Three-Dimensional Morphology of the Palate in Patients With Bilateral Complete Cleft Lip and Palate at the Stage of Permanent Dentition

Zbyněk Šmahel, R.N.Dr., C.Sc., Jana Velemínská, R.N.Dr., Ph.D., Pavel Trefný, M.U.Dr., Ph.D., Živa Müllerová, M.U.Dr., C.Sc.

Objective: **Three-dimensional analysis of palate size and shape in 30 patients with complete bilateral cleft lip and palate (BCLPc) at the stage of permanent dentition.**

Design: **Cross-sectional study based on laser scanning.**

Subjects: **Thirty dental casts of boys approximately 15 years old with BCLPc and 28 dental casts of healthy boys of the same age.**

Interventions: **Arched-lip suture with periosteoplasty and push-back of the palate with pharyngeal-flap surgery.**

Main Outcome Measures: **Data on palate height in the 210 defined locations and on palate widths and profile area in 10 transverse sections.**

Results: **The palate in patients with BCLPc was conical and narrower than in control study subjects, much more anteriorly than posteriorly. From the canines posteriorly, the palate was of almost constant height of 10 mm in the midline, being higher than in control study subjects at this location and lower more posteriorly (by 24% to 29% between molars). The area of transverse sections was reduced as compared with control study subjects from the first premolars posteriorly and reached more than 40% between molars. The length of the palate up to the first molars was not changed.**

Conclusion: **BCLPc subjects exhibited narrow, low, and flat palate. Palate size and shape differences indicate a substantial reduction of the space for the tongue.**

KEY WORDS: *bilateral complete cleft lip and palate, palate shape, palate size, permanent dentition, three-dimensional analysis*

Bilateral complete cleft lip and palate (BCLPc) is the most severe impairment among typical orofacial clefts associated with the greatest growth deviations during development. In newborns, because of the lateral displacement of maxillary segments, the alveolar arch is wider than in healthy individuals, with increased steepness of palatal shelves (Huddart, 1970). Thus, palate area and volume are larger. Premaxillary protrusion is typical. After cheiloplasty, because of the increased lip tension, premaxillary protrusion as well as the width of the anterior part of the arch are reduced (Kramer et al., 1994; Honda et al., 1995). After palatoplasty, because of scar tension and ossification of the palate by osseous bridges without growth suture (Prydso et al., 1974), the posterior part of the arch is similarly reduced, though less than the anterior part. All of these pre- and postsurgical changes have been confirmed by Heidbuchel et al. (1998a, 1998b). Peterka (1984) cross-sectionally measured dental casts of patients with BCLPc who were between 3 and 15 years of age. Before the patients underwent palate surgery at age 3 years, Peterka recorded a wider arch between molars and its rapid reduction after palatoplasty. In spite of the orthodontic expansion, there was only very small widening of the dentoalveolar arch during childhood, with a difference as compared with control study subjects of 9 mm between canines and 3 mm between second premolars (successors of the second deciduous molars) at age 15 years. Width reduction between second premolars appeared only after age 10 years; whereas, it was apparent between canines at age 5 years. Schliephake et al. (2006) also could not find any deviation in posterior arch width at age 10 years, and Wada et al. (1984) confirmed at age 4 years a narrower anterior part of the arch but not a narrower posterior part. The length of the arch from papilla up to the tuberosities in the study by Peterka (1984) reached control values between ages 8 and 10 years, because of the backward shift of the

Dr. Šmahel is Professor and Head, Department of Anthropology and Human Genetics, Faculty of Science and Chairman, Committee for Postgraduate Studies in Anthropology, Charles University, Prague. Dr. Velemínská is Assistant Professor, Department of Anthropology and Human Genetics, Faculty of Science, Charles University. Dr. Trefný is Scientific Worker, Department of Anthropology and Human Genetics, Faculty of Science, Charles University and affiliated with the Institute of Dental Research, General Faculty Hospital, Prague. Dr. Müllerová is Orthodontist in private practice and affiliated with Faculty Hospital Královské Vinohrady, Prague, Czech Republic.

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Address correspondence to: Dr. Zbyněk Šmahel, Chair of Anthropology and Human Genetics, Faculty of Science, Charles University, Viničná 7, 128 44 Prague 2, Czech Republic. E-mail smahel@natur.cuni.cz.

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premaxilla, being shorter by 4 mm at the age of 15 years. Similarly, Heidbuchel and Kuijpers-Jagtman (1997) recorded a shorter dental arch from age 9 years onward.

Studies of maxillary arch formation in adults with BCLPc have confirmed the narrower arch and its smaller length; however, because of differences in treatment, some discrepancies in the literature may exist. Various studies also mentioned deformed and shallow palates (Okazaki et al., 1991; Kilpeläinen and Laine-Alava, 1996; Kilpeläinen et al., 1996); however, there is very little objective information on palate shape and morphology not only in clefts and other upper-jaw malformations but also in healthy study subjects (e.g., see review in Šmahel et al., 2003; Ciusa et al., 2007). These studies inevitably require precise three-dimensional measurements associated with sophisticated equipment and software.

In our previous studies, we conducted three-dimensional analysis of the size and shape of the palate in study subjects (boys) with isolated cleft palate (Šmahel et al., 2003) and with unilateral complete cleft lip and palate (Šmahel et al., 2004) at approximately age 15 years, using Fourier-transform profilometry. In patients with isolated cleft palate (CP), shortening and narrowing of the dentoalveolar arch and, from the first premolars posteriorly, flattening of the palate that increased posteriorly were revealed. The contours of the palate vault in transverse sections were on average symmetrical; although, individual asymmetries were quite common. In patients with unilateral complete cleft lip and palate (UCLPc), the dentoalveolar arch was narrower, more anteriorly than posteriorly; however, the arch was not shorter. The height of the palate was lower from the canines posteriorly, and the difference as compared with control study subjects increased in this direction. The lowering was not substantially larger than in CP, and the same holds true for the reduction of area of transverse sections. The palatal vault was asymmetrical, highest anteriorly on the cleft side and posteriorly on the noncleft side.

The above-mentioned studies of subjects with BCLPc evaluated basic dental arch dimensions and height of the palate. It can be concluded that the palate of treated BCLPc subjects differs from that of healthy individuals, especially in the width of the anterior dental arch and height of the palate.

Therefore, limited space for the tongue can be supposed. Our motivation was to quantify the differences in the size, shape, and symmetry of the palatal vault between BCLPc and healthy subjects using a method allowing us to evaluate the surface of the palate in detail. We also compare the morphology of the palate in BCLPc with the other two types of clefts studied earlier (Šmahel et al., 2003, 2004).

Materials and Methods

The group of boys with BCLPc comprised 30 individuals of Czech origin with a mean age of 14.7 years (range 12.1 to 16.5 years). Only nonsyndromic patients were included, and none of them had any associated major malformations. Five patients had a unilateral mucous bridge (Simonart's band). Dental casts were used for the analysis. The prerequisites for inclusion in the group were the absence of imperfections of the dental cast surface, complete replacement of deciduous teeth, and at least partial eruption of both second permanent molars. All patients underwent surgery at the Clinic of Plastic Surgery in Prague during the 1970s and 1980s by the same method: lips underwent a modified Veau procedure (arched sutures on both sides at the same time), combined in 24 cases with primary periosteoplasty at an average age of 7.9 months (range 4 to 11 months); palates were modified by push-back with two flaps and upper-based pharyngeal flap surgery at an average age of 5.0 years (range 3.8 to 6.0 years). The method used was described by Kuderová et al. (1996). The vestibulonasal communication was closed or still present in 20 patients, and the oronasal communication was closed or still present in seven patients (both in five patients); deepening of the vestibulum was performed in nine boys and premaxillary setback in two. Only in one patient was a secondary cancellous bone graft implanted into the alveolar process, and in another one, secondary lengthening of the palate by Z-plasty was performed.

Tonsillectomy was performed in seven boys, and adenoidectomy was performed in five; both procedures were performed in three. In all patients, usually repeatedly, corrections of the lip and nose were made, including the columellar lengthening with a fork flap in 28 individuals. However, only two repairs of the oronasal communication, performed before the age of dental-cast evaluation, and one palate Z-plasty could locally affect the configuration of the palate behind the canines as analyzed in this study.

All patients underwent long-term orthodontic treatment in a specialized department of the Clinic of Plastic Surgery in Prague with the objective of expanding the dental arch, aligning the teeth into the arch, and forming appropriate jaw relations. However, the premaxilla was not pressed or pulled backward. The treatment was based on removable appliances (upper plate with screw); fixed appliances were used in the permanent dentition only in a few patients later in the period. Neither presurgical jaw orthopedics nor rapid palate expansion were used. The dentition was complete only in 6 of 30 patients (20%). The central incisor was missing in one patient unilaterally (because of injury), lateral incisors were missing in 11 individuals on both sides (extractions) and in nine on one side (three agenesis, six extractions); in two patients they were duplicated unilaterally and in two bilaterally. Nonduplicated incisors were slightly more frequent in the maxilla (13) than in the premaxilla (11). The canine was absent in three individuals unilaterally (extractions), the first premolars in two individuals unilaterally (extractions) and in two bilaterally (extractions), the second premolars in five individuals unilaterally (three agenesis, two extractions) and in two bilaterally (extractions). The first molars were missing in three patients on one side and in one patient on both sides (extractions). In 13 of the patients, more categories of teeth were missing.

Control maxillary dental casts were evaluated in 28 healthy boys of Czech origin with a mean age of 14.7 years (range 14.1 to 15.7 years). The casts were made in the mid-1970s in Brno schools. The criteria for inclusion were complete dentition (with the exception of the third permanent molars) and absence of any orthodontic anomaly or treatment. Thus, only individuals with ideal occlusion were involved. They were described in more detail in our previous study (Šmahel et al., 2003).

Instead of Fourier-transform profilometry based on projection of structured light, as used in previous studies, laser scanning was applied. Both techniques of surface scanning are based on the principle of optical triangulation and are fully comparable with respect to resolution and accuracy. A laser beam is projected onto the examined surface, and the linelike beam image is recorded by a CCD (charge-coupled device) camera to calculate the x, y, and z coordinates. To digitize the maxillary dental stone casts, we used a three-dimensional laser scanner Roland LPX-250 (Roland DG, Hamamatsu, Japan) with a lateral resolution of 200 μm. Scanning was performed using Dr. PICZA 3 software (Roland DG). The casts were scanned on the rotated plate first from a direction perpendicular to the occlusal plane. Subsequently, rescanning of selected areas from two to six other planes (each about 30° to 45° to the occlusal plane) was performed to record the structures that were inaccessible from the first view. Raw scan data were processed using Pixform reverse engineering software (Roland DG). This procedure included cleaning, merging of multiple scans, hole-filling, decimating, smoothing, and global remeshing. The number of triangles ranged from 80,000 to 140,000, depending on the size of the dental cast. To analyze quantitatively the surface of the palate, a conversion of the original polygon mesh to a NURBS (nonuniform rational B-spline) surface was performed with the use of Rhinoceros 3.0 software (McNeel & Associates, Seattle, WA). The method was described and illustrated in Trefný et al. (2005).

The next procedure depended on the definition of palatal plane and median line of the palate. The palatal plane was defined by the most anterior landmark on the dental papilla and landmarks on the alveolar process posterior to the distopalatal cusp of both first molars (points 1 through 3 on Fig. 1). All measured dimensions are related to the reference plane defined in this way. The median line of the palate is defined by the papilla (landmark 1) and center (point P) of the distance between the first molars at the most medial cervical margins of the mesiopalatal cusps (landmarks 4 and 5). At this center, perpendicularly to the palatal plane and to the median line of the palate, the eighth section was constructed by means of D-AS, new custom software that we developed in-house (Fig. 2). The remaining seven sections divided the palate at equidistant intervals in an anterior direction, and another two sections with the same intervals are automatically constructed posteriorly. Further landmarks are located on the most medial cervical surfaces of individual teeth (Fig. 2) and demarcate the area of the palate where individual dimensions were to be measured. To evaluate the surface of the palate in detail, we divided the left and right part of the each transverse section cord into 10 equal intervals (of 10%). At these points, we then measured the height of the palate from the reference plane using D-AS software (i.e., at 210 landmarks). The software also measured the width of the palate (dentoalveolar arch) at the site of transverse sections, the maximal height of the palate in each half of the section profile, the length of the palate from papilla up to the eighth section, and the area of transverse sections.

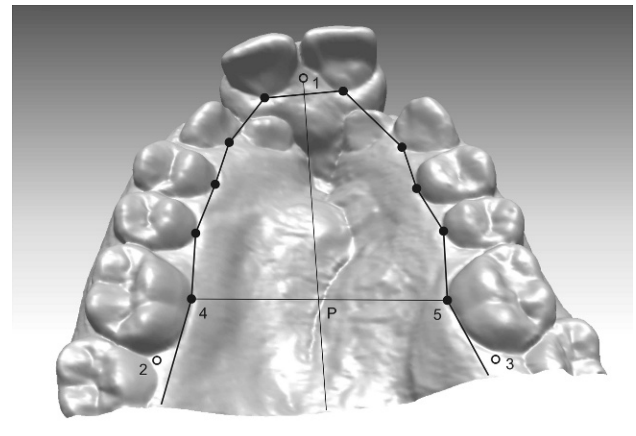

FIGURE 1 Three-dimensional model of the dental arch and palate of an individual with BCLPc. Landmarks 1 through 5 and P determine the reference plane, midline of the palate, and position of the eighth transversal section. Unnumbered (unlabeled) landmarks demarcate the palate area to be measured (see text for definition of landmarks).

Dahlberg error as well as the precision and reliability of the measurements were calculated in all sections. Reliability of the measurements was somewhat higher as compared with a similar method published earlier (Trefný et al.,

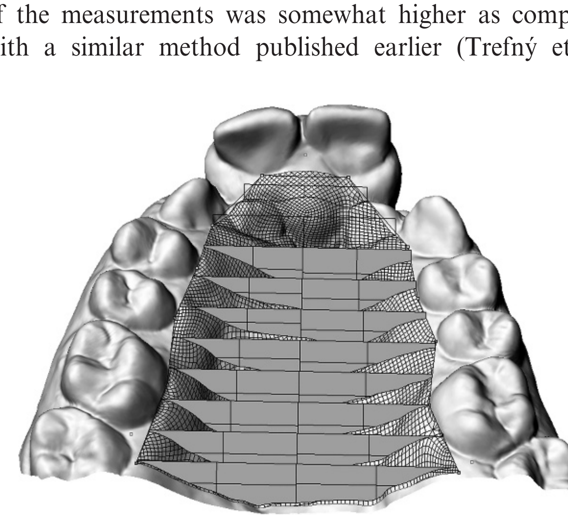

FIGURE 2 Three-dimensional model of the dental arch and palate of the same individual as in Figure 1, showing section profiles 3 through 10.

TABLE 1 Palate Height and Width and Area of Sections 3 Through 5 in Patients With BCLP and in Study Control Subjects*

	Section 3					*Section 4*					*Section 5*				
	Mean		*SD*			*Mean*		*SD*			*Mean*		*SD*		
Variable	*Controls*	*BCLP*	*Controls*	*BCLP*	*p Value*	*Controls*	*BCLP*	*Controls*	*BCLP*	*p Value*	*Controls*	*BCLP*	*Controls*	*BCLP*	*p Value*
R 0%	0.77	3.04	0.51	2.13	**.000**	0.77	1.78	0.55	1.59	**.002**	0.86	0.95	0.62	1.23	.726
R 10%	1.43	3.68	0.59	2.26	**.000**	1.98	2.52	0.61	1.63	.107	2.17	1.81	0.70	1.37	.210
R 20%	2.12	4.47	0.58	2.49	**.000**	3.07	3.44	0.68	1.69	.284	3.68	2.90	0.73	1.50	**.016**
R 30%	2.61	5.35	0.60	2.68	**.000**	4.02	4.43	0.86	1.72	.259	5.25	4.23	0.96	1.51	**.004**
R 40%	3.28	6.24	0.75	2.64	**.000**	5.29	5.57	1.03	1.83	.494	7.18	5.50	1.10	1.70	**.000**
R 50%	3.98	7.16	0.88	2.72	**.000**	6.59	6.67	1.17	2.02	.845	8.98	6.71	1.34	1.93	**.000**
R 60%	4.63	8.18	0.99	2.87	**.000**	7.57	7.88	1.25	2.28	.528	10.21	7.74	1.46	2.02	**.000**
R 70%	5.15	9.07	1.09	2.90	**.000**	8.14	8.82	1.36	2.31	.180	10.81	8.57	1.51	1.98	**.000**
R 80%	5.51	9.57	1.13	2.56	**.000**	8.50	9.59	1.41	2.32	**.037**	11.10	9.23	1.57	2.06	**.000**
R 90%	5.77	9.82	1.12	2.54	**.000**	8.72	9.90	1.45	2.36	**.027**	11.17	9.80	1.61	2.29	**.011**
Midline	5.79	9.74	1.13	2.52	**.000**	8.70	9.84	1.50	2.41	**.036**	11.10	9.95	1.66	2.43	**.042**
L 90%	5.63	9.47	1.12	2.46	**.000**	8.56	9.39	1.47	2.35	.115	11.06	9.63	1.61	2.50	**.013**
L 80%	5.34	9.03	1.14	2.47	**.000**	8.22	8.81	1.45	2.33	.253	10.82	9.03	1.54	2.53	**.002**
L 70%	4.93	8.40	1.18	2.57	**.000**	7.73	8.03	1.38	2.21	.546	10.37	8.34	1.47	2.52	**.000**
L 60%	4.34	7.53	1.16	2.54	**.000**	6.97	7.16	1.38	2.01	.680	9.54	7.43	1.38	2.20	**.000**
L 50%	3.57	6.61	1.11	2.28	**.000**	5.89	6.26	1.35	1.88	.388	8.21	6.48	1.36	1.92	**.000**
L 40%	2.88	5.68	0.99	2.10	**.000**	4.63	5.31	1.24	1.78	.101	6.53	5.40	1.32	1.67	**.006**
L 30%	2.26	4.72	0.84	1.97	**.000**	3.51	4.29	1.14	1.73	**.049**	4.81	4.17	1.17	1.67	.102
L 20%	1.72	3.82	0.70	1.88	**.000**	2.64	3.25	0.98	1.71	.106	3.30	2.89	0.94	1.60	.242
L 10%	1.06	3.02	0.67	1.71	**.000**	1.42	2.26	0.99	1.61	**.021**	1.80	1.72	0.96	1.55	.826
L 0%	0.68	2.41	0.63	1.64	**.000**	0.77	1.43	0.71	1.48	**.035**	0.97	0.98	0.75	1.43	.972
R maximum height†	5.97	10.16	1.15	2.51	**.000**	8.87	10.02	1.46	2.38	**.031**	11.36	10.14	1.58	2.64	**.038**
L maximum height†	5.88	10.39	1.14	2.70	**.000**	8.82	10.29	1.48	2.33	**.006**	11.26	10.31	1.64	2.30	.079
Palate width	27.64	19.91	1.80	2.85	**.000**	29.75	22.14	1.97	3.59	**.000**	32.23	24.70	2.02	4.03	**.000**
Section area	101.93	135.14	22.28	43.40	**.001**	171.22	140.54	31.31	44.60	**.004**	243.98	153.65	39.75	47.33	**.000**

* BCLP = bilateral complete cleft lip and palate; L = left side; R = right side. All values are in millimeters, except for section area (millimeters squared).

† Height measured in each 10% of the width of the right and left sides of the palate.

2004). Coefficients of reliability in the BCLPc series were higher than 0.98 in all measurements (Table 5).

Statistical analysis was performed using Statistica 6.0 software (StatSoft, Tulsa, OK). F-statistics and the two-tailed Student's *t* test for independent samples were used for intergroup comparison. The height differences between the right and left side within each group were evaluated using the paired Student's *t* test. The Kolmogorov-Smirnov test confirmed normal distribution of all variables, with the exception of three in the 10th section. They included marginal height characteristics of little importance (right, 10%; left, 10%; $p < .05$; left, 0%; $p < .01$). Correlation coefficients between palate width and height in the midline were also calculated.

The first and second transverse sections were not evaluated because the first section practically coincides with the line connecting the palate margins of the crowns of the first incisors, and the second section passes regularly over the highly deformed cleft area. In some dental stone casts, the posterior margin was cut obliquely with respect to the midline. Therefore, the 10th section profile could not be evaluated in five individuals. In the figures, different transverse sections are projected into the equal width of the baseline (palate width); the actual values of widths in patients as compared with study control subjects are presented in Tables 1 through 3.

Results were compared with the previously examined groups of patients with CP and UCLPc (Šmahel et al., 2003, 2004). The CP group consisted of 29 Czech boys with an average age of 15.3 years who underwent surgery in Prague and who also underwent pushback (three flaps) with pharyngeal flap surgery at an average age of 4.5 years. The UCLPc group consisted of 30 Czech boys with an average age of 14.8 years who underwent surgery in Prague and who underwent lip suture by the Tennison method, also with primary periosteoplasty at age 8.5 months and palate correction by push-back (two flaps) with pharyngeal flap surgery at age 4.9 years. Thus, the age of examination as well as the time and method of surgery were similar in all groups (except for the necessary difference in lip suture). All series of patients were orthodontically treated in the same department, and prerequisites for inclusion of dental casts into the study were also the same. The "Ethical Principles for Medical Research Involving Human Subjects" outlined in the World Medical Association Declaration of Helsinki were followed.

Results

The palate height in the median line (10 mm) was constant from the third section (behind canines) to the end of the palate in individuals with BCLPc and thus

TABLE 2 Palate Height and Width and Area of Sections 6 Through 8 in Patients with BCLP and Study Control Subjects*

	Section 6					*Section 7*					*Section 8*				
	Mean		*SD*			*Mean*		*SD*			*Mean*		*SD*		
Variable	*Controls*	*BCLP*	*Controls*	*BCLP*	*p Value*	*Controls*	*BCLP*	*Controls*	*BCLP*	*p Value*	*Controls*	*BCLP*	*Controls*	*BCLP*	*p Value*
R 0%	0.66	0.70	0.59	1.20	.876	1.13	0.56	0.74	0.92	**.012**	0.75	0.10	0.62	0.74	**.001**
R 10%	2.20	1.44	0.72	1.41	**.013**	2.80	1.21	0.94	1.22	**.000**	2.44	0.95	1.08	0.81	**.000**
R 20%	4.26	2.53	0.74	1.63	**.000**	5.09	2.39	1.02	1.66	**.000**	5.42	2.14	1.39	1.34	**.000**
R 30%	6.23	3.96	1.02	1.77	**.000**	7.23	3.80	1.35	1.79	**.000**	7.78	3.72	1.42	1.66	**.000**
R 40%	8.54	5.35	1.35	1.87	**.000**	9.55	5.29	1.60	1.83	**.000**	9.91	5.26	1.59	1.73	**.000**
R 50%	10.58	6.49	1.47	1.90	**.000**	11.54	6.54	1.60	1.88	**.000**	11.80	6.73	1.62	1.81	**.000**
R 60%	11.91	7.55	1.45	1.95	**.000**	12.83	7.64	1.51	1.96	**.000**	13.09	7.94	1.51	1.97	**.000**
R 70%	12.61	8.46	1.44	1.97	**.000**	13.54	8.83	1.42	2.13	**.000**	13.82	9.22	1.46	2.43	**.000**
R 80%	12.95	9.36	1.47	2.07	**.000**	13.87	9.74	1.46	2.40	**.000**	14.15	10.09	1.50	2.73	**.000**
R 90%	12.99	9.96	1.54	2.18	**.000**	14.00	10.28	1.52	2.40	**.000**	14.32	10.51	1.59	2.83	**.000**
Midline	12.94	10.30	1.59	2.36	**.000**	13.99	10.58	1.54	2.46	**.000**	14.32	10.59	1.64	2.58	**.000**
L 90%	12.83	10.20	1.58	2.55	**.000**	13.83	10.55	1.53	2.65	**.000**	14.14	10.62	1.64	2.57	**.000**
L 80%	12.62	9.69	1.54	2.64	**.000**	13.55	10.22	1.48	2.69	**.000**	13.88	10.31	1.59	2.60	**.000**
L 70%	12.15	8.79	1.47	2.39	**.000**	13.11	9.40	1.40	2.44	**.000**	13.46	9.79	1.54	2.48	**.000**
L 60%	11.30	7.82	1.41	2.15	**.000**	12.34	8.47	1.35	2.31	**.000**	12.72	8.95	1.56	2.45	**.000**
L 50%	9.89	6.80	1.47	1.98	**.000**	11.03	7.42	1.40	2.20	**.000**	11.49	7.81	1.69	2.33	**.000**
L 40%	7.96	5.53	1.63	1.59	**.000**	9.12	6.06	1.45	1.93	**.000**	9.75	6.20	1.79	2.10	**.000**
L 30%	5.97	4.09	1.52	1.39	**.000**	6.92	4.24	1.43	1.42	**.000**	7.73	4.15	1.78	1.58	**.000**
L 20%	4.07	2.61	1.29	1.28	**.000**	4.79	2.61	1.48	1.26	**.000**	5.43	2.29	1.75	1.29	**.000**
L 10%	2.06	1.44	1.11	1.16	**.045**	2.57	1.38	1.50	1.08	**.001**	2.68	0.99	1.48	0.98	**.000**
L 0%	0.71	0.65	0.73	1.11	.788	1.15	0.61	0.79	0.92	**.019**	0.93	0.38	0.68	0.81	**.006**
R maximum height†	13.30	10.58	1.41	2.55	**.000**	14.15	10.95	1.51	2.55	**.000**	14.50	11.01	1.57	2.60	**.000**
L maximum height†	13.05	10.55	1.59	2.27	**.000**	14.06	10.83	1.53	2.47	**.000**	14.39	10.92	1.62	2.69	**.000**
Palate width	34.80	27.70	2.05	4.34	**.000**	36.05	30.21	1.93	4.24	**.000**	37.16	32.99	2.01	4.28	**.000**
Section area	308.85	173.17	45.88	49.70	**.000**	350.90	195.55	49.23	54.97	**.000**	372.49	216.00	53.95	61.37	**.000**

* BCLP = bilateral complete cleft lip and palate; L = left side; R = right side. All values are in millimeters, except for section area (millimeters squared).
† Height measured in each 10% of the width of the right and left sides of the palate.

TABLE 3 Palate Height and Width and Area of Sections 9 and 10 in Patients With BCLP and in Study Control Subjects*

	Section 9					*Section 10*				
	Mean		*SD*			*Mean*		*SD*		
Variable	*Controls*	*BCLP*	*Controls*	*BCLP*	*p Value*	*Controls*	*BCLP*	*Controls*	*BCLP*	*p Value*
R 0%	0.86	0.00	0.63	0.71	**.000**	1.09	0.52	0.74	1.91	.176
R 10%	2.32	0.68	1.11	0.70	**.000**	2.56	1.12	1.24	2.01	**.004**
R 20%	5.18	1.74	1.60	1.07	**.000**	5.29	2.25	1.68	2.12	**.000**
R 30%	7.70	3.38	1.68	1.51	**.000**	7.64	3.74	1.78	2.19	**.000**
R 40%	9.71	5.16	1.66	1.75	**.000**	9.56	5.59	1.68	2.87	**.000**
R 50%	11.51	6.68	1.75	1.82	**.000**	11.28	6.87	1.74	2.84	**.000**
R 60%	12.90	7.95	1.60	1.90	**.000**	12.63	8.02	1.62	2.83	**.000**
R 70%	13.67	9.13	1.49	2.52	**.000**	13.44	8.88	1.51	2.81	**.000**
R 80%	14.03	9.89	1.50	2.77	**.000**	13.85	9.57	1.53	2.84	**.000**
R 90%	14.16	10.36	1.61	2.90	**.000**	13.95	9.99	1.65	3.01	**.000**
Midline	14.13	10.47	1.71	2.76	**.000**	13.91	9.92	1.75	2.94	**.000**
L 90%	13.97	10.40	1.74	2.55	**.000**	13.81	9.74	1.80	2.74	**.000**
L 80%	13.71	10.02	1.66	2.45	**.000**	13.56	9.41	1.71	2.56	**.000**
L 70%	13.25	9.57	1.56	2.38	**.000**	13.03	8.93	1.67	2.47	**.000**
L 60%	12.45	8.80	1.55	2.50	**.000**	12.12	8.22	1.74	2.43	**.000**
L 50%	11.20	7.63	1.56	2.40	**.000**	10.76	7.20	1.82	1.93	**.000**
L 40%	9.45	5.86	1.49	2.21	**.000**	9.10	5.40	1.79	1.44	**.000**
L 30%	7.54	3.60	1.36	1.89	**.000**	7.28	3.45	1.76	1.63	**.000**
L 20%	5.04	1.87	1.49	1.59	**.000**	4.88	1.98	1.86	1.67	**.000**
L 10%	2.34	0.73	1.30	1.28	**.000**	2.28	0.93	1.40	1.74	**.004**
L 0%	0.91	0.06	0.60	1.05	**.001**	1.05	0.52	0.65	1.64	.151
R maximum height†	14.38	10.80	1.60	2.69	**.000**	14.19	10.14	1.61	2.91	**.000**
L maximum height†	14.20	10.80	1.69	2.80	**.000**	14.01	10.29	1.72	2.98	**.000**
Palate width	38.64	36.60	1.98	4.32	.038	40.34	37.17	2.06	5.76	**.014**
Section area	379.44	230.40	53.61	64.36	**.000**	391.04	222.93	59.31	62.87	**.000**

* BCLP = bilateral complete cleft lip and palate; L = left side; R = right side. All values are in millimeters, except for section area (millimeters squared).
† Height measured in each 10% of the width of the right and left sides of the palate.

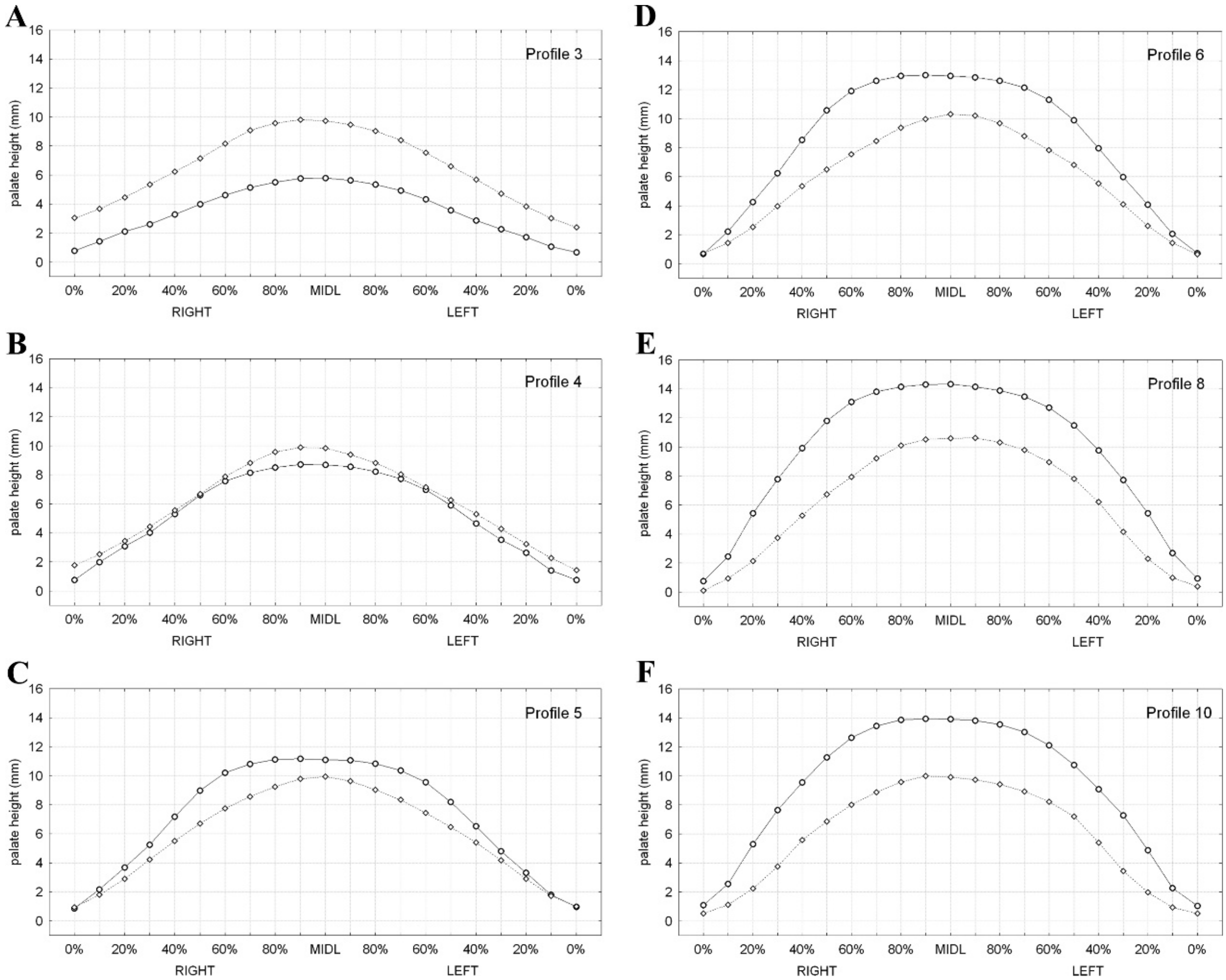

FIGURE 3 Comparison of palatal vault profiles 3 through 10 in study control subjects (solid line) versus patients with BCLPc (dashed line).

predetermines the results for comparison of particular profiles with the study control group (Fig. 3). The third profile lies higher compared with the control group; the height of the palate is larger throughout in relation to the defined plane of the palate, including the marginal values. These outer values show that the alveolar ridges are lifted upward into the cleft fissures. The base of profile 4 lies at approximately the same level in clefts as in the control group (the difference is 1 mm on the right and 0.7 mm on the left); and in the midline, the profile is slightly higher (within 80% from the right to midline; $p < .05$). Profile 5 is slightly lower in the midline in clefts ($p < .05$) than in control subjects; in lateral areas, the difference is greater. In the remaining sections (profiles 6 through 10), the palate vault in clefts is always significantly lower than in the control group. Profiles 4 through 7 also show that the palate after palatoplasty is conical upwardly, without the wide arc of the vault (the shape of an inverse V). This is evident despite the fact that the base of the profiles is in reality narrower than in the control group (see width of the palate). In profiles 8 through 10, the palate is already rounder; however, even here it is narrower in the cranial direction on all levels compared with the control group. Figure 4 compares profiles 4, 6, 8, and 10 in clefts as well as in the control group. In both cases, the palate in the midline is highest in the eighth section between first molars. This applies in similar fashion to the maximal palate height, which always differs only minimally from the height in the midline (>0.5 mm only in the third section). Relevant statistical values are listed in Tables 1 through 3.

The midsagittal section of the palate, compared with earlier evaluated groups with CP and UCLPc, is shown in Figure 5. In the latter type of cleft, the palate is flatter; however, in the anteroposterior direction, its vault increases; whereas, in BCLPc, it is equally high from the third section. Therefore, in profiles 3 and 4 (i.e., approximately to the level of the first premolars), the palate in BCLPc is higher than in the control group; posteriorly, it is lower. Lowering in the sixth section reaches 20%, and in subsequent profiles, it gradually reaches 24% to 29%. Data for the second and third sections are virtual (in the defect behind the premaxilla); they average 2.3 mm and 7 mm, respectively.

The width of the dentoalveolar arch (Fig. 6) in bilateral clefts is significantly smaller than in study control subjects, and the difference decreases posteriorly from 8 mm in the

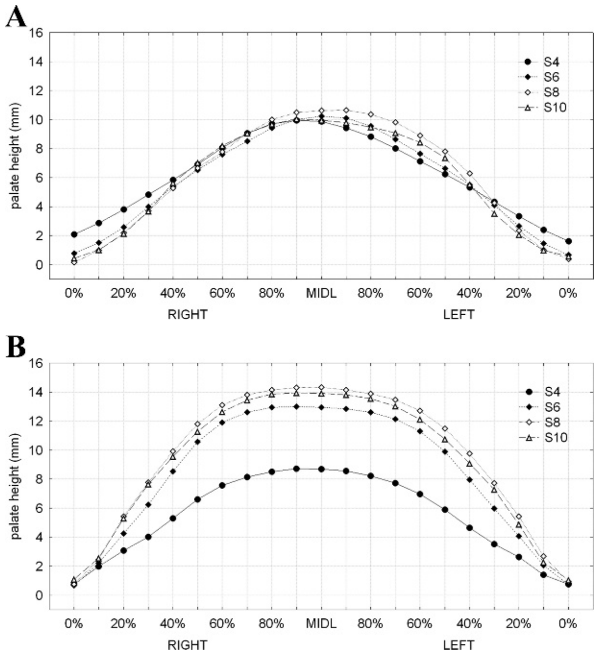

FIGURE 4 Profiles of transverse sections 4, 6, 8, and 10 in patients with BCLPc (A) compared with study control subjects (B).

3rd section to 7 mm in the 6th section, 6 mm in the 7th section, 4 mm in the 8th section, and only 2 to 3 mm in the 9th and 10th sections. Curves for CP and UCLPc show less narrowing of the arch, particularly anteriorly in CP and posteriorly in UCLPc. The length of the dentoalveolar arch up to the first molars was not increased in BCLPc compared with the control group (difference = 1 mm; Table 4).

The area of individual profiles (Fig. 7) shows evidence of a significant decrease of the palate space for the tongue. In the posterior area of the palate, the decrease is greater compared with that in CP, significantly in the seventh section ($p < .05$), but the same as in UCLPc. The area of the second and third profiles in BCLPc is slightly greater (by 54 mm^2 and 33 mm^2, respectively) compared with that in the control group because it is situated into the "hole" behind the premaxilla. From the fourth profile onward, the area is smaller and the difference compared with the control group increases gradually. The difference in the fifth section reaches

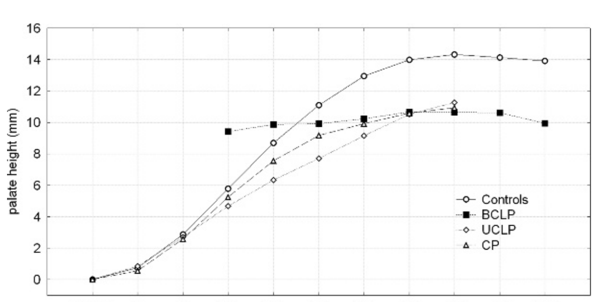

FIGURE 5 The midsagittal section of the palate in patients with BCLPc and study control subjects, as compared with previously examined patients with UCLPc and isolated CP. S1 = section 1, etc.

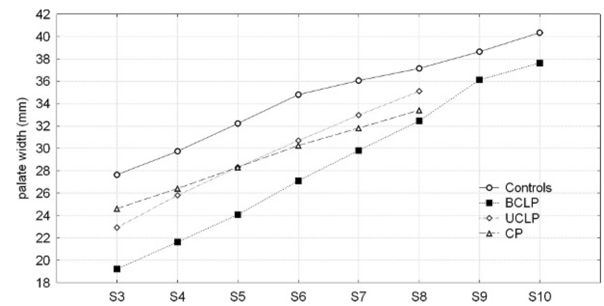

FIGURE 6 Width of the palate (transverse sections) in patients with BCLPc and control subjects, as compared with previously examined patients with UCLPc and isolated CP. S3 = section 3, etc.

37% and is 39% to 44% in subsequent sections. In absolute values, the area of the fourth profile in BCLPc is decreased by 31 mm^2, in the fifth profile by 90 mm^2, in the sixth profile by 135 mm^2, and in subsequent profiles by 149 to 168 mm^2.

Asymmetry of the palate height was found in three sections, always at $p < .05$. In the fourth profile, the right side at the level of 80% to 90% of the width was higher by 0.8 and 0.5 mm; in the eighth and ninth profiles, the right side at the level of 50% to 60% of width was lower by 0.9 to 1.1 mm. Small asymmetries can be observed in particular profiles (Fig. 3). We have not included these results in the tables because of their random character; relevant mean values of the palate height, as well as the standard deviations (SDs) are shown in Tables 1 through 3. Although only little asymmetries of the palate height were found at the sample level, they are common in individual cases. Figure 8 shows a number of extreme shapes of the palatal vault in BCLPc subjects.

The higher SDs of height measurements in BCLPc compared with those in the control group, particularly in anterior sections (third and fourth profiles), and the more than double SDs in the width and length of the dentoalveolar arch, confirm high variability in the palate formations in these clefts. The F-test demonstrated significant differences in width dimensions of all sections and of palate length; however, with the exception of the third section, the differences between profile areas were not significant. As for height variables, the F-test showed varied results. Correlation coefficients between the width and height of the palate were significant, with $p < .05$ only in the third ($r = 0.39$) and ninth ($r = 0.37$) sections.

TABLE 4 Palate Length in Patients With BCLP as Compared With Study Control Subjects, UCLP, and CP*

	Mean		*SD*		
Variable	*BCLP*	*Controls*	*BCLP*	*Controls*	*p Value*
Palate length	29.84	28.77	4.82	1.56	.268
	BCLP	*UCLP*	*BCLP*	*UCLP*	
Palate length	29.84	28.03	4.82	2.16	.066
	BCLP	*CP*	*BCLP*	*CP*	
Palate length	29.84	26.24	4.82	2.64	.001

* BCLP = bilateral complete cleft lip and palate; CP = isolated cleft palate; UCLP = unilateral complete cleft lip and palate. All values are in millimeters.

TABLE 5 Dahlberg Error and Coefficient of Reliability of the Measurement of Sections 3 Through 10

	Section 3		*Section 4*		*Section 5*		*Section 6*		*Section 7*		*Section 8*		*Section 9*		*Section 10*	
Variable	SD_E	*R*	SD_E	*R*	SD_E	*R*	SD_E	*R*	SD_E	*R*	SD_E	*R*	SD_E	*R*	SD_E	*R*
R 0%	0.129	0.997	0.059	0.999	0.093	0.995	0.038	0.999	0.047	0.996	0.060	0.989	0.058	0.995	0.401	0.995
R 10%	0.164	0.996	0.060	0.999	0.056	0.998	0.032	0.999	0.030	0.999	0.033	0.997	0.029	0.997	0.450	0.994
R 20%	0.116	0.998	0.059	0.999	0.051	0.999	0.033	0.999	0.030	0.999	0.046	0.998	0.027	0.999	0.860	0.984
R 30%	0.103	0.999	0.043	1.000	0.040	0.999	0.039	0.999	0.032	1.000	0.040	0.999	0.032	1.000	1.539	0.960
R 40%	0.092	0.999	0.073	0.999	0.052	0.999	0.044	0.999	0.045	0.999	0.035	1.000	0.036	1.000	0.182	0.999
R 50%	0.085	0.999	0.058	0.999	0.053	0.999	0.055	0.999	0.043	0.999	0.034	1.000	0.036	1.000	0.203	0.999
R 60%	0.099	0.999	0.070	0.999	0.051	0.999	0.066	0.999	0.037	1.000	0.030	1.000	0.050	0.999	0.137	1.000
R 70%	0.103	0.999	0.054	0.999	0.039	1.000	0.053	0.999	0.049	1.000	0.035	1.000	0.041	1.000	0.074	1.000
R 80%	0.091	0.999	0.060	0.999	0.045	0.999	0.053	0.999	0.038	1.000	0.037	1.000	0.041	1.000	0.064	1.000
R 90%	0.079	0.999	0.048	1.000	0.048	1.000	0.036	1.000	0.039	1.000	0.033	1.000	0.046	1.000	0.130	1.000
Midline	0.080	0.999	0.057	1.000	0.043	1.000	0.034	1.000	0.030	1.000	0.030	1.000	0.073	1.000	0.045	1.000
L 90%	0.084	0.999	0.076	0.999	0.044	1.000	0.034	1.000	0.031	1.000	0.033	1.000	0.045	1.000	0.038	1.000
L 80%	0.109	0.998	0.069	0.999	0.044	1.000	0.035	1.000	0.031	1.000	0.030	1.000	0.037	1.000	0.055	1.000
L 70%	0.121	0.998	0.081	0.999	0.049	1.000	0.036	1.000	0.032	1.000	0.030	1.000	0.038	1.000	0.046	1.000
L 60%	0.172	0.996	0.059	0.999	0.043	1.000	0.046	1.000	0.028	1.000	0.027	1.000	0.033	1.000	0.048	1.000
L 50%	0.110	0.998	0.064	0.999	0.041	1.000	0.039	1.000	0.034	1.000	0.030	1.000	0.035	1.000	0.045	1.000
L 40%	0.106	0.997	0.060	0.999	0.052	0.999	0.036	1.000	0.035	1.000	0.029	1.000	0.041	1.000	0.045	1.000
L 30%	0.096	0.998	0.064	0.998	0.042	0.999	0.036	0.999	0.038	0.999	0.039	0.999	0.048	0.999	0.057	1.000
L 20%	0.095	0.997	0.071	0.998	0.053	0.998	0.035	0.998	0.044	0.998	0.046	0.998	0.056	0.998	0.063	1.000
L 10%	0.091	0.997	0.075	0.997	0.059	0.998	0.038	0.997	0.050	0.996	0.050	0.996	0.059	0.996	0.068	1.000
L 0%	0.090	0.997	0.058	0.998	0.061	0.997	0.041	0.997	0.051	0.995	0.058	0.993	0.068	0.992	0.161	0.999
R maximum height	0.084	0.999	0.056	1.000	0.042	1.000	0.034	1.000	0.030	1.000	0.030	1.000	0.071	1.000	0.052	1.000
L maximum height	0.068	0.999	0.058	0.999	0.048	1.000	0.043	1.000	0.036	1.000	0.029	1.000	0.072	1.000	0.038	1.000
Palate width	1.427	0.999	0.816	1.000	0.840	1.000	0.933	1.000	0.895	1.000	0.906	1.000	0.946	1.000	2.436	1.000
Section area	0.098	0.999	0.066	1.000	0.059	1.000	0.050	1.000	0.050	1.000	0.060	1.000	0.079	1.000	0.548	0.998

Discussion

BCLPc differs from other types of clefts by the constant height of the palate through the length of maxilla. This phenomenon is associated with the persisting separation of the premaxilla and the defect between premaxilla and maxilla. The same height of the edges of individual profiles as in the control group shows that it would be possible to use dental papilla as a structure to define the reference plane of the palate because the premaxilla in the vertical direction was well integrated into the alveolar arch. The higher position of the third profile is associated with the cleft defect and has been explained. The same length of the palate as in the control group shows that during treatment, the premaxilla was also adequately positioned in the anteroposterior direction. However, these data are averages, and in individual cases, the situation does not have to be ideal, even though we did not note more severe deviations in our patients. The average insignificant difference between the right and left halves of the palate behind the canines (profile 3) also confirms the midline position of the premaxilla, justifying the use of the papilla as a landmark defining the median line of the palate (difference = 0.7 mm; $p = .127$).

Considerable narrowing of the palate (of the dentoalveolar arch) anteriorly is associated with bilateral impairment; much smaller narrowing posteriorly is a result of effective orthodontic treatment. The question remains whether missing lateral incisors could result in decreased width of the dental arch. However, subgroups of patients with BCLPc with (n = 19) and without (n = 11) missing lateral incisors did not show any differences in width parameters of transverse sections. Maxillary constriction, as opposed to widening in infants before lip suture, was also illustrated in untreated adults with BCLPc (Bishara et al., 1978; da Silva Filho et al., 1998). This is due to deficient palate growth, free space between palatal shelves, and the

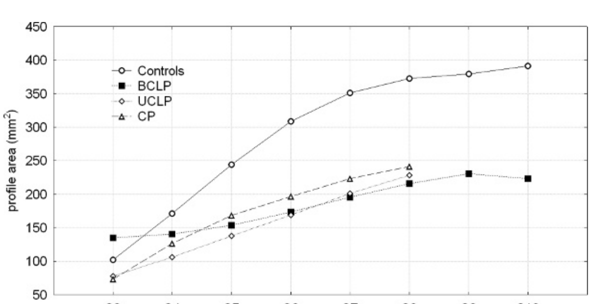

FIGURE 7 **Total area of transverse sections in patients with BCLPc and control subjects, as compared with previously examined patients with UCLPc and isolated CP. S3 = section 3, etc.**

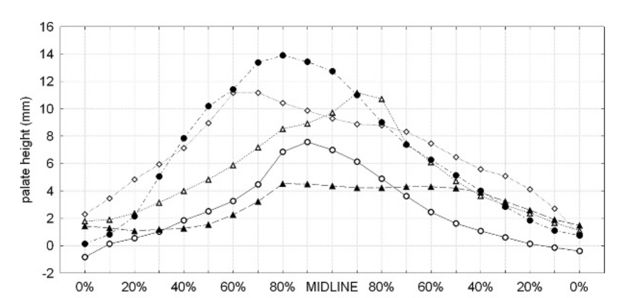

FIGURE 8 **Profiles of the eighth transverse section of the palate in five selected patients demonstrating the highest and lowest palate in the series and asymmetry of the palatal vault.**

pressure of surrounding tissues on maxillary segments. However, measurements on dental casts were not performed, so there are no data for comparison with narrowing in study subjects who underwent surgery. In contrast, radiographic cephalometric analyses of a series of untreated patients are available showing premaxillary protrusion and other craniofacial deviations (Ortiz-Monasterio et al., 1966; da Silva Filho et al., 2003).

The more conical shape of the palate anteriorly is associated with the greatest degree of narrowing. Because the width of the dentoalveolar arch as well as the height of the palate is decreased, their relationship is expressed in positive values for correlation coefficients (from 0.08 to 0.39). However, only 2 of 10 coefficients were significant. The association of a higher palate with a narrower arch is thus a visual impression only.

The significantly lower and narrower palate in patients with BCLPc is documented by the decreased area of the transverse sections and confirms lack of space for the tongue. Compensation in the anterior palate associated with the defect behind the premaxilla is minimal and functionally unsuitable. Lessening of the space between the molars is slightly greater than in CP but the same as in UCLPc. Reduction of the space for the tongue contributes to speech pathology, opening of the bite, oral breathing, and posterior rotation of the mandible, which cannot be managed well orthodontically (Okazaki et al, 1991; Šmahel et al., 2003).

The smaller palate area and volume resulting from a narrower and shallower palate may reflect preoperative reduction of palatal shelves and their surface tissue area, as demonstrated by Huddart (1970) and Lo et al. (2003). A similar reduction of palate surface area in untreated adults with BCLPc or other types of palate clefts has been described by Diah et al. (2007). Thus, preoperative palate area deficiency may predict final reduction of palate volume or even flattening of the palate. Correlation analysis of preoperative and final characteristics under discussion in the same individuals may answer this question.

Results confirm that in comparison with other types of clefts, bilateral impairment imposes the most significant defect in upper jaw formation and still remains a therapeutic problem. Aside from the detached premaxilla and associated deformations, this primarily constitutes narrowing of the dentoalveolar arch, severe in the anterior part of the palate; whereas, flattening of the palate and reduction of the size of the palate are not significantly different compared with the one-sided deformity. Narrowing of the arch (palate) at the level of the canines (third profile) is almost double that in the one-sided clefts; however, between molars, the difference is evidently less (Šmahel et al., 2004). We found the opposite situation in the isolated cleft palate (Šmahel et al., 2003), where smaller narrowing in the anterior palate is associated with an intact dentoalveolar arch and greater narrowing posteriorly is most likely associated with less-aggressive expansion in this slighter impairment. The sum of profile areas 3 to 8 in BCLPc is larger than the sum in UCLPc (1014 mm^2 versus 920 mm^2) but the same as in CP (1028 mm^2). As compared with study control subjects (1549 mm^2) and SDs of individual areas in BCLPc (43 to 61 mm^2), differences between individual cleft types are small.

Although the length of the dentoalveolar arch (up to the first molars) was decreased in the group with CP, most likely because of the missing teeth, in patients with UCLPc it corresponded to that of control subjects, possibly because of the remaining anterolateral distortion of the anterior part of the larger maxillary segment. Within the context of the lasting protrusion of the premaxilla, the length of the arch is greater in BCLPc, significantly so compared with CP but only insignificantly in comparison with UCLPc (Table 4). High variability in the palate form in BCLPc requires careful interpretation of mean values. However, the distribution of variables was normal, making the assessment of results possible if caution is exercised.

Missing teeth in 80% of the patients in our group were associated with therapeutic extractions and congenital agenesis and mostly involved lateral incisors (66%). Suzuki et al. (1992) found missing lateral incisors in BCLP patients (including incomplete) in 48% (26/54); however, more often the incisors were found in the maxilla (22 times) rather than in the premaxilla (5 times), in one case contralaterally on opposite sides of the cleft. Equally important, Ranta (1986) reported that most of the cleft-affected study subjects had upper lateral incisors on the distal side of the alveolar cleft. The difference in our ratio is attributable to extractions.

Missing teeth and predominantly small protrusion of the premaxilla could influence localization of transverse sections. Thus, their position presented in the description of the results serves an orientation role. In any case, the sections in all patients were at the same proportion of the overall palate length. Similarly, the differences in section locations between compared types of clefts were negligible in relation to the amount of change and similar palate length.

Our results characterize the described treatment protocol. Of the procedures used, primary periosteoplasty may influence the anterior width of the alveolar arch, and our subsequent study of submucous clefts shows that pushback compared with Furlow Z-plasty lowers palate height and that pharyngeal flap might displace the highest point of the palate anteriorly. The new protocol of BCLPc treatment in Prague includes lip suture at age 3 months (arched suture without periosteoplasty) and palate suture without pharyngeal flap surgery between the ages of 9 and 12 months. Relatively recently, lip suturing has come to be performed in newborns (Borský et al., 2007).

Abnormalities in palate formation and the dentoalveolar arch in facial clefts have serious functional consequences (speech, mastication, mode of breathing, swallowing, and Eustachian tube function) and esthetic consequences (maxillary retrusion, mandibular growth rotation and facial height, dentition appearance, and others). Despite this, until now virtually no attention has been paid to more accurate studies of palate size and morphology. This is without a doubt due to the difficulties associated with three-dimensional analyses. Besides our already-mentioned studies, studies by Kilpeläinen and Laine-Alava (1996) and by Kilpeläinen et al. (1996) found, by manual counting of moiré fringes, that after surgery the palate is shallow, narrow, and more asymmetrical, with the deepest point displaced posteriorly. We cannot confirm the latter finding. Those authors also reported decreased palate length in all types of clefts, except of the submucous variety. We can confirm this only in isolated cleft palate. Those authors, however, included all types of clefts, with patients from a wide age range 5 to 24 years. Okazaki et al. (1991), also using moiré, found in children with UCLPc at the age of 4 to 5 years a narrower, shorter, and shallower palate, especially in children with palatalized articulation. The results indicated the importance of palate size to the quality of speech. These findings were described in more detail in our previous study (Šmahel et al., 2003). Mishima et al. (2001) used a computer-controlled three-dimensional contact-measuring apparatus and recorded less change in palate surface in infants with incomplete, rather than complete UCLP, at the age of 1 to 18 months. Braumann et al. (2002) developed a new three-dimensional method of analysis of the edentulous maxilla and applied it in 10 infants with UCLPc. We have found no other three-dimensional studies of the size and configuration of the palate in facial clefts. Therefore, further investigations, especially in relation to impaired function and postnatal development, are highly desirable.

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