Intraoperative Vascular Anatomy, Arterial Blood Flow Velocity, and Microcirculation in Unilateral and Bilateral Cleft Lip Repair

Andreas A. Mueller, M.D., D.M.D.
Dieter Schumann, M.D., D.M.D.
Rajgopal R. Reddy, M.B.B.S., B.D.S.
Katja Schwenzer-Zimmerer, M.D., D.M.D.
Magdalena Mueller-Gerbl, M.D.
Hans-Florian Zeilhofer, M.D., D.M.D.
Hermann F. Sailer, M.D., D.M.D.
Srinivas Gosla Reddy, M.D., M.B.B.S., Ph.D.

Basel and Zurich, Switzerland; and Saidabad, Hyderabad, India

Background: Cleft lip repair aims to normalize the disturbed anatomy and function. The authors determined whether normalization of blood circulation is achieved.
Methods: The authors measured the microcirculatory flow, oxygen saturation, and hemoglobin level in the lip and nose of controls ($n = 22$) and in patients with unilateral and bilateral cleft lip–cleft palate. The authors measured these parameters before lip repair ($n = 29$ and $n = 11$, respectively), at the end of lip repair ($n = 27$ and 10, respectively), and in the late postoperative period ($n = 33$ and $n = 20$, respectively). The arterial flow velocity was measured in unilateral groups at the same time points ($n = 13$, $n = 11$, and $n = 12$, respectively). Statistical differences were determined using analysis of variance.
Results: Before surgery, the arterial flow velocities and microcirculation values were similar on each side of the face and between groups. The microcirculatory flow was significantly higher in the prolabium of bilateral patients than in the philtrum of controls. All circulation values in unilateral and bilateral patients in the late postoperative period were within the range of controls and of those before surgery. Intraoperatively, the authors consistently found a perforating artery on the superficial side of the transverse nasalis muscle.
Conclusions: There appears to be no intrinsic circulatory deficit in unilateral and bilateral cleft lip–cleft palate patients. The increased flow in the prolabium indicates a strong hemodynamic need in this territory, compelling its vascular preservation. Whether surgical preservation of the nasalis perforator artery is of long-term benefit should be addressed in future studies. (*Plast. Reconstr. Surg*. 130: 1120, 2012.)
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Cleft lip repair techniques differ mainly in the design of the skin incisions, how the muscle portions are reconstructed, and how the nasal framework is repositioned.[1] The vascular anatomy has remained largely unaddressed in current surgical techniques, and the reasons for this have yet to be explored.

Normal blood supply is a precondition for development and growth. Thus, it would be of clinical interest to determine whether cleft anatomy leads to a change in the blood supply before or after surgery.

Current techniques for cleft lip repair exclude surgical anastomosis of the lip artery. However, this clinical approach is not based on blood circulation data and so the current standard must be challenged. Vascular damage in cleft surgery interrupts the existent hemodynamics and necessitates further trauma to stop the bleeding, after which the blood circulation may take several months to recover.[2] Gentle surgical soft-tissue han-

From Craniomaxillofacial Surgery, University Hospital Basel; the Hightech Research Center of Craniomaxillofacial Surgery, University of Basel; the G. S. R. Institute of Craniomaxillofacial and Facial Plastic Surgery; the Anatomical Institute, Macroanatomy and Muskuloskeletal Anatomy, Laboratory for Functional Macromorphology; and Cleft-Children International CCI.
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dling with blood vessel preservation is perhaps one of the decisive factors for why long-term outcome is better if the cleft surgery is performed by experienced surgeons operating with "soft hands."[3,4]

Cadaver cleft lip studies provide timeless information on the vascular network but lack in vivo functional information.[5–9] To improve our understanding of the blood circulation in cleft lip, we assessed both the arterial vascular flow and the microcirculation before, at the end and late after cleft lip repair, and in a healthy control group. The results are discussed in relation to the vascular anatomy encountered during cleft lip surgery and in relation to the vascular anatomy of normal cadaver dissections.

PATIENTS AND METHODS

Ethical committees at the institutions of two of the authors (A.A.M. and S.G.R.) approved the study protocol. We included patients with unilateral or bilateral complete cleft lip–cleft palate. Those in the healthy control group had undergone various surgical procedures and had a healthy nose-lip anatomy. During the measurements, the patients were kept in the supine position and under general anesthesia. All patients were operated on by the same surgeon (R.R.R.) using a previously published surgical technique.[10] Before the skin incision, 1 ml of lidocaine (1%) with epinephrine (1:100,000) was injected submucosally and intramuscularly along the incision markings. Bipolar cautery was used to stop bleeding that was not stopped by compression (Force FX coagulation system; Valleylab, Boulder, Colo.). We measured the microcirculation in the following groups:

Controls (n = 22).
Unilateral cleft lip–cleft palate patients before lip repair (n = 29).
Unilateral cleft lip–cleft palate patients at the end of lip repair (n = 27).
Unilateral cleft lip–cleft palate patients in the late postoperative period (n = 33).
Bilateral cleft lip–cleft palate patients before lip repair (n = 11).
Bilateral cleft lip–cleft palate patients at the end of lip repair (n = 10).
Bilateral cleft lip–cleft palate patients in the late postoperative period (n = 20).

We measured the arterial vascular flow in the following groups:

Unilateral cleft lip–cleft palate patients before lip repair (n = 13).
Unilateral cleft lip–cleft palate patients at the end of lip repair (n = 11).
Unilateral cleft lip–cleft palate patients in the late postoperative period (n = 12).

We defined "late postoperative" as more than 6 months after lip repair. All patients measured at the end of lip repair had also been measured before surgery.

Microcirculation Flow, Oxygenation, and Hemoglobin

Peripheral tissue perfusion was assessed using the O2C-1212 measuring system (LEA Medizintechnik, Giessen, Germany).[11] This system combines white-light tissue spectrometry and laser Doppler flowmetry and makes the following measurements simultaneously:

1. The microcirculatory flow in vessels less than 100 μm in diameter, expressed in arbitrary units.
2. The postcapillary oxygenated hemoglobin, expressed as a percentage of the total hemoglobin.
3. The relative hemoglobin level in vessels less than 100 μm in diameter, expressed in arbitrary units.

We used an LSx-8c probe (LEA Medizintechnik) to obtain measurements on the columella; for all other points, we used an LF-2 probe (LEA Medizintechnik) (tip diameter, 4 and 12 mm, respectively). The approximate detection depths of the probes were 0.88 mm (LSx-8c) and 1.41 mm (LF-2). To avoid pressure-induced flow artifacts, we fixed the probes to the skin with double-sided adhesive tape (LTDT-001; LEA Medizintechnik).

To allow for comparisons between the groups, we set the measuring points on the keratinized skin at corresponding anatomical landmarks (Fig. 1): lateral lip, cupid, philtrum or prolabium, columella, and ala. In unilateral cleft lip–cleft palate patients, we classified the symmetrical points as cleft or noncleft side, whereas in bilateral cleft lip–cleft palate patients and controls we classified them as right and left side.

Arterial Flow Velocity

The arterial blood flow velocity was assessed using a continuous-wave Doppler device (EZ-Dop; Compumedics, Singen, Germany) using an 8-MHz probe with a tip diameter of 4 mm (HD.CW0800.06; MTB Medizintechnik Basler, Regensdorf, Switzerland). The probe angulation was chosen to maximize the signal, and the mean and maximum ve-

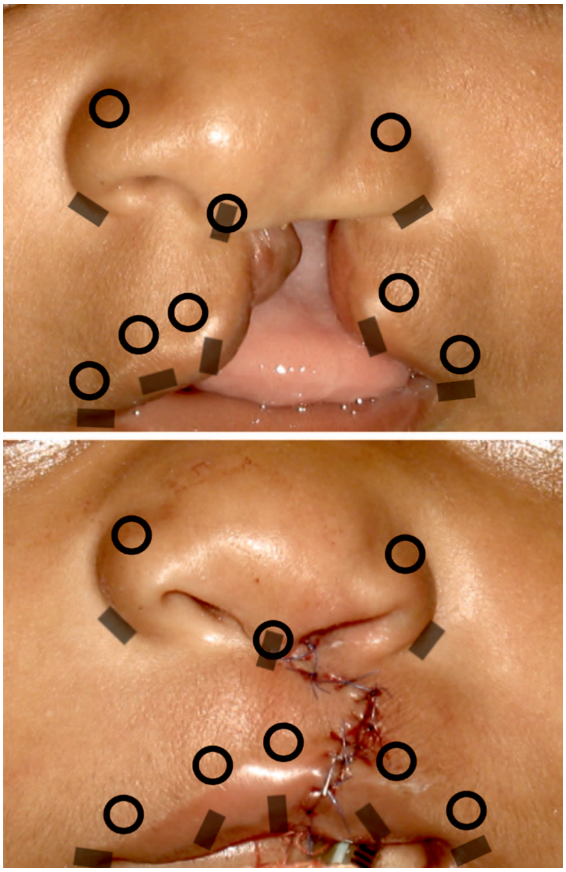

Fig. 1. Sites where the blood circulation was measured. At the points marked by *open circles*, we measured the microcirculatory flow, oxygen saturation, and hemoglobin levels with an optical probe through the keratinized skin. At the points marked by *filled rectangles*, we measured the flow velocity in the underlying artery with an 8-MHz sound Doppler device. Corresponding sites were measured before and after surgery in unilateral and bilateral cleft lips and in healthy controls.

locity (in centimeters per second) values were recorded.

We measured the blood flow velocity in the superior labial artery at the height of the labial commissure, cupid point, and labial tubercle. At the alar base and columella, we measured the blood flow velocity in the detected artery, regardless of the origin of its arterial main supply (Fig. 1).

Statistical Analysis

We performed a one-way analysis of variance of data from identical or symmetrical measuring points. We used the Tukey multiple-comparison test to detect differences between groups, and between cleft and noncleft sides.

Anatomical Dissections

The facial arterial network was dissected in 12 adult, formalin-fixed cadavers with the aid of a surgical microscope and microsurgical instruments (S&T, Neuhausen, Switzerland).

RESULTS

Arterial Blood Flow Velocity

No significant differences in vascular blood flow velocities were found at corresponding measuring points between the cleft and noncleft sides or between groups ($p = 0.05$, analysis of variance with the Tukey post hoc comparisons) (Table 1).

Microcirculatory Flow

The microcirculatory flow was significantly higher in the prolabium of bilateral cleft lip–cleft palate patients before lip repair than in the philtrum of unilateral cleft lip–cleft palate patients and controls. The microcirculatory flow was significantly lower at the end of lip repair than before lip repair at two points: in unilateral cleft lip–cleft palate patients at the noncleft side ala, and in bilateral cleft lip–cleft palate patients at the left ala. In addition, the microcirculatory flow at corresponding points was similar on the cleft and noncleft sides in unilateral cleft lip–cleft palate patients; bilateral cleft lip–cleft palate patients and controls; and before, after, and later after lip repair ($p = 0.05$, analysis of variance with Tukey post hoc comparisons) (Table 2).

Postcapillary Hemoglobin Oxygenation

The hemoglobin oxygen saturation in the cleft-side lateral lip in unilateral cleft lip–cleft palate patients was significantly lower at the end of lip repair than before lip repair. In addition, the microcirculatory oxygen saturation was similar on the cleft and noncleft sides in unilateral cleft lip–cleft palate patients; bilateral cleft lip–cleft palate patients and controls; and before, after, and later after lip repair ($p = 0.05$, analysis of variance with Tukey post hoc comparisons) (Table 3).

Microcirculatory Hemoglobin Level

The relative hemoglobin level in the columella was significantly lower before lip repair in unilateral cleft lip–cleft palate patients than in bilateral cleft lip–cleft palate patients and controls, whereas it was significantly higher in unilateral cleft lip–cleft palate patients at the end of lip repair than before lip repair or in the late postoperative period. Furthermore, the relative hemoglobin level in the late postoperative period was

Table 1. Arterial Blood Flow Velocity in Unilateral Complete Cleft Lip–Cleft Palate Patients*

	Before Lip Repair (n = 13)[1]		End of Lip Repair† (n = 11)[2]		Late Postoperatively (n = 12)[3]		
Measuring Point	Maximum	Mean	Maximum	Mean	Maximum	Mean	ANOVA of Mean Values
Superior labial artery							
Commissure							
Cleft side	304 (85)	118 $(48)_{a,b}$	113 (32)	39 $(13)_{a}$	242 (122)	84 $(56)_{a,b}$	$F_{5, 30} = 2.537$, $p < 0.05$
Noncleft side	193 (88)	79 $(35)_{a,b}$	192 (108)	94 $(59)_{a,b}$	296 (143)	129 $(55)_{b}$	
Cupid							
Cleft side	150 (107)	73 (63)	103 (63)	48 (24)	101 (41)	56 (37)	$F_{5, 46} = 1.689$, p = NS
Noncleft side	163 (65)	93 (51)	107 (48)	34 (18)	164 (98)	81 (53)	
Tuberculum	146 (51)	88 (33)	111 (50)	50 (36)	145 (74)	80 (53)	$F_{2, 23} = 1.792$, p = NS
Columella branch	138 (58)	67 (39)	90 (23)	21 (12)	122 (54)	66 (47)	$F_{2, 23} = 2.272$, p = NS
Lateral nasal artery							
Ala base							
Cleft side	166 (61)	75 (50)	136 (59)	57 (24)	92 (31)	35 (12)	$F_{5, 50} = 0.737$, p = NS
Noncleft side	128 (79)	54 (40)	156 (88)	72 (70)	65 (22)	21 (7)	

ANOVA, analysis of variance; NS, not significant.
*Data are mean (SD) values in centimeters per second. A continuous-wave Doppler device using an 8-MHz probe was used. Note: Within rows of symmetric or the same measuring points, means with different subscript letters (*a* and *b*) differ at $p < 0.05$, according to the Tukey multiple-comparisons test.
†Same individuals as measured before lip repair.
[1–3]Sample sex distribution and mean age (male/female, month, SD): [1](8/5, 13, 15), [2](6/5, 13, 16), [3](11/1, 16, 9).
[3]Months after lip repair (mean, SD): (8, 4).

similar on the cleft and noncleft sides in unilateral cleft lip–cleft palate patients, bilateral cleft lip–cleft palate patients and controls, and compared with before lip repair ($p = 0.05$, analysis of variance with Tukey post hoc comparisons) (Table 4).

Vascular Anatomy in Cadaver Dissections

The following findings were encountered consistently in the dissections. The thickness of the superior labial artery was asymmetric in most cases (Fig. 2, *above* and *below, right*). The dominant side connected to a branch to the labial tubercle and to at least two philtral branches (Fig. 2, *above* and *below, left*): a thick branch deep to the muscle and a thinner one superficial to it. The deep philtral branch ran around the lip muscle in front of the anterior nasal spine and connected to the columellar branch (Fig. 2, *above* and *below, left*), and the superficial philtral branch ramified to the caudal nasal septum (Fig. 2, *center, left*). The superior and inferior alar arteries connected either caudally to the superior labial artery (Fig. 2, *above*) or laterally to the facial artery (Fig. 2, *center, right*).

Vascular Anatomy in Cleft Lip Repair

On the noncleft side, we frequently encountered an artery of 1 to 2 mm in diameter in the submucosa of the lip band, running along the posterior side of the lip muscle (Fig. 3). During the subperiosteal approach to the caudal septal part, this artery was shifted laterally and preserved. On the cleft side, we encountered a submucosal lip artery more rarely.

On the cleft side, we consistently encountered an artery of 1- to 2-mm diameter in the subcutaneous plane of the hairy nostril skin—the artery perforated out of the inferior head of the transverse nasalis muscle (Fig. 4). The bleeding that occurred when the artery was accidentally cut always required coagulation. This artery was equally present in unilateral and bilateral cleft lip–cleft palate patients.

In the prolabium of bilateral cleft lip–cleft palate patients, we regularly encountered two arteries (Fig. 5) running on the right and left sides of the prolabium, being most superficial at the midway point between the columella–prolabial junction and the planned cupid points.

DISCUSSION

Circulation before Lip Repair

Before surgery, the arterial flow velocities and microcirculation values were symmetric on the cleft and noncleft sides, and in all cleft groups and controls. Despite the aberrant cleft vascular anatomy, a symmetric and normal blood supply was found. Cleft repair should aim to preserve this function.

Anatomical studies have demonstrated that the superior labial artery is thicker on the cleft side than on the noncleft side, and a fibrosis of the unoperated cleft muscles has been presumed.[5,12]

Table 2. Microcirculatory Flow in Unilateral and Bilateral Complete Cleft Lip–Cleft Palate Patients and Controls*

Measuring Point	Control (n = 22)[1]	Before Lip Repair: UCLP (n = 29)[2]	Before Lip Repair: BCLP (n = 11)[3]	End of Lip Repair†: UCLP (n = 27)[4]	End of Lip Repair†: BCLP (n = 10)[5]	Late Postoperatively: UCLP (n = 33)[6]	Late Postoperatively: BCLP (n = 20)[7]	ANOVA
Lateral lip								
Cleft side or left side	95 (33)$_{a,b,c,d}$	89 (35)$_{a,b,c,d}$	113 (59)$_{a,b,c,d}$	67 (69)$_{a,b}$	54 (52)$_{a,b,c}$	112 (77)$_{b,c,d}$	130 (99)$_{c,d}$	$F_{13,288} = 3.868$, $p < 0.001$
Noncleft side or right side	95 (51)$_{a,b,c,d}$	92 (60)$_{a,b,c,d}$	98 (58)$_{a,b,c,d}$	47 (35)$_{a}$	64 (35)$_{a,b,c,d}$	90 (58)$_{a,b,c,d}$	143 (80)$_{d}$	
Cupid								
Cleft side or left side	104 (43)$_{a,b,c,d}$	93 (68)$_{b,d}$	184 (81)$_{c}$	60 (54)$_{a,d}$	72 (47)$_{a,b,d}$	117 (76)$_{a,b,c,d}$	98 (70)$_{a,b,c,d}$	$F_{13,247} = 3.679$, $p < 0.001$
Noncleft side or right side	128 (52)$_{b,c}$	89 (58)$_{a,b,d}$	128 (40)$_{a,b,c}$,	62 (46)$_{a,d}$	75 (48)$_{a,b,d}$	111 (40)$_{a,b,c,d}$	108 (75)$_{a,b,c,d}$	
Philtrum/prolabium	119 (52)$_{a,b}$	116 (44)$_{a,b}$	216 (87)$_{d}$	78 (55)$_{b,c}$	172 (87)$_{a,b,d}$	120 (50)$_{a,b}$	169 (83)$_{a,d}$	$F_{6,125} = 6.596$, $p < 0.001$
Columella	122 (38)	119 (59)	130 (36)	95 (65)	129 (50)	122 (66)	119 (52)	$F_{6,145} = 1.148$, p = NS
Ala								
Cleft side or left side	104 (47)$_{a}$	98 (38)$_{a}$	88 (11)$_{ab}$	70 (29)$_{a,b}$	81 (68)$_{a,b}$	72 (39)$_{a,b}$	86 (55)$_{a,b}$	$F_{13,238} = 2.589$, $p < 0.01$
Noncleft side or right side	77 (24)$_{a,b}$	97 (43)$_{a}$	100 (44)$_{a,b}$	51 (21)$_{b}$	91 (23)$_{a,b}$	83 (45)$_{a,b}$	70 (38)$_{a,b}$	

UCLP, unilateral cleft lip–cleft palate; BCLP, bilateral cleft lip–cleft palate; ANOVA, analysis of variance; NS, not significant.

*Data are mean (SD) values in arbitrary units. The approximate optical measurement depth was 0.88 mm on the columella and 1.41 mm at all other points. Note: Within rows of symmetric or the same measuring points, means with different subscript letters (*a*, *b*, *c*, and *d*) differ at p< 0.05, according to the Tukey multiple-comparisons test.

†Same individuals as measured before lip repair.

[1–7]Sample sex distribution and mean age (male/female, month, SD): [1](15/7, 62, 36), [2](18/11, 9, 6), [3](9/2, 14, 20), [4](17/10, 9, 6), [5](8/2, 14, 21), [6](22/11, 46, 47), [7](14/6, 41, 36).

[6,7]Months after lip repair (mean, SD): [6](28, 33), [7](31, 33).

However, no corresponding circulatory discrepancies have been found, which emphasizes the need to complement morphologic descriptions with appropriate functional measurements.

Although the blood supply on the cleft and noncleft sides did not differ from controls, there was a difference in the midline blood supply. The prolabium of bilateral cleft lip–cleft palate patients had a significantly increased microcirculatory flow, and the columella of unilateral cleft lip–cleft palate patients had a significantly decreased hemoglobin level.

In a circulatory steady state, the hemoglobin level reflects the microvascular density in the tissue. The columella in unilateral cleft lip–cleft palate patients lacks the connection of an inferior alar artery on the cleft side and thus its hemodynamic force to the columella.[13,14] Because the hemodynamic force is a key stimulus for the development and maturation of the vascular bed, this might partially explain the decreased relative hemoglobin level in the unilateral cleft lip–cleft palate columella.

In the prolabium of bilateral cleft lip–cleft palate patients, we attribute the increased microcirculation flow to a strong hemodynamic need in this territory. The nutritive needs of the premaxilla might be not fully met by the posterior septal artery, thus requiring a complementary supply from the prolabium circulation.[8]

Circulation at the End of Lip Repair

The microcirculation flow in the prolabium of bilateral cleft lip–cleft palate patients remained higher than in controls and unilateral cleft lip–cleft palate patients, both directly at the end of lip repair and in the late postoperative period. We attribute this to the intraoperative vessel preservation in the prolabium (Fig. 5). The surgical repair in bilateral cleft lip–cleft palate did not reduce the high microcirculation flow in the prolabium, and thus we assume that the microcirculatory requirements were maintained.

A venous stasis in the microcirculation can be detected by an increase in hemoglobin level together with a decrease in flow. We encountered this at the end of lip repair in the columella of unilateral cleft lip–cleft palate patients. The venous drainage through the columella runs in normal anatomy to the philtral plexus and to the septal mucosa plexus.[15,16] Thus, release of the caudal septum and the medial rotational incision might have interfered tempo-

Table 3. Postcapillary Hemoglobin Oxygenation in Unilateral and Bilateral Complete Cleft Lip–Cleft Palate Patients and Controls*

		Before Lip Repair		End of Lip Repair†		Late Postoperatively		
Measuring Point	**Control (n = 22)[1]**	**UCLP (n = 29)[2]**	**BCLP (n = 11)[3]**	**UCLP (n = 27)[4]**	**BCLP (n = 10)[5]**	**UCLP (n = 33)[6]**	**BCLP (n = 20)[7]**	**ANOVA**
Lateral lip								
Cleft side, left	67 (11)$_{a,c}$	59 (11)$_{a,c}$	61 (9)$_{a,b,c}$	48 (21)$_{b}$	53 (22)$_{b,c}$	66 (17)$_{a,c}$	65 (14)$_{a,c}$	$F_{13,288} = 6.777$, $p < 0.001$
Noncleft side, right	66 (16)$_{a,c}$	54 (12)$_{b,c}$	56 (6)$_{a,b,c}$	44 (15)$_{b}$	39 (23)$_{b}$	63 (17)$_{a,c}$	68 (12)$_{a,c}$	
Cupid								
Cleft side, left	54 (18)$_{a,b}$	54 (14)$_{a,b}$	71 (12)$_{a}$	50 (22)$_{a,b}$	58 (18)$_{a,b}$	63 (15)$_{a,b}$	65 (16)$_{a,b}$	$F_{13,245} = 2.845$, $p < 0.001$
Noncleft side, right	62 (12)$_{a,b}$	47 (12)$_{b}$	63 (10)$_{a,b}$	48 (25)$_{a,b}$	57 (24)$_{a,b}$	57 (12)$_{a,b}$	62 (14)$_{a,b}$	
Philtrum/prolabium	63 (12)	56 (15)	61 (20)	52 (21)	69 (18)	61 (13)	60 (15)	$F_{6,125} = 1.176$, p = NS
Columella	44 (12)$_{a,b}$	43 (20)$_{a,b}$	51 (14)$_{a,b}$	43 (19)$_{a,b}$	65 (22)$_{a}$	41 (17)$_{b}$	45 (13)$_{a,b}$	$F_{6,142} = 2.101$, p = NS
Ala								
Cleft side, left	56 (15)	53 (13)	62 (9)	50 (17)	42 (11)	47 (15)	51 (15)	$F_{13,237} = 1.111$, p = NS
Noncleft side, right	51 (14)	50 (14)	55 (10)	46 (20)	51 (17)	47 (17)	52 (16)	

UCLP, unilateral cleft lip–cleft palate; BCLP, bilateral cleft lip–cleft palate; ANOVA, analysis of variance; NS, not significant.
*Data are mean (SD) values expressed as a percentage of the total hemoglobin. The approximate optical measurement depth was 0.88 mm on the columella and 1.41 mm at all other points. Note: Within rows of symmetric or the same measuring points, means with different subscript letters (a, b, and c) differ at $p < 0.05$, according to the Tukey multiple-comparisons test.
†Same individuals as measured before lip repair.
[1–7]Sample sex distribution and mean age (male/female, month, SD): [1](15/7, 62, 36), [2](18/11, 9, 6), [3](9/2, 14, 20), [4](17/10, 9, 6), [5](8/2, 14, 21), [6](22/11, 46, 47), [7](14/6, 41, 36).

Table 4. Microcirculatory Hemoglobin Level in Unilateral and Bilateral Complete Cleft Lip–Cleft Palate Patients and Controls*

		Before Lip Repair		End of Lip Repair†		Late Postoperatively		
Measuring Point	**Control (n = 22)[1]**	**UCLP (n = 29)[2]**	**BCLP (n = 11)[3]**	**UCLP (n = 27)[4]**	**BCLP (n = 10)[5]**	**UCLP (n = 33)[6]**	**BCLP (n = 20)[7]**	**ANOVA**
Lateral lip,								
Cleft side, left	76 (4)$_{d}$	74 (6)$_{b,c,d}$	72 (9)$_{a,b,c,d}$	72 (8)$_{a,b,c,d}$	66 (10)$_{a}$	76 (8)$_{d}$	78 (6)$_{d}$	$F_{13,\ 288} = 5.748$, $p < 0.001$
Noncleft side, right	77 (5)$_{d}$	72 (6)$_{a,b,c,d}$	71 (6)$_{a,b,c,d}$	69 (5)$_{a,b,c}$	68 (8)$_{a,b}$	75 (7)$_{c,d}$	79 (5)$_{d}$	
Cupid								
Cleft side, left	75 (6)	72 (6)	77 (4)	77 (8)	73 (7)	75 (9)	76 (5)	$F_{13,\ 247} = 1.299$, p = NS
Noncleft side, right	77 (6)	73 (8)	71 (9)	72 (10)	76 (8)	75 (6)	75 (7)	
Philtrum/prolabium	77 (6)$_{a,b}$	73 (8)$_{a}$	78 (9)$_{a,b}$	74 (11)$_{a}$	86 (9)$_{b}$	76 (7)$_{a,b}$	77 (5)$_{a,b}$	$F_{6,\ 125} = 2.510$, $p < 0.05$
Columella	58 (8)$_{a,b}$	51 (7)$_{c}$	61 (8)$_{a,b}$	60 (9)$_{a}$	62 (9)$_{a,b}$	53 (9)$_{b,c}$	57 (7)$_{a,b,c}$	$F_{6,\ 144} = 5.006$, $p < 0.001$
Ala								
Cleft side, left	75 (5)	71 (7)	72 (4)	73 (7)	67 (5)	73 (6)	75 (4)	$F_{13,\ 238} = 1.592$, p = NS
Noncleft side, right	74 (5)	71 (7)	71 (9)	69 (6)	72 (4)	73 (6)	73 (6)	

UCLP, unilateral cleft lip–cleft palate; BCLP, bilateral cleft lip–cleft palate; ANOVA, analysis of variance; NS, not significant.
*Data are mean (SD) values in arbitrary units. The approximate optical measurement depth was 0.88 mm on the columella and 1.41 mm at all other points. Note: Within rows of symmetric or the same measuring points, means with different subscript letters (a, b, c, and d) differ at $p < 0.05$, according to the Tukey multiple-comparisons test.
†Same individuals as measured before lip repair.
[1–7]Sample sex distribution and mean age (male/female, month, SD): [1](15/7, 62, 36), [2](18/11, 9, 6), [3](9/2, 14, 20), [4](17/10, 9, 6), [5](8/2, 14, 21), [6](22/11, 46, 47), [7](14/6, 41, 36).

rarily with the venous drainage—even though the medial rotation incision did not cross the midline. A sharp downturned back-cut was performed as necessary in the midline to allow for rotation (Fig. 4, *above, left*).

The blood circulation at the end of lip repair is influenced by multiple factors, including surgically induced vasodilatation, vascular coagulation, change in tissue tension, and systemic hemodynamic conditions. Thus, assumptions about cause-and-effect relationships must be made with caution. However, the cumulative effect of these factors appears to have led to an arterial blood flow velocity and microvascular

Fig. 2. Characteristics of the normal vascular anatomy. The superior labial artery (*SLA*) is dominant on one side (*solid arrow*) (*above* and *below, right*). The superficial (*dashed arrow*) and deep (*solid arrowhead*) philtral artery, and the labial tubercle branch (*pound sign*) are mainly supplied by the dominant side (*above* and *below, right*). The deep philtral artery runs posteriorly to the labial muscle (*asterisk*) and connects to the columellar artery (*open triangle*), and the superficial philtral artery ramifies (*open arrowhead*) to the caudal nasal septum (*above* and *center, left* and *below, left*). The arterial trunk of the ala and inferior alar artery (*IAA*) connects either caudally to the superior labial artery (*above*, both sides of the cadaver) or laterally to the facial artery (*FA*) (*center, right*, cadaver's right side). Scale increments indicate millimeters. *FV*, facial vein.

flow in the lip and philtrum at the end of surgery that did not differ from the corresponding preoperative data. It is thus understandable that the evolution from staged to synchronous bilateral cleft lip repair proceeded without healing problems.

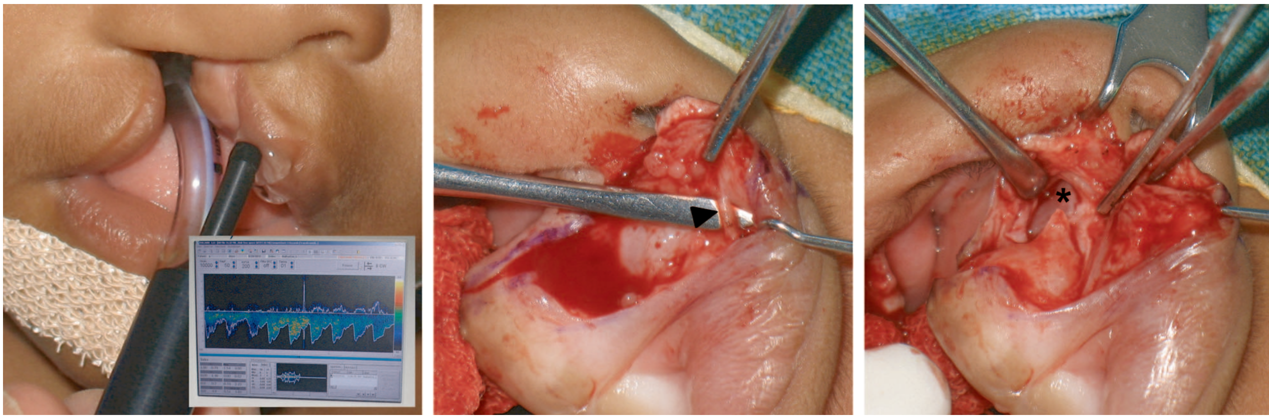

Fig. 3. Superior labial artery on the noncleft side. (*Left*) Frequently, the artery proceeds to the labial tubercle and can be localized before surgery by its strong Doppler signal. (*Center*) During surgery, the artery (*arrowhead*) is encountered in the submucosa of the lip band and frequently can be preserved. (*Right*) The caudal septum (*asterisk*) is approached from the cleft side and does not interfere with the artery.

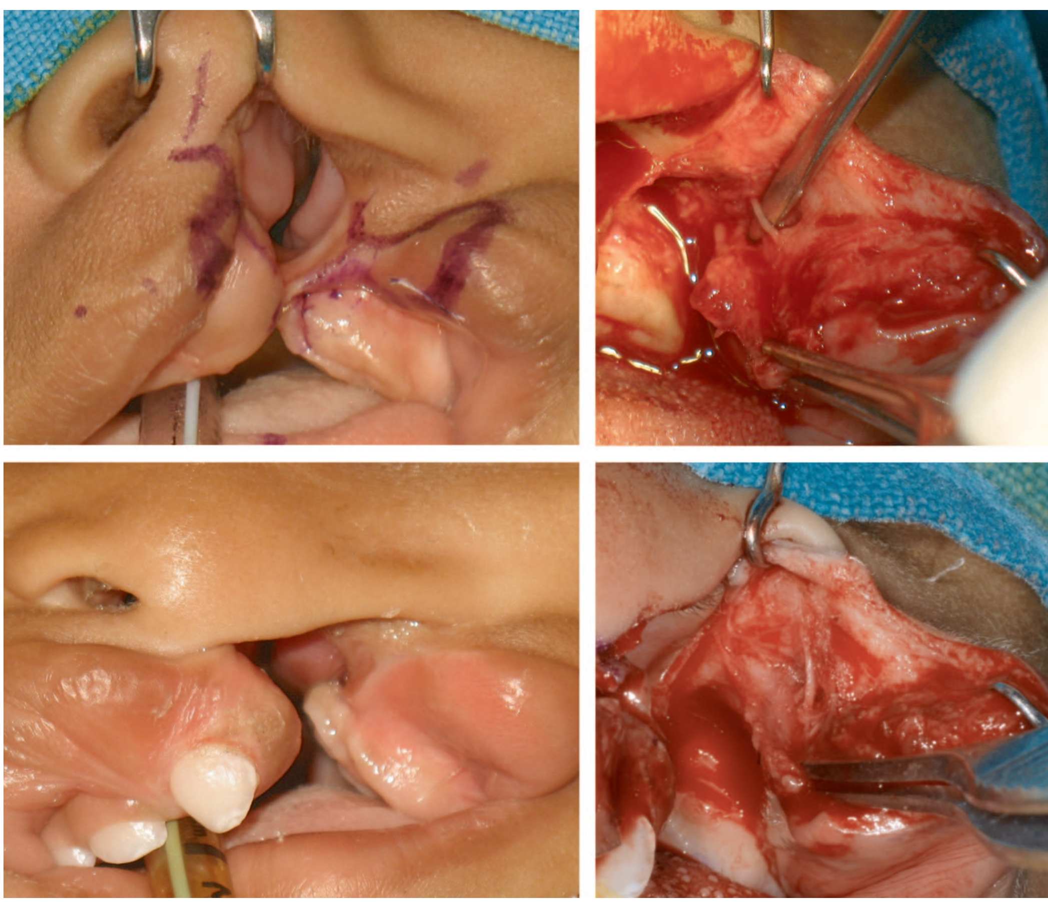

Fig. 4. The perforating artery of the transverse nasalis muscle on the cleft side in two patients before surgery and intraoperatively. In the subcutaneous plane of the hairy nostril skin (*left*), a 1- to 2-mm-thick artery is consistently found during dissection of the transverse nasalis muscle, which is held in the forceps (*right*). The localization and course of this artery are constant, which makes its surgical preservation easier.

Circulation in the Late Postoperative Period and in Normal Controls

In the late postoperative period, the arterial blood flow velocity and microcirculation in unilateral and bilateral cleft lip–cleft palate patients were the same as in controls and the same as before surgery. We conclude that cleft lip repair without a surgical anastomosis of the lip artery

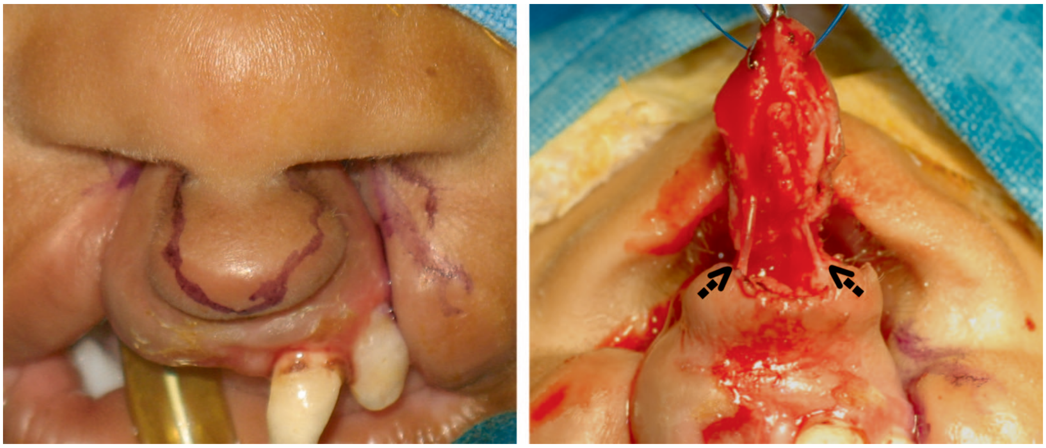

Fig. 5. The prolabium arteries. (*Left*) In the middle of the prolabium, between the columella base and the planned cupid points, a pair of prolabium arteries (*arrow*) is frequently observed running subcutaneously. (*Right*) While dissecting the prolabium from distal to proximal under constant tension, these arteries can be identified and preserved independently of the skin incision design.

allowed for normal circulatory development. This is consistent with the blood supply observed in normal faces, wherein the circulation is balanced on each side of the face independently and does not rely on a superior labial artery anastomosis.[17–20] The microcirculation measurement depth of 1.41 mm corresponds to the deep reticular network of the skin. This network is fed by collaterals of the superior labial artery and is therefore related to the circulation in the lip muscle.[21,22]

Hemodynamic forces are key elements for the remodeling of the vascular network after acute arterial occlusion. In arteriogenesis, shear stress induces the recruitment of arteriolar collaterals, which in turn differentiate into new arteries.[23,24] The circulation was completely restored after carotid ligation in growing animals, but there was a reduction in facial muscle weight.[25] Thus, the recovery of blood circulation observed in the present study may not represent the recovery of growth potential.

Intraoperative Arteries

The cleft interrupts the normal course of the superior labial artery. Published schematic illustrations show that the superior labial artery on the cleft side runs to the alar base and joins the facial artery.[6,26,27] Conversely, photographs of arteriograms[5,28,29] and illustrations derived therefrom[9,30] show a superior labial artery that thins out at the inner side of the cleft nostril, whereas the superior alar branches connect laterally to the facial artery. Our intraoperative findings concur well with the arteriographic pattern.

We consistently found an arterial branch at the inner side of the cleft nostril. The artery emerged on top of the dissected transverse nasalis muscle and was easily preserved after its course had been estimated. We speculate that preserving this artery weakens postoperative cleft nostril contraction.

The facial vascular pattern does not develop as a stepwise branching from proximal to distal. Rather, preferred routes in a territory are formed consequent to its hemodynamic need and are connected to supplying trunks from distal to proximal. The cleft might reduce the available options for alar connections to supplying trunks, which leads to a more uniform vascular pattern on the cleft side. This might explain why we consistently found an artery on the inner side of the cleft nostril.

Summary and Clinical Interpretation

We studied the arterial flow velocity and microcirculation in cleft lip. Contrary to the asymmetric vascular anatomy in cleft lips, we found no functional asymmetry. Our results support the current standard of cleft-lip repair that does not involve surgical anastomosis of the lip artery.

Although the blood circulation did not differ from that of controls in the late postoperative period, we cannot assume that vascular function was normal in all aspects, especially with regard to its ability to support growth potential. We therefore advocate strict vascular preservation in cleft surgery. The complex relationship between vascular anatomy and physiology necessitates further in vivo circulatory measurements to assess the optimal blood circulation for cleft surgery.

The surgical vascular anatomy exhibited a high degree of uniformity, which simplifies its consideration in current cleft surgical techniques. This finding has been confirmed for the paramedian prolabial arteries and the transverse nasalis perforating artery.

CONCLUSIONS

The blood circulation in unilateral and bilateral cleft lip–cleft palate patients remains balanced before and after surgery and is comparable to the normal situation, with no sign of an intrinsic circulatory deficit or a need for surgical arterial anastomosis. The increased flow in the prolabium of bilateral cleft lip–cleft palate patients indicates a strong hemodynamic need in this territory, compelling its vascular preservation. We consistently found a perforating artery on the superficial side of the transverse nasalis muscle. Whether or not the surgical preservation of this artery has any long-term benefit should be addressed in future studies.

Andreas A. Mueller, M.D., D.M.D.
Craniomaxillofacial Surgery
University Hospital Basel
Spitalstrasse 21
4031 Basel, Switzerland
anmueller@uhbs.ch

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