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ORIGINAL ARTICLE

Morphometric evaluation of cranial base and sella turcica in patients with bilateral agenesis of maxillary lateral incisors

Nehir Canigur Bavbek[1] · **Basak Arslan Avan**[1]

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Abstract

The aim of this paper is to evaluate the dimensions and morphology of cranial base and sella turcica in patients with bilateral agenesis of maxillary lateral incisors (BMLI). This retrospective study was conducted on lateral cephalometric radiographs of 34 female patients with BMLI (17.69 ± 2.96 years) and 34 female patients with complete dentation and skeletal Class 1 relationship serving as a control group (17.22 ± 2.2 years). Basicranial and maxillomandibular variables together with linear dimensions and morphology of sella turcica were evaluated. Differences between groups were analyzed by Student's *t* test for parametric variables and Mann–Whitney *U* test for nonparametric variables. Chi-square test followed by post hoc test with Bonferroni correction was used for categoric variables ($p < 0.05$). When compared to control group, N–S–Se angle was less negative, dimensions between Ba–Se, N–Ba, and N–Ar were larger, and SNA angle was smaller in BMLI group. There were no significant differences between groups regarding the linear dimensions of sella turcica. However, variations in sella turcica morphology were more frequent in BMLI group ($n = 17$; 50%) when compared to control group ($n = 2$; 5.8%). The most common morphologic variations in BMLI group were oblique anterior wall (20.6%) and irregularity (notching) in the posterior part of sella turcica (14.7%). The present study showed a statistically significant relationship between the presence of BMLI with some craniofacial parameters and morphological variations of sella turcica. This information may be useful as an additional and early diagnostic tool for BMLI and to highlight the possible links to its development.

Keywords Sella turcica · Cranial base · Absence of lateral incisors · Agenesis · Cephalometry

Introduction

Congenital absence of teeth is one of the frequent dental anomalies in orthodontics. After the third molars, the most commonly affected permanent teeth are maxillary lateral incisors and mandibular second premolars [1–3]. Unilateral or bilateral agenesis of maxillary lateral incisors can be seen with a varying prevalence in different populations, and factors such as ethnic background, race, and gender have been found to be responsible for this [4]. Treatment of bilateral agenesis of maxillary lateral incisors (BMLI) requires a complex orthodontic treatment and a multidisciplinary approach, since BMLI can be associated with palatally displaced canines, absence of some other teeth, distal angulation of mandibular second premolars, tooth size discrepancy, and some craniofacial syndromes such as cleft lip and palate [5, 6].

Teeth originate from neural crest cells which also contribute to the formation of cranial base [7]. Based on this idea, it is thought that there might be a relationship between tooth agenesis and development of craniofacial structures [8–12]. Considering that different regions of maxilla and mandible are in a developmental relationship with different regions of cranium, a more specific examination of the region of agenesis is important for the reliability of the results [7]. In addition, the examination of sella turcica region may also help to explain this relationship.

Sella turcica houses the pituitary gland and is an important structure for orthodontics due to its appearance in lateral cephalometric radiographs and the determination of the sella point. Various methods have been determined to evaluate the dimensions of sella turcica [13, 14]. However, it is important to detect the normal appearance of the region in terms of morphology and to distinguish it from its healthy state

✉ Nehir Canigur Bavbek
ncanigur@yahoo.com; nehir.canigurbavbek@gazi.edu.tr

[1] Department of Orthodontics, Faculty of Dentistry, Gazi University, 82nd Road No: 2 06510 Emek, Cankaya, Ankara, Turkey

in case of pathology [13, 14]. There are also studies in the literature showing a relationship between changes in sella turcica morphology and dental anomalies such as impaction, agenesis, and transposition [15–18].

The majority of the studies that put forward the relationship between tooth agenesis and craniofacial development have evaluated a variety of tooth agenesis patterns together with the aid of different classification systems [2, 8–10, 17, 19]. Although different agenesis patterns can be observed, most of them have been detected only once and agenesis patterns that show high probability of repeatability is very limited [3, 20]. Therefore, rather than evaluating cranial base and sella turcica morphology in a heterogeneous agenesis group with different and possibly nonrepeatable patterns, selecting a specific group of patients would provide more accurate and valuable clinical results. With these in mind, the association between BMLI and craniofacial morphology have been studied, since BMLI may negatively affect the quality of life of patients due to esthetic concerns and this patient group deserves a special attention for a better understanding of their craniofacial characteristics [5, 12, 19, 21–24]. However, most of these studies have concentrated on dental and maxillomandibular relationship rather than cranial base and sella turcica [5, 21, 22], and therefore, the information related to this area is still very limited [12, 23]. Yet, these aforementioned studies have focused on sella turcica bridging in particular, which is just one of the morphological variations of sella [12, 19, 23]. Based on these reasons, the aim of this study is to analyze the dimensions and morphology of cranial base and sella turcica in patients with BMLI and to compare it with a control group.

The null hypothesis of this study is that there are no differences between patients with BMLI and control group regarding the cranial base and sella turcica morphology.

Materials and methods

Ethical approval for this retrospective study was obtained from the Ethical Committee of Gazi University (604.01.02-2020-238). A statistical power analysis was performed for sample size estimation with G*Power Software (v3.1.3; Franz Faul, Universität Kiel, Germany). Based on the data from a previous study [18], to test the difference between groups with an alpha level of 0.05 and 90% power, the projected sample size was determined to be at least 29 subjects in each group.

The lateral cephalometric radiographs of patients with BMLI were intended to form the study material of this study. To detect these patients' records, a computer-based search was performed with the keywords 'missing teeth' by the aid of a digital archive program (FileMaker Pro 11.0v1; FileMaker, Santa Clara, California, USA) in Department of Orthodontics, Faculty of Dentistry, Gazi University. Among 7219 currently available patient records, 647 patients with missing teeth were then selected for a more detailed evaluation. The main inclusion criteria for the study group were as follows:

1. 14 years or older.
2. No other dental anomalies (supernumerary teeth, other congenitally or otherwise missing teeth, impacted teeth except third molars, size and shape anomalies, etc.) except BMLI.
3. Complete eruption of all permanent teeth except third molars.
4. Completion of skeletal maturation according to hand–wrist radiographs [25].
5. No history of craniofacial syndromes and/or orthodontic treatment that would affect the growth and development of craniofacial structures.

As a result, the records of 48 (34 females, 14 males) patients with BMLI that followed the inclusion criteria were obtained. However, due to the unbalanced number of patients between males and females, the records of male patients were excluded in this step to eliminate the possible effect of gender difference [8, 23]. In the final stage, the lateral cephalometric radiographs of 34 female patients (17.69 ± 2.96 years) with BMLI were evaluated in the study for further analyses.

A control group was constituted from the patients in the archives of the same department, whose radiographs were taken prior to the initiation of their orthodontic treatment. Control group was matched with the study group according to age and gender to eliminate their possible effects. Inclusion criteria for control group were:

1. No tooth anomaly including agenesis, impaction, transposition, size and shape anomalies, etc.
2. Complete eruption of all permanent teeth except third molars.
3. Skeletal Class 1 (ANB: 0–4°) with optimal vertical growth pattern (SN/GoGn: $32° \pm 6°$).
4. Completion of skeletal maturation according to hand–wrist radiographs [25].
5. No history of craniofacial syndromes and/or orthodontic treatment that would affect the growth and development of craniofacial structures.

The inclusion criteria were entered to the digital archive program, and the results were sorted according to the age of patients at the time of their initial records, beginning from the latest record added to the archive. The patients in the final BMLI group were sorted according to their chronological age expressed in years, as well, and each record was

matched with the record of a female subject at the same age consecutively beginning from the top record of that age on the list. With these guiding principles to overcome a possible selection bias, the final control group material was composed of lateral cephalometric radiographs of 34 females with a mean chronological age of 17.22 ± 2.2 years.

Lateral cephalometric radiographs were traced manually by one examiner (BAA). The other author (NCB) covered the names of the patients and their groups with a sticker and filed the radiographs miscellaneously to prevent any bias before the main observer started tracing. Cephalometric landmarks used in the study are given in Table 1. Eight linear and nine angular measurements were made to evaluate the morphology of cranial base and maxillomandibular relationship (Fig. 1) [26]. The linear dimensions of sella turcica were measured according to the definitions of Silverman [27]. Length is the maximum anteroposterior distance between the crest of tuberculum sella and dorsum sella, diameter is the distance from the crest of tuberculum sella to the deepest point in the inner curvature of posterior wall of sella, and depth is the perpendicular distance from the length of sella to the deepest part of the floor of the sella (Fig. 2). Sella turcica morphology was determined according to the morphological classification of Axelsson et al. [13]: normal, oblique anterior wall, double contour of the floor, bridging, irregularity or notching in the posterior part of dorsum sellae, and pyramidal shape of dorsum sella (Fig. 3). To detect the intraexaminer reliability, randomly selected radiographs from each group ($n = 14$/each) were retraced 1 month after the first tracings by the same examiner. Prior to statistical analysis, the magnification factor value was adjusted to 1:1 for all linear measurements to eliminate the magnification differences.

Statistical analysis

Statistical analyses were performed with JASP statistical software (Version 0.11.1; JASP Team, 2019). Intraclass correlation coefficient (ICC) was used for the repeatability analysis of linear and angular measurements of cranial base and sella turcica, while Fleiss' Kappa was used to assess the repeatability of morphological categorization of sella turcica. Data were given as mean, standard deviation, minimum and maximum values for continuous variables, and frequencies for the categorical variables. Normality of the data was assessed by Shapiro–Wilk test. Differences between groups were tested using Student's *t* test for parametric variables, while Mann–Whitney *U* test was used for nonparametric variables. Chi-square test followed by post hoc test with Bonferroni correction was used for categoric variables. $P < 0.05$ was accepted to be statistically significant.

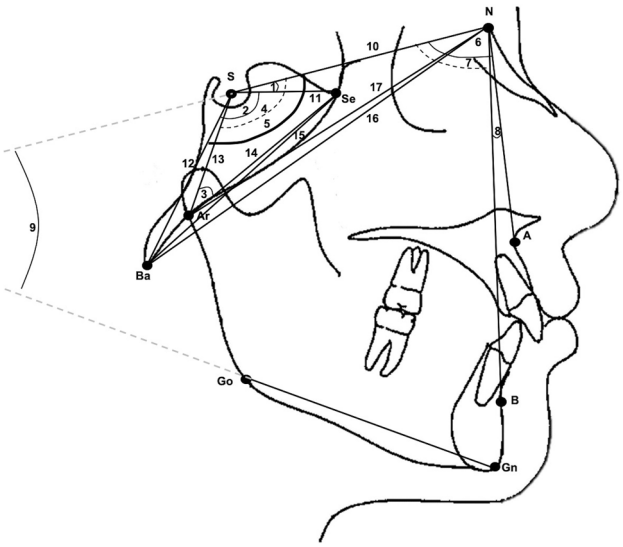


Fig. 1 Linear and angular measurements related to cranial base and maxillomandibular relationship: angular; 1: N–S–Se; 2: Se–S–Ba; 3: S–Ar–Se; 4: N–S–Ar; 5: N–S–Ba; 6: SNA; 7: SNB; 8: ANB; 9: SN/GoGn; linear; 10: S–N; 11: S–Se; 12: S–Ba; 13: S–Ar; 14: Ar–Se; 15: Ba–Se; 16: N–Ba; 17: N–Ar

Table 1 Cephalometric landmarks used in the study

A point	Deepest point of the anterior outline of the upper alveolar process
B point	Deepest point of the anterior outline of the mandibular alveolar process
Sella (S)	Geometrical center of sella turcica
Sphenoidale (Se)	Intersection of the ala major ossis sphenoidalis and the anterior cranial fossa, corresponding to the intersection of the anterior outline of the medial cranial fossa and the inferior contour of the anterior cranial fossa
Nasion (N)	Most anterior point of the frontonasal suture in the midsagittal plane
Basion (Ba)	Most posteroinferior point of the clivus in the midsagittal plane, corresponding to the midpoint on the anterior margin of the foramen magnum
Articulare (Ar)	Constructed intersection of lower rim of the cranial base and the posterior outline of the mandibular corpus
Gonion (Go)	A point at the intersection of lines tangent to the posterior and lower border of the mandible
Gnathion (Gn)	The most anterior inferior point of the mandibular symphysis

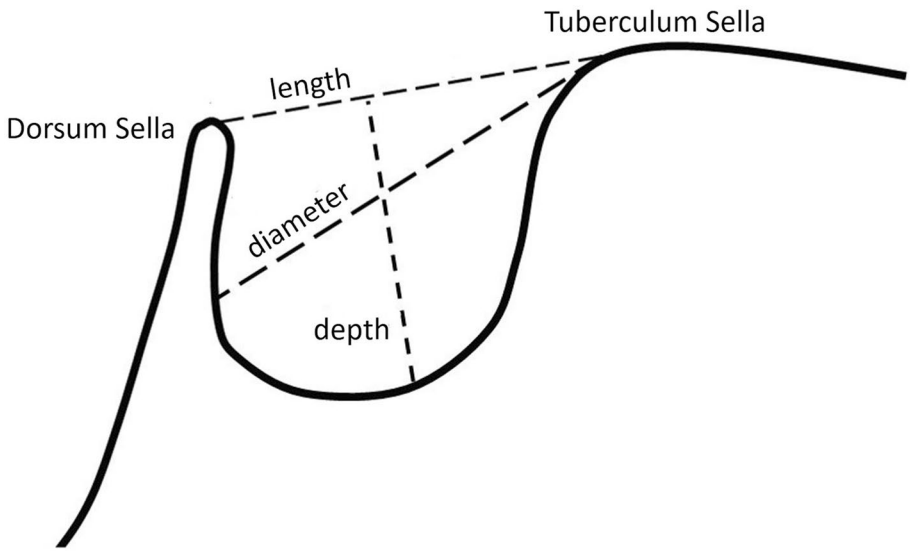


Fig. 2 Linear dimensions of sella turcica

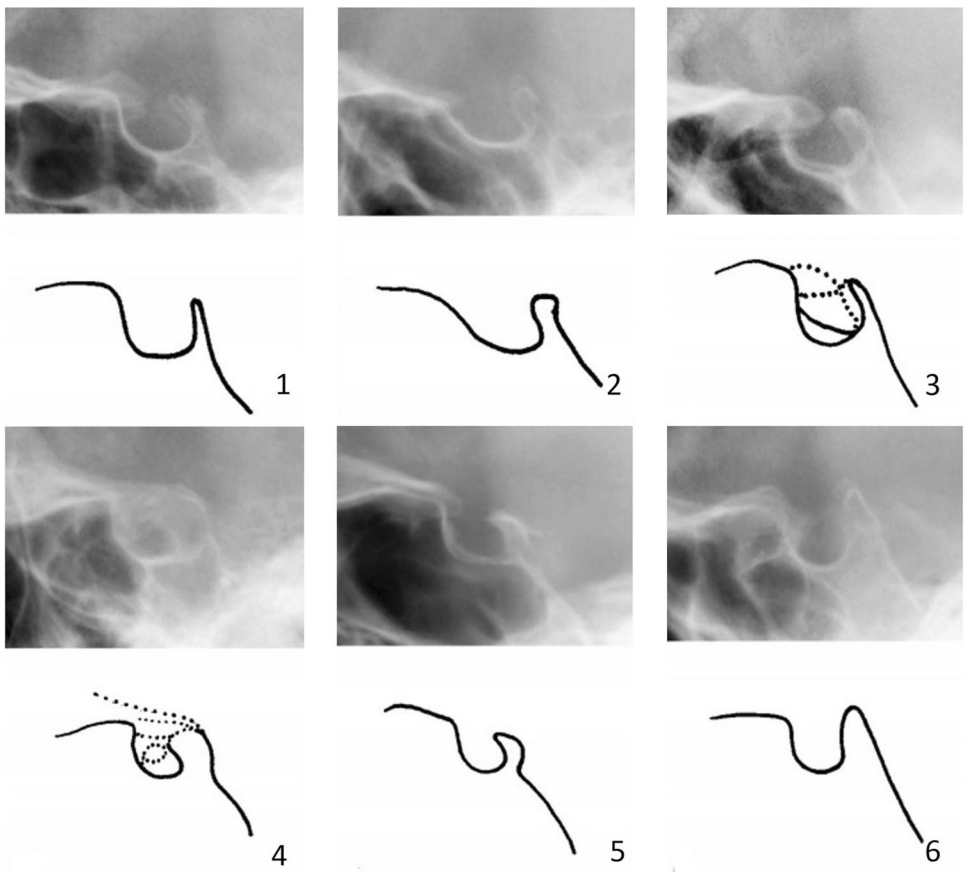


Fig. 3 Evaluation of morphologic variations of sella turcica according to the definitions of Axelsson et al. [13]: 1: normal sella turcica; 2: oblique anterior wall; 3: double contour of the floor; 4: bridging; 5: irregularity or notching in the posterior part of dorsum sellae; 6: pyramidal shape of dorsum sella

Results

ICC was found to be between 0.931 and 1.000 for continuous variables, while Fleiss' Kappa value of 0.879 was found for classification of sella turcica morphology, which all indicated a high intra-observer consistency. The age distribution of the groups was found to be similar ($p = 0.585$).

Table 2 gives the descriptive statistics of the groups and the results of inter-group comparisons. There were no significant differences between the groups regarding the linear dimensions of sella turcica. When compared to control group, N–S–Se angle was less negative, Ba–Se, N–Ba, and

Table 2 Descriptive and comparative analysis of sella turcica, cranial base, and maxillomandibular measurements between study groups (SD: Standard deviation)

/(mm) ∠ (°)	BMLI		Control		*p*
	Mean ± SD	Min–Max	Mean ± SD	Min–Max	
Sella turcica					
/ Length	10.96 ± 4.41	1–27	10.59 ± 1.65	7–13	0.574[a]
/ Diameter	14.76 ± 3.59	7.7–29	13.77 ± 1.46	11–17	0.158[a]
/ Depth	9.45 ± 1.82	2.9–12	9.63 ± 1.14	7–13	0.941[a]
Anterior cranial base					
/ S–N	71.29 ± 3.48	65–79.2	69.85 ± 3.81	61.5–82	0.108[b]
/ S–Se	25.78 ± 3.23	20.1–36.5	25.19 ± 2.76	20–32.5	0.519[a]
∠ N–S–Se	− 0.82 ± 4.66	− 12–10	− 3.60 ± 4.66	− 15–8	0.030*[b]
Posterior cranial base					
/ S–Ba	47.0 ± 4.46	41.1–57	44.87 ± 4.46	33–54.5	0.101[a]
/ S–Ar	36.05 ± 3.55	26.8–44	34.81 ± 3.90	27–45	0.174[b]
/ Ar–Se	55.98 ± 4.65	44–66	54.72 ± 4.0	48–64.5	0.236[b]
/ Ba–Se	67.83 ± 4.68	60–78.5	64.92 ± 3.75	57–73	0.006**[b]
∠ Se–S–Ba	135.02 ± 7.28	111–149	134.40 ± 5.54	121.5–146	0.454[a]
∠ S–Ar–Se	21.04 ± 4.30	15.5–32	20.74 ± 2.55	16.5–25	0.662[a]
Total cranial base					
/ N–Ba	108.46 ± 5.65	99–118.8	104.69 ± 5.41	93–114	0.007**[b]
/ N–Ar	97.28 ± 5.68	84.2–109.45	94.46 ± 5.46	85.5–107	0.041*[b]
∠ N–S–Ar	126.25 ± 5.72	113–137	125.46 ± 4.89	114.5–137	0.540[b]
∠ N–S–Ba	132.03 ± 4.99	118.5–140.5	130.52 ± 5.21	120–142	0.225[b]
Maxillomandibular relationship					
∠ SNA	79.29 ± 3.37	74–86	81.09 ± 2.89	76–87	0.022*[b]
∠ SNB	77.90 ± 3.72	71–86.5	78.68 ± 2.79	73.5–85	0.332[b]
∠ ANB	1.40 ± 2.23	− 4–5	2.41 ± 1.16	0–4	0.050[a]
∠ SN/GoGn	30.78 ± 3.37	21–42	31.47 ± 3.17	23–35.5	0.504[a]

[a]Mann–Whitney *U* test

[b]Student's *t* test

*$P < 0.05$

**$P < 0.01$

N–Ar dimensions were larger, and SNA angle was smaller in BMLI group with statistical significances.

Table 3 gives the distribution of sella turcica morphology in the groups. It can be seen that normal sella turcica morphology was more frequently observed in control group ($n = 32$; 94.2%) when compared to BMLI group ($n = 17$; 50%), and this difference was statistically significant. The most common morphologic variation in BMLI was oblique anterior wall (20.6%), followed by irregularity (notching) in the posterior part of the sella turcica (14.7%). More frequent occurrence of oblique anterior wall in BMLI group showed a statistical significance when compared to control group.

Table 3 Distribution of morphologic variations of sella turcica in the study groups

	Normal sella turcica	Oblique anterior wall	Double contour of the floor	Sella turcica bridge	Irregularity (notching) in the posterior part of the sella turcica	Pyramidal shape of the dorsum sella	*p*
BMLI ($n = 34$) 17 (50%)[a]	7 (20.6%)[b]	1 (2.9%)	2 (5.9%)	5 (14.7%)	2 (5.9%)	0.003**
Control ($n = 34$) 32 (94.2%)[a]	1 (2.9%)[b]	1 (2.9%)	0	0	0	

Same letters in a column show statistical significance

**$P < 0.01$

Discussion

The interplay between common developmental genetic backgrounds of craniofacial region and teeth have led researchers to explore a possible link between agenesis and variations in craniofacial region [17, 19, 23]. With that respect, the cranial base and sella turcica are commonly analyzed components of craniofacial region as they are assumed to play important roles on the development of adjacent anatomical structures [8, 17, 24, 26]. Since the non-syndromic background and significant contributions of genetic factors have been mentioned for the occurrence of BMLI [20], this study aimed to assess the relationship between BMLI and morphologic variations in the cranial base and sella turcica. According to the results of our study, the null hypothesis was partially rejected, since prevalence of morphologic variations in sella turcica was significantly increased in patients with BMLI, linear total cranial base length was greater and SNA angle was smaller when compared to a healthy, fully dentate skeletally Class 1 control group.

Various studies have been conducted to understand some craniofacial parameters related to BMLI [11, 12, 21, 22, 24]. However, evaluation of cranial base and sella turcica region is still very limited [12, 23]. In fact, sella turcica, anterior cranial base, maxilla, and the maxillary incisors are located in the frontonasal developmental field, which means they all develop from the same group of neural crest cells [28]. Although the exact cause of BMLI is still unclear, the possibility that non-syndromic BMLI may be related to developmental disturbances has yet to be approved. Therefore, evaluation of cranial base and sella turcica in a single study focusing on patients with BMLI was thought to be beneficial to add on to our knowledge in this field.

The influence of age and gender on dimensions and morphology of sella turcica and cranial base in healthy subjects has been investigated. It is indicated that the dimensions of sella turcica increase with age to adapt the increase in the volume of pituitary gland with development [13]. After 10–12 years of age, sella turcica almost reaches its adult size and its linear dimensions become relatively stable [29]. On the other hand, the cranial base provides adaptation between neurocranium and viscerocranium during growth and reaches 90% of its adult size approximately at the age of 13 [30]. However, chronological age may not always be a true estimate for the evaluation of skeletal maturity due to the personal differences on the pubertal growth rate, and bone age assessment from hand and wrist radiographs may be more concise in that respect [31]. To compensate the possible effects of normal growth and development on the data, records of patients of 14 years or older during postpubertal growth period according to their hand and wrist radiographs were included in this study. Apart from age, variations due to gender in different areas of craniofacial region have also been reported [8, 32]. As a consequence of the retrospective nature of this study, the number of available records of male patients was very limited after applying the inclusion criteria when compared to females, which was consistent with the previous literature that report higher BMLI prevalence in females [1, 3, 4, 11]. Therefore, males were not included to eliminate the risk of skewing cephalometric measurements with sexual differences in craniofacial morphology [8]. Owing to these facts, the final study sample consisted of only the records of female patients who were 14 years or older.

Oeschger et al. [32] showed that patients with hypodontia have significantly smaller craniofacial configurations when compared to age- and sex-matched control groups. However, they further stated that the main governing force of cranial base development is the enlargement of the brain, and therefore, these effects are very limited and modular. Supporting this phenomenon, despite some studies reporting deviations in the craniofacial morphology with the presence of permanent tooth agenesis [33], Bondarets et al. [34] concluded that the typical dentofacial pattern in persons with severe hypodontia is mostly because of dental and/or functional compensations rather than an altered pattern of growth or development. On the other hand, some studies found no difference in the craniofacial morphology of hypodontia patients when they were grouped according to the location of missing teeth (anterior vs posterior) [8, 10], while others reported that anterior tooth agenesis affect craniofacial morphology more than posterior agenesis [35]. Similarly, Tavajohi-Kermani et al. [2] found significant correlations between cranial base measurements and maxillary tooth agenesis group. These contradictory conclusions may be a result of evaluating different types of agenesis patterns together as a single group. In this study, we found significantly greater posterior and total cranial base lengths in patients with BMLI when compared to control subjects, but anterior cranial base was not affected. In addition, the angle between anterior and middle cranial base was less negative in patients with BMLI. Our results are contradictory to the results of previous literature showing significantly shorter anterior cranial base length in patients with both BMLI and other types of agenesis [9, 18, 24, 35], and studies reported either no significant differences or shorter posterior and total cranial base dimensions in hypodontia patients [9, 24, 36]. The role of genetic background on the length of cranial base and possible differences in anterior or posterior inclination of cranial base in our study population may be the reason for these controversies [37]. Continuing with cranial base angle, larger cranial base angle was reported in patients with maxillary hypodontia [2], agenesis of maxillary canines [38],

and presence of solitary median maxillary central incisor [18]. On the other hand, there are also studies that found no links between these two parameters [8, 9, 24]. Although we were unable to detect a significant difference between groups regarding cranial base angle (N–S–Ba or N–S–Ar), the angular bending between anterior and mid-cranial base (N–S–Se) showed significantly more posterior inclination in patients with BMLI. These differences between studies may be explained with low and inconsistent correlations between cranial base flexure depending on sella, large interindividual variations in the cranial base angle, different study samples and different reference points [26, 36].

Sella turcica is an important region for orthodontics as it is traced to detect its geometric center, sella point, during the evaluation of some skeletal parameters in lateral cephalometric radiographs. However, its morphologic variations also give important information to the clinicians and to be able to differentiate normal and pathological conditions, it is essential to use an objective classification system. Although there are different classifications of image of sella turcica in lateral cephalometric radiographs, not all of them evaluate all anatomic components of sella turcica in detail. With that aim, Axelsson et al. [13] have introduced a thorough classification system, which analyzes the morphologic changes of tuberculum, dorsum, and floor of sella turcica together with the image of interclinoid ligaments. Anatomic variations of sella turcica can also be detected in healthy individuals and this may not always be counted as a symptom of a pathological condition [13]. However, it should also be noted that for patients with non-syndromic tooth agenesis, the morphologic variations of sella turcica are reported to be more common [17, 18]. From a genetic point of view, tooth agenesis may well be related to morphologic variations in sella turcica, since neural crest cells are involved in the development and formation of both anterior and intermediate lobes of the pituitary fossa and the teeth [28, 39]. Recently, Ozturk et al. [12] reported higher prevalence of complete sella turcica bridging in patients with BMLI than in the control group. Similarly, Alqahtani [23] found that probability of detecting sella turcica bridging was 2.5 times greater in patients with maxillary lateral incisor agenesis. On contrary, Scribante et al. [19] found no significant increase in the prevalence of complete sella turcica bridge in patients with maxillary lateral incisor agenesis when compared with the controls. In our study, the total percentage of morphological variations was found to be significantly higher in BMLI patients (50% in BMLI versus 5.8% in control) and the most commonly detected variations were oblique anterior wall (20.6%) followed by irregularity or notching in the posterior part of sella turcica (14.7%), sella turcica bridge (5.9%), and pyramidal shape of dorsum sella (5.9%) (Table 3). Although sella turcica bridging was not the most common variation, this may be a result of different classification systems used in our study and in previous studies. However, our results are in accordance with the previous literature which indicated an association between sella turcica morphology and tooth agenesis. In that aspect, morphologic variations in sella turcica may complement to the diagnostic criteria when clinicians suspect the possibility of BMLI.

Regarding the dimensions of sella turcica, no differences were found between BMLI and control groups. This result was in accordance with the results of Scribante et al. [19]. On contrary, Alqahtani [23] reported significantly shorter sella length in patients with missing maxillary lateral incisors, but they had a very wide age range (12–43 years), included both genders, and evaluated a group with both unilateral and bilateral agenesis. The data are very limited in this area and not much work was found for comparative evaluations. However, together with the morphologic variations, these results confirm the importance of a careful analysis of sella turcica region during diagnosis and treatment planning in patients with BMLI.

In this study, the sagittal position of maxilla with respect to anterior cranial base was affected negatively from the presence of BMLI, which was observed as a statistically significant decrease in SNA angle in these subjects when compared to controls, which is in accordance with the results of Woodworth et al. [24] This finding is also similar to the results of previous studies focusing on patients with different types of agenesis patterns [2, 10, 11, 18, 33]. This result can be attributed to the dentoalveolar collapse due to the missing teeth in the anterior maxillary region, which may also change the position of A point or the tongue–lip pressure balance [9, 24]. Moreover, we were unable to detect any difference in sagittal position of the mandible (SNB angle) as well as sagittal (ANB angle) or vertical (SN/GoGn angle) skeletal relationship of BMLI group when compared to the skeletally Class 1 and normodivergent control group, which was similar to the findings of previous researchers [9, 22]. Contrary to our findings, Woodworth et al. [24] found a skeletal Class 3 tendency in patients with BMLI with shorter facial height and anterior rotation of the mandible. The wide age range in that study may be held responsible for this conflict. The development of maxilla occurs earlier than mandible and shares a more common developmental timing with the teeth, while mandibular development continues until late adolescence. This may also explain why regardless of the number or location of missing teeth, the maxilla is affected negatively from agenesis [32]. In addition, Chung et al. [40] found that as the number of congenitally missing teeth increases, the differences with the control group become more remarkable, and when the teeth in the posterior region is still in place, they protect the vertical relationship and the rotation of the mandible. This fact may also give an explanation why the presence of BMLI has minor effects on maxilla–mandibular relationship.

This study has some strong sides and limitations. First, a very specific agenesis type is chosen for evaluation, and it is one of the few studies focusing on the association of cranial base and sella turcica with development of BMLI. Despite this fact, this is a retrospective study conducted from the lateral cephalograms of female patients only, which is the main limitation of our data. However, to overcome this limitation, detailed inclusion criteria based on previous literature findings are set during patient selection. Still, it would be valuable to confirm our results with a larger sample size in future studies.

Conclusion

- The present study showed a statistically significant relationship between BMLI with some craniofacial parameters and morphological variations of sella turcica when compared to a skeletally Class 1 fully dentate control group.
- Total cranial base length was increased, and the angulation between anterior and middle cranial base was more posteriorly oriented in patients with BMLI.
- Maxilla had a more retruded sagittal position, but this did not change the sagittal skeletal relationship of patients with BMLI.
- Significantly increased prevalence of morphological variations of sella turcica was detected in patients with BMLI, but the linear dimensions of sella turcica were not affected.
- The relationship between sella turcica and cranial base with BMLI may be beneficial for early diagnosis of BMLI as well as explaining the possible links about its development.

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Compliance with ethical Standards

Conflict of interest The authors declare that they have no conflict of interest.

References

1. Rakhshan V, Rakhshan A. Systematic review and meta-analysis of congenitally missing permanent dentition: sex dimorphism, occurrence patterns, associated factors and biasing factors. Int Orthod. 2016;14:273–94.
2. Tavajohi-Kermani H, Kapur R, Sciote JJ. Tooth agenesis and craniofacial morphology in an orthodontic population. Am J Orthod Dentofacial Orthop. 2002;122:39–47.
3. Souza-Silva BN, Vieira WA, Bernardino IM, Batista MJ, Bittencourt MAV, Paranhos LR. Non-syndromic tooth agenesis patterns and their association with other dental anomalies: a retrospective study. Arch Oral Biol. 2018;96:26–32.
4. Khalaf K, Miskelly J, Voge E, Macfarlane TV. Prevalence of hypodontia and associated factors: a systematic review and meta-analysis. J Orthod. 2014;41:299–316.
5. Garib DG, Alencar BM, Lauris JR, Baccetti T. Agenesis of maxillary lateral incisors and associated dental anomalies. Am J Orthod Dentofacial Orthop. 2010;137(732):e1-6.
6. Lai LH, Hui BK, Nguyen PD, Yee KS, Martz MG, Bradley JP, et al. Lateral incisor agenesis predicts maxillary hypoplasia and Le Fort I advancement surgery in cleft patients. Plast Reconstr Surg. 2015;135:142e-e148.
7. Kjaer I. Mechanism of human tooth eruption: review article including a new theory for future studies on the eruption process. Scientifica (Cairo). 2014;2014:341905.
8. Endo T, Ozoe R, Yoshino S, Shimooka S. Hypodontia patterns and variations in craniofacial morphology in Japanese orthodontic patients. Angle Orthod. 2006;76:996–1003.
9. Endo T, Yoshino S, Ozoe R, Kojima K, Shimooka S. Association of advanced hypodontia and craniofacial morphology in Japanese orthodontic patients. Odontology. 2004;92:48–53.
10. Yuksel S, Ucem T. The effect of tooth agenesis on dentofacial structures. Eur J Orthod. 1997;19:71–8.
11. Bassiouny DS, Afify AR, Baeshen HA, Birkhed D, Zawawi KH. Prevalence of maxillary lateral incisor agenesis and associated skeletal characteristics in an orthodontic patient population. Acta Odontol Scand. 2016;74:456–9.
12. Ozturk T, Atilla AO, Yagci A. Cervicovertebral anomalies and/or normal variants in patients with congenitally bilateral absent maxillary lateral incisors: a comparative lateral cephalometric study. Angle Orthod. 2020. https://doi.org/10.2319/061919-418.1.
13. Axelsson S, Storhaug K, Kjaer I. Post-natal size and morphology of the sella turcica. Longitudinal cephalometric standards for Norwegians between 6 and 21 years of age. Eur J Orthod. 2004;26:597–604.
14. Andredaki M, Koumantanou A, Dorotheou D, Halazonetis DJ. A cephalometric morphometric study of the sella turcica. Eur J Orthod. 2007;29(5):449–56.
15. Leonardi R, Barbato E, Vichi M, Caltabiano M. A sella turcica bridge in subjects with dental anomalies. Eur J Orthod. 2006;28:580–5.
16. Leonardi R, Farella M, Cobourne MT. An association between sella turcica bridging and dental transposition. Eur J Orthod. 2011;33:461–5.
17. Sato D, Endo T. Size and bridging of the sella turcica in Japanese orthodontic patients with tooth agenesis. Odontology. 2020;108:730–7.
18. Kjaer I, Becktor KB, Lisson J, Gormsen C, Russell BG. Face, palate, and craniofacial morphology in patients with a solitary median maxillary central incisor. Eur J Orthod. 2001;23:63–73.
19. Scribante A, Sfondrini MF, Cassani M, Fraticelli D, Beccari S, Gandini P. Sella turcica bridging and dental anomalies: is there an association? Int J Paediatr Dent. 2017;27:568–73.
20. Gkantidis N, Katib H, Oeschger E, Karamolegkou M, Topouzelis N, Kanavakis G. Patterns of non-syndromic permanent tooth agenesis in a large orthodontic population. Arch Oral Biol. 2017;79:42–7.
21. Buyuk SK, Ozkan S, Benkli YA, Arslan A, Celik E. Evaluation of the skeletal and dental effects in orthodontic patients with maxillary lateral incisor agenesis. J Esthet Restor Dent. 2017;29:284–90.
22. Pinho T, Pollmann C, Calheiros-Lobo MJ, Sousa A, Lemos C. Craniofacial repercussions in maxillary lateral incisors agenesis. Int Orthod. 2011;9:274–85.

23. Alqahtani H. Association between sella turcica bridging and congenitally missing maxillary lateral incisors. J Dent Sci. 2020;15:59–64.
24. Woodworth DA, Sinclair PM, Alexander RG. Bilateral congenital absence of maxillary lateral incisors: a craniofacial and dental cast analysis. Am J Orthod. 1985;87:280–93.
25. Greulich WW, Pyle SP. Radiographic atlas of skeletal development of the hand and wrist. 2nd ed. Stanford: Stanford University Press; 1966.
26. Proff P, Will F, Bokan I, Fanghanel J, Gedrange T. Cranial base features in skeletal Class III patients. Angle Orthod. 2008;78:433–9.
27. Silverman FN. Roentgen standards fo-size of the pituitary fossa from infancy through adolescence. Am J Roentgenol Radium Ther Nucl Med. 1957;78:451–60.
28. Arntsen T, Kjaer I, Sonnesen L. Lengths of the maxillary central incisor, the nasal bone, and the anterior cranial base in different skeletal malocclusions. Acta Odontol Scand. 2009;67:265–70.
29. Melsen B. The cranial base: The postnatal development of the cranial base studied histologically on human autopsy material. Acta Odont Scand. 1974;32(Suppl. 62):9–126.
30. Polat OO, Kaya B. Changes in cranial base morphology in different malocclusions. Orthod Craniofac Res. 2007;10:216–21.
31. Flores-Mir C, Nebbe B, Major PW. Use of skeletal maturation based on hand-wrist radiographic analysis as a predictor of facial growth: a systematic review. Angle Orthod. 2004;74:118–24.
32. Oeschger ES, Kanavakis G, Halazonetis DJ, Gkantidis N. Number of teeth is associated with facial size in humans. Sci Rep. 2020;10:1820.
33. Nodal M, Kjaer I, Solow B. Craniofacial morphology in patients with multiple congenitally missing permanent teeth. Eur J Orthod. 1994;16:104–9.
34. Bondarets N, Jones RM, McDonald F. Analysis of facial growth in subjects with syndromic ectodermal dysplasia: a longitudinal analysis. Orthod Craniofac Res. 2002;5:71–84.
35. Ben-Bassat Y, Brin I. Skeletodental patterns in patients with multiple congenitally missing teeth. Am J Orthod Dentofacial Orthop. 2003;124:521–5.
36. Kumar S, Mahabob N. Hypodontia and hypoplasia of mandible: a rare defect caused by combination therapy. J Pharm Bioallied Sci. 2013;5:S182–4.
37. Tiro A, Dzemidzic V, Salaga-Nefic S, Redzic I, Nakas E. Heritability of craniofacial characteristics in twins—cephalometric study. Med Arch. 2019;73:205–8.
38. Arvedsen KP, Kjaer I. Dental and craniofacial findings in 91 individuals with agenesis of permanent maxillary canines. Eur Arch Paediatr Dent. 2017;18:243–50.
39. Sharpe PT. Neural crest and tooth morphogenesis. Adv Dent Res. 2001;15:4–7.
40. Chung LK, Hobson RS, Nunn JH, Gordon PH, Carter NE. An analysis of the skeletal relationships in a group of young people with hypodontia. J Orthod. 2000;27:315–8.

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