orthodontists' (six Brazilian and six Spanish), and 12 maxillofacial surgeons' (six Brazilian and six Spanish) ratings were saved. Specialists and laypeople raters (eye-trained or not, respectively) were asked to aesthetically evaluate the facial mid-third of each patient based on:

What personal opinion does the projection of the mid-face profile view deserve? (Include the maxillomalar, paranasal, and lip projection areas; and exclude the nose from your evaluation); a glossary of terms was added to be read before opening the survey:

1. Mid-face: area below eyes and over upper lip.
2. Profile: most anterior facial lining.
3. Maxillomalar: entire cheek area. Paranasal: inferior and lateral to the nose.
4. Lip projection: UL anterior position. Raters did not have previous knowledge about UI- BL distances, aims or whether the images corresponded to presurgical or postsurgical records.

The respondents ranked patients' attractiveness on a Likert scale (a validated psychometric score to measure opinions and perceptions),[18] ranging from 1 to 5, marking just one option: 1 = very poor, 2 = deficient, 3 = acceptable, 4 = good, and 5 = excellent. A dichotomic classification simplifies the results, differentiating between negative ('very poor' and 'deficient') and positive scores ('good' and 'excellent'), obviating the 'acceptable' score on the grounds that it constituted a neutral response.

Data analysis

It was performed using the SPSS 15.0.0 (SPSS Inc.) and EPIDAT 4.2. (Conselleria de Sanidade), the descriptive analysis included: mean, standard deviation (SD), minimum, maximum, and median for continuous variables, and absolute and relative frequencies (percentages) for all categorical parameters. Reliability between raters was calculated using the Fleiss Kappa index and 95% CI estimated by the jackknife method. To study the validity of rater assessment, a mean between-raters score was calculated and correlated with the distance measurement using Pearson's correlation coefficient. The normal distribution of both measurements was checked accordingly, and the sample size proved moderately large (n = 40). Comparisons of correlation coefficients between different groups of raters were made with Wald's Chi^2 test based on a linear regression model using generalised estimation equations (GEE). Statistical significance was $p < 0.05$.

Results

The demographic data is presented in Table 2. There were 74 evaluators, with a mean (SD) age of 39.6 (10.0) years (range: 21–73). A total of 34 Europeans and 40 Americans completed 2960 aesthetic evaluations (Table 3), clustered into four groups, each with 740 evaluations. The best-rated groups corresponded to group 3 (UI-BL 0–4 mm) with 61.8% of positive evaluations (Good: 42.3%, Excellent

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Table 1
Photographic sample of patients in the different groups presented in the survey.

	Spain	Brazil
Group 1 BL-UI ≤ - 4 mm		
Group 2 BL-UI > -4 - 0 mm		
Group 3 BL-UI > 0 - 4 mm		
Group 4 BL-UI ≥ 4 mm		

Abbreviation: BL-UI = Barcelona line, upper incisor. Published with the patient's consent.

19.5%), followed by group 4 (UI-BL ≥4 mm) with 61.1% (Good: 47.6%, Excellent 13.5%) again with positive evaluations. On the other hand, group 1 (UI-BL ≤−4 mm) received the poorest rating with 71.8% of negative evaluations (Deficient 40.4% and very poor 31.4%), followed by group 2 (UI-BL −4–0 mm) with 59.6% (Deficient 46.1%, good 13.5%), which represent the third rated place.

Considering the results of this dichotomic classification, the inter-rater reliability for all 74 evaluators was moderate (k = 0.49, 95%CI: 0.39 to 0.59). Moderate concordance was observed in all subgroups, though no statistically significant differences were found on establishing comparisons by profession (laypeople: k = 0.54); healthcare professionals: (orthodontists k = 0.58, surgeons k = 0.43), location (Europe k = 0.46; America k = 0.54), age (≤35 years k = 0.56; >35 years k = 0.43) or gender (males k = 0.51; females k = 0.48).

Regarding the association between the mean assessment of the evaluators and UI-BL distance (Table 4), a moderate-strong association was found (r = 0.68, p < 0.001) (Fig. 2). The analysis comparing different rater's demographic data reported the following results: regarding rater age, statistical significances were found (p = 0.014):

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Table 2
Demographic data of the study raters, showing the origin, gender, and age distribution.

Origin and sex	Healthcare professionals (n)	Age (years) Minimum-maximum range	Orthodontist (n)	Age (years) mean (SD)	Maxillofacial surgeon (n)	Age (years) mean (SD)	Laypeople (n)	Age (years) mean (SD)	Total n (%)
Europe	12	40.1 (21–73)	6	43.3 (10.2)	6	36.8 (4.8)	22	39.3 (11.4)	34 (46)
Spain	12	40.1 (8.3)	6	43.3 (10.2)	6	36.8 (4.8)	19	39.5 (11.8)	31 (41.9)
Italy	–	–	–	–	–	–	3	39 (10.5)	3 (4.1)
America	12	33.5 (3.4)	6	34.8 (1.7)	6	32.2 (4.3)	28	42.3 (10.6)	40 (54)
Brazil	12	33.5 (3.4)	6	34.8 (1.7)	6	32.2 (4.3)	–	–	12 (16.2)
USA	–	–	–	–	–	–	15	43.0 (11.4)	15 (20.3)
Venezuela	–	–	–	–	–	–	11	39.5 (7.9)	11 (14.9)
Costa Rica	–	–	–	–	–	–	1	65	1 (1.4)
Colombia	–	–	–	–	–	–	1	65	1 (1.4)
Sex:						–			74 (100)
Males	14		7	37.3 (5.1)	7	34.9 (3.4)	25	40.6 (10.3)	39 (52.7)
Females	10		5	41.6 (11.6)	5	34.0 (7.1)	25	41.4 (11.8)	35 (47.3)
Total	24	36.8 (7.1)	12	39.1 (8.3)	12	34.5 (5.0)	50	41 (11)	74 (100)

Table 3
General rater evaluation of each of the patient groups.

	n	%	Very poor	%	Deficient	%	Acceptable	%	Good	%	Excellent	%	Dic. scale	%
Group 1 ≤ -4 mm	740	100	**232++**	**31.4++**	**299+++**	**40.4+++**	**144+**	**19.5+**	55	7.4	10	1.4	**531***	**71.8***
Group 2> -4-0 mm	740	100	82	11.1	**341+++**	**46.1+++**	**186++**	**25.1+**	**100+**	**13.5+**	31	4.2	**441***	**59.6***
Group 3> 0 – 4 mm	740	100	11	1.5	103	13.9	**169+++**	**22.8+++**	**313+++**	**42.3+++**	**144+**	**19.5+**	**457****	**61.8****
Group 4≥ 4 mm	740	100	14	1.9	98	13.2	**166++**	**22.4++**	**352++**	**47.6+++**	**100+**	**13.5+**	**452****	**61.1****

+++: Highest selected rating.
++: Second selected rating.
+: Third selected rating.
Dic. Scale: Dichotomic scale
*: More negative votes (Result of the sum of more voted categories, excluding acceptable as a neutral rating)
**: More positives votes (Result of the sum of more voted categories, excluding acceptable as a neutral rating)

Table 4
Pearson's coefficient (p-value) and comparison from the GEE linear regression model between mean assessment and Barcelona line-upper incisor distances in the different groups studied.

Variable	r	p value	p value for comparison
All raters	0.68		<0.001***
Profession:			<0.001***
Laypeople	0.74	<0.001***	
Dental raters	0.47	0.002**	
Healthcare specialty:			0.479
Orthodontist	0.43	0.005**	
Surgeon	0.49	0.001**	
Origin:			0.065
Europe	0.43	0.006**	
America	0.48	0.002**	
Age:			0.014*
≤35 years	0.49	0.001**	
>35 years	0.41	0.009**	
Gender:			0.339
Male	0.44	0.005**	
Female	0.48	0.002**	

*p < 0.05; **p < 0.01; ***p < 0.001.

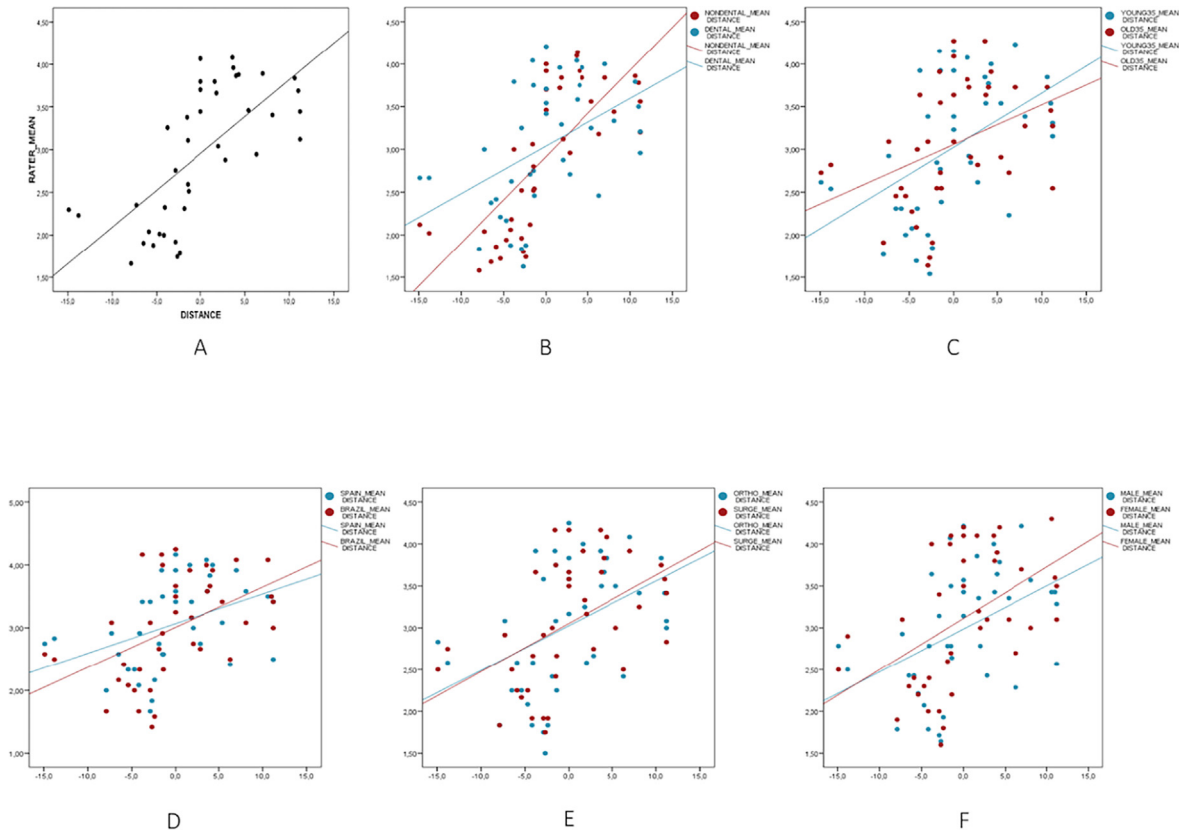

Fig. 2. Pearson's correlation coefficient between the mean assessment of 74 raters (vertical axis) and BL-UI distance in mm (horizontal axis). **A:** general correlation (r = 0.68). **B:** comparing laypeople (r = 0.74, p < 0.001) and professional raters (r = 0.47, p = 0.002). **C:** comparing young raters (r = 0.49, p = 0.001) and raters >35 years of age (r = 0.41, p = 0.009). **D:** comparing Brazilian (r = 0.48, p = 0.002) and Spanish raters (r = 0.43, p = 0.006). **E:** comparing orthodontists (r = 0.43, p = 0.005) and surgeons (r = 0.49, p = 0.001). **F:** comparing males (r = 0.44, p = 0.005) and females (r = 0.48, p = 0.002).

the younger the rater (r = 0.49, p = 0.001), the greater the correlation to positive UI-BL distance, respect old raters (r = 0.41, p = 0.009). Laypeople showed greater association with respect to positive UI-BL distances (r = 0.74, p < 0.001), which is a more protruded profile, compared to healthcare workers (r = 0.47, p = 0.002). Meanwhile, non-significant differences were reached when comparing the country of origin of the healthcare raters, although the asso-

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ciation was stronger for Brazilians (r = 0.48, p = 0.002) than for Spanish raters (r = 0.43, p = 0.006). Non-significant differences were found between orthodontists (r = 0.43, p = 0.005) and surgeons (r = 0.49, p = 0.001), as well as between males (r = 0.44, p = 0.005) and females (r = 0.48, p = 0.002).

Discussion

The multicentre study seems to validate BL as an aesthetic sagittal reference for the diagnosis of DFD and planning of OS, satisfying the opinion of specialists and overall non-healthcare workers, with a strong agreement correlation between mean-rater assessment and the UI-BL distance (r = 0.68; p < 0.001). Although there were no statistical differences between raters, a better inter-rater agreement correlation was found among laypeople than healthcare professionals. On the other hand, the younger the rater, the greater the inter-agreement; rater age was a relevant factor influencing the level of concordance (p = 0.048).

The correlation between the mean rater evaluation and UI-BL distance (study validity) increased significantly among laypeople (r = 0.74) compared to healthcare workers (r = 0.47), while no differences were found between orthodontists and surgeons. Laypeople scored higher on positive UI-BL distances; in negative distance UI-BL the healthcare workers assigned higher scores. Similarly, the younger the rater, the stronger the positive correlation with UI-BL distance (p = 0.014). In the same context, Brazilian professionals showed closer correlations than Spanish professionals, though differences were not significant, this could be explained by slight differences in age (Brazilian professionals younger: 33.5 ± 3.4 than Spanish: 40.1 ± 8.3) (Table 2).

Despite the moderate correlations of the mean score/UI-BL, the inter-rater reliability assessment, and the proportions, a message is pointed out regarding the aesthetic preferences of non-trained and young people, who unconsciously preferred anteriorly projected faces. Otherwise, healthcares could have been influenced by past education based on cephalometries, occlusal correction and retrusive profile preferences, instead of the possible current 'bi-protrusive' demands. Similarly, the Resnick et al study,[19] which used the Andrews analysis, supports the BL firstly because it found that healthcares choose a more posterior male upper incisor - goal anterior limit line (UI-GALL) distance, compared with non-healthcare workers. Secondly, the respondents choose 3.5 times more females with UI-GALL distance of +4 mm; likewise, the 'least aesthetic' was UI-GALL: – 4 mm. In turn, another study[20] found that Andrew´s GALL: 0 mm differs considerably based on an analysis of a sample of orthodontic patients (women: 3.7 ± 5.4 mm/men: 4.5 ± 5.1 mm). Thus, even with the non-statistically significance in the BL study, a better score for 'protrusive' profiles could suggest it as the preferred standard aesthetic profile.

Accordingly, bi-protrusive profiles could be more attractive than retrusive profiles[11,14,15,17,21,22] attributable to a subconscious association with youthful appearances.[23] Conversely, a lack of ST support is associated with ageing secondary to thin lips, downturned oral commissures, and deepened labiomental folds. So, when the skeletal volume is increased as BL suggests, a ST support is obtained due to a reverse face-lifting[24] resulting in skin tension, fuller lips, commissures shifted upwards, shorter, and less deep nasolabial folds,[25] with a better mandible-neckline definition.

Facial beauty is subjective and cephalometries cannot predict attractiveness because; first, the wrong assumption about occlusion correction results in beautiful and functional profiles.[26] Second, analyses based on intracranial horizontal lines such as Sella-Nasion,[8] or Frankfort plane[27–31] add errors due to positional variations and skull base disparities, while extracranial references such as the NHO, can be preferred for surgical planning.[16] On the other hand, Arnett's analysis[13] is concerned with about aesthetics (while previous studies focused on occlusion factors), but the maxilla is guided sagittally by a TVL passing through Sn, which will be altered in hypoplastic maxillaries and modified by surgery; furthermore, the analysis was made from a single rater perspective and involved a single racial sample.

Different authors have suggested the forehead and UI as harmony drivers, to avoid surgically-modifiable references; Andrews[21] defined an empirical goal to achieve ideal outcomes, correlating the UI position according to forehead sagittal inclination, although good intra-rater and inter-rater agreement were demonstrated,[32] the UI position could be miscorrected due to forehead alterations, or misalignment of the UI with respect to the alveolar bone or occlusal plane.[19] Other reports[17] published after our renamed BL protocol (UI- STP, 2010), used the forehead axis and glabella[14] as references for UI-positioning. In short, there is consensus among different analyses, considering attractive faces as reflecting the clinical outcomes more than standard measurements.[19]

Additional considerations should be highlighted when planning OS with BL:

a) Profile pictures in NHO suffices to evaluate BL-UI relation, making diagnosis easier and less invasive. But the NHO transposition to DICOM allows accurate planning.
b) According to BL, most DFD patients present a bi-retrusive skeleton; maxillary advancement therefore may be aesthetically appropriate for both class II and III. Although it seems paradoxical, at our institutions, mandibular advancement has been indicated in 94% of class III DFD, and maxillary advancement in 95% of class II subjects.[33]
c) Skeletal counter clockwise rotation results in aesthetic ST support, eliminating the 'normal occlusion' concept, but the proper UI position with respect to the maxillary plane should be accurately preserved.
d) Bimaxillary advancement and counterclockwise rotation enlarge the airway, and BL showed to be adequate in deciding where to sagittally reposition the maxilla in sleep apnoea patients.[34]
e) The sagittal position of the UI with the BL ('in' or 'anteriorly') depends on UL thickness, sex, fillers, and personal considerations.

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The study limitations are firstly, the applicability of BL as well as the scoring of raters to and by other racial groups, are not known; then a multi-racial study should be performed. Furthermore, attractiveness was rated only on lateral photographs, so dynamic 3D-evaluations could yield different opinions. Finally, BL was not compared with other reference planes, which could be the objective of future studies. The above limitations point to the need for caution in drawing conclusions from the results obtained.

Conclusion

The results suggest that protrusive middle-third facial profiles are preferable. Moreover, BL could be proposed as a reference for sagittal maxillary repositioning, since it is a simple, individualised, and reproducible diagnostic and planning tool, that could be added as part of the academic armamentarium in OS.

Disclosure statement

All the authors have read and approved this manuscript.

Ethics statement/confirmation of patient permission

Study approved by Institutional Review Board of Teknon Medical Center (Ref. 2020/90-MAX-CMT) Parecer Consubstanciado Do CEP¨(Ref. 661.499). Study in accordance with ethical Declaration of Helsinki. Patient written informed consent was obtained for accessing the database.

Conflict of interest

We have no conflicts of interest.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.bjoms.2022.10.002.

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