Integrated Vascular Architecture of the Hard Palate and Musculovascular Organization of the Upper Lip: Surgical Relevance in Cleft Reconstruction

Ph.D. Thesis

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1. Introduction

Accurate wound healing is fundamental to the success of surgical interventions, particularly in the aesthetic region of the face, where primary wound healing via optimal angiogenesis is essential to minimize complications such as haemorrhage, infections, necrosis and excessive scarring. In cleft repair, multiple staged interventions are often required at different times, which may interfere with maxillary growth and long-term functional development. Potential long-term complications include secondary deformities or dehiscence of the lip and nose, palatal fistula formation, necrosis and auditory dysfunction.

The orofacial region receives its blood supply primarily from branches of the facial- (FA) and maxillary artery, both branches of the external carotid artery (ECA). This follows the embryological transition from the internal carotid to the external carotid system and development of the first and second pharyngeal arch. This transition in vascularization may determine the dominance of specific vessels, subsequent musculoskeletal development and hence prominence fusion. In cleft malformations, normal development is hindered and therefore vascularization may further be disrupted and suggests limited collateral vascularization. The superior labial artery (SLA), a highly variable branch of the FA plays a dominant role in vascular upper lip perfusion. It courses beneath or within the fibres of the orbicularis oris muscle (OOM), giving rise to ascending branches lateral to the philtrum and septal branches supplying the nasal septum through deep and a superficial plane. Additional, vascular contributions arise from the infraorbital artery (IOA) and branches of the ophthalmic artery to supply the nostrils and nasal septum. The upper lip is primarily composed of the OOM, which unites with the lower lip at the oral commissure and functions in coordination with the levator labii superioris (LLSM), levator labii superioris alaeque nasi (LLSANM), risorius, zygomatic, depressor anguli oris, levator anguli oris, nasalis and buccinator muscles to regulate facial expressions and oral competence. At the level of the apex of the upper lateral incisor of the anterior maxilla lies the myrtiform fossa, which serves as the origin of several nasolabial muscles, that have historically been described using different terminologies. From an embryologic perspective, cleft lip and alveolus result from failed fusion of the maxillary and nasal prominences, also impacting the osseous morphology of the myrtiform fossa, leading to impaired premaxillary growth, due to abnormal tooth eruption, tongue pressure, deviated muscle vectors and occlusal forces. The nasolabial muscles exhibit displaced insertions in cleft lip patients, affecting the planar arrangement of the anatomical subunits of the lateral cleft margins, including the cheek, nasal sill and nostril.

The hard palate is formed by the premaxilla, the palatine process of the maxillary bone and the horizontal plates of the palatine bones, which contain the greater and lesser palatine foramina. In the midline of the palate runs the palatine raphe, which is limited within the premaxilla by the nasopalatine foramen and its canal. The nasopalatine artery (NPA), the terminal branch of the sphenopalatine artery (SPA) traverses the nasopalatine canal to supply the anterior palate. Posteriorly, the descending palatine artery divides into the greater palatine (GPA) and lesser palatine (LPA) arteries as it enters or courses within the greater palatine canal. After emerging through the greater palatine foramen, the GPA courses anteriorly within the lateral palatine groove to anastomose with the NPA. Although detailed knowledge of anatomy is critical for surgical safety, musculovascular patterns may deviate in cleft malformations, necessitating awareness of collateral pathways.

Consequently, ex vivo techniques have become essential for comprehensively mapping musculovascular relationships in both soft and hard tissues, thereby facilitating improved surgical planning and reconstruction.

2. Objectives

The aim of this PhD dissertation is to characterize the extra- and intraosseous vascular anastomoses of the hard palate and the nasolabial region, and to translate these anatomical findings into clinically relevant recommendations for incision and flap design in cleft repair. Although cleft surgery has a long-standing history with numerous established techniques, the detailed vascular anatomy of the hard palate and the musculovascular morphology of the myrtiform area in cleft individuals remains incompletely understood.

This dissertation addresses two primary research questions:

(1) How are the intra- and extraosseous vascular anastomoses of the hard palate organized, and how can incision and flap design be optimized to preserve these collateral pathways in patients with cleft palate?

(2) How does the arrangement of nasolabial musculature and its associated vascular supply influence surgical strategies in cleft lip-nose repair?

By integrating detailed anatomical insights with clinical considerations, our research aimed to optimize surgical maneuver to improve functional and aesthetic outcomes and reduce complications during and after cleft surgery.

3. Material and Methods

The research presented in this dissertation is based on human cadaveric studies conducted entirely at the Department of Anatomy, Histology and Embryology of Semmelweis University, Budapest, Hungary and correlated with clinical observations through interdisciplinary collaboration with international surgeons. The specimens were prepared and dissected using various anatomical embalming and injection techniques to analyze vascular and muscular patterns in cleft-related regions of the hard palate and upper lip.

- In the first study, intraosseous vascular pathways of the palate were analyzed in 11 adult cadaver heads (7 males, 4 females; aged 50–85 years) using the corrosion casting technique, is based on two successive processes to visualize the acrylic resin injected arteries in relation to the bone in fresh specimens.
- In the second study, the collateral vascularization of the hard palate was investigated in 12 adult cadaver heads (7 males, 5 females; aged 55–90 years) and one aborted fetus (26 weeks of intrauterine age) presenting with a unilateral complete cleft of the hard and soft palate. The adult specimens were processed using the corrosion casting technique, while the cleft fetus was embalmed in formaldehyde and injected with a white-colored barium sulfate agent.
- In the third study, the musculovascular anatomy of the nasolabial region was investigated in 21 adult specimens (11 males, 10 females; mean age 73 years) and 3 aborted fetuses (18, 20, and 24 weeks of intrauterine age). This study analyzed the vascular supply and muscular structures of the upper lip, philtrum, and nostril regions. The adult specimens were embalmed using formaldehyde (7 specimens), Thiel solution (10 specimens), or prepared using the corrosion casting technique (4 specimens). In the Thiel-embalmed specimens, arteries were injected with latex milk, whereas in the unfixed specimens corrosion casting was used. The fetal specimens were embalmed in a formaldehyde solution.

4. Results

Hard palate and alveolar arterial architecture and collateral circulation patterns in normal palate

The course of different extra- and intraosseous arterial pathways was identified using the corrosion casting technique in normal adult specimens. In addition to the primary supply provided by GPA-LPA-NPA, a complex vascular network was observed, suggesting the presence of collateral circulation capable of compensating in cases of vascular compromise.

Extraosseous vascularization:

- In the posterior portion of the palate between the maxillary tuberosity and the pterygoid hamulus, the GPA, LPA and maxillary artery formed a complex retrotuberal vascular network.

Intraosseous vascularization:

Following dissolution of the bone, intraosseous anastomoses between multiple arteries were identified at the level of the alveolar ridges, hard palate, and intermaxillary suture, particularly within the region of the anterior nasal spine. This anastomotic network established collateral communication with various vascular territories, especially the premaxilla, vestibular aspect, and nasal cavity:

- Intraosseous anastomoses were formed between branches of the bilateral IOAs, which connected with the NPA and GPA in the premaxilla.
- Vertico-oblique intraosseous anastomoses between branches of posterior superior alveolar artery (PSAA)/IOA and the GPA revealed after maceration of the anterolateral maxillary wall and alveolar crest.
- Horizontal bony perforating anastomoses (transverse loop): transverse connections between GPA branches and PSAA/IOA branches located in the interdental septum and alveolar crest. Arterial perfusion exhibited a palatal-to-buccal directionality. Around the alveolar socket, intraseptal branches of this loop formed a vascular network, which were also observed in various dental status.

- In the middle portion of the median palatine suture, a larger penetrating artery is formed by the anastomosis of the bilateral GPAs.
- The anterior and middle portion of the palate, mainly at the height of the premolar area, is perforated by branches of the GPA. These branches traversed the palatine process of the maxilla and anastomosed with the posterior septal nasal branches (branches of the SPA) at the floor of the nasal cavity. The alveolar ridge territory is mainly supplied by intraosseous branches of the IOA.

Vascular architecture in the unilateral cleft palate

In the fetal specimen, the GPA was enlarged and orientated more laterally. The extraosseous vessels were described according to their anastomosing patterns into a medial cleft zone and a lateral non-cleft zone related to the position of the GPA. The following observations were made:

- In the cleft zone, the bilateral GPA anastomoses and, hence, palatal perforating and penetrating arteries were absent due to the cleft appearance. However, the GPA and its branches followed the non-cleft anatomy until the cleft edges limited them. The vessels did not follow the cleft borders but ran perpendicular to them.
- In the non-cleft zone, the branches of GPA were enlarged and anastomosed with subbranches of the FA/IOA in the anterior aspect of the palate. These anastomoses were found over the alveolar ridge. One GPA branch crossed the alveolar ridge in the anterior portion of the palate. The musculature of the soft palate attached from an anterolateral direction to the left GPA on the hard palate.

Upper lip musculovascular architecture influencing cleft lip-nose repair

The myrtiform fossa was the origin of several muscles influencing nasolabial muscle vectors in the superficial and deep plane. In the superficial plane three muscles were identified such as the LLSM, the LLSANM, and the incisivus labii superioris muscle (ILSM) which integrates into the OOM. No direct attachments to the lateral crus were identified from the aforementioned muscles; instead, connections were observed primarily through dense connective tissue extending into the deeper plane.

In the deep plane of the myrtiform fossa, LLSM and LLSANM showed continuity by sending fibres to the deep muscles, again three muscles were observed from medial to lateral: the depressor septi nasi (DSNM), the myrtiformis (MM), and the nasalis (NM) muscles with alar (ANM) and transverse (TNM) part. All three originated with periosteal attachments from the myrtiform fossa, ranging between the apical regions of the upper canine and first incisor. Together we labelled these muscles as the myrtiform muscular system (MMS), because of their intricate and interdependent functionalities, reflecting their cooperative dynamics within the nasolabial region. The TNM followed the contour of the nose and was inserted into the dorsum of the nose. The ANM connected to the lateral surface of the lateral alar crus and its fibrofatty tissue. The DSNM maintained a consistent anchorage to the cartilaginous nasal septum and the nasal tip from an inferior direction.

The MMS showed two different patterns, based on the presence of the MM. A W-shaped pattern was observed in 69.2% and a V-shaped pattern was observed in 30.8%. The W-pattern was formed laterally by the NM, centrally by the fibres of the MM, and medially by the DSNM. The MM originated either from the myrtiform fossa or from the base of the DSNM. Based on the cranial attachment of the MM, three distinct W-patterns were identified, each oriented toward the alar base, the nasal sill or both:

- Type Wa (55.5%): The MM attaches to the alar base.
- Type Wb (33.3%): The MM attaches to the nasal sill.
- Type Wc (11.1%): The MM splits into two heads, attaching to both the alar base and the nasal sill.

The V-pattern appeared when the MM was absent and was formed by the NM and DSNM, positioned laterally and medially, respectively, and replaced the absent MM. Either muscle could become dominant, though both were more developed in V-patterns compared to their appearances in W-patterns.

The vascularization of the alar base, the nasal sill and the nasal septum was provided by branches of the FA, SLA, IOA, and dorsal nasal artery (DNA) with variable contributions.

The extent of these contributions largely depended on the morphology and dominance of the SLA. A unilateral dominance was observed in 85% of cases with a tendency toward for right-sided SLA dominance (right/left = 60/40). The dominant side provided arterial supply not only to the ipsilateral-, but also to the contralateral lip, philtrum, and parts of the nostril area based on four subtypes:

- In type A (35.7%), the ipsilateral nostril region—including the ala and base, nasal sill, and septum—was supplied by the FAs and SLAs. The superior part of the ala received branches of the lateral nasal branch of the FA, while the subalar branch (SAB), arising directly from the FA, supplied the inferior part of the ala in the superficial plane. SLA sub-branches were identified in the deep plane. Although the SLA showed no dominant supply pattern, the philtral and septal branches (PSB) of SLA showed a unilateral dominancy and contributed to the supply of the contralateral nasal septum.
- In type B (35.7%), a pronounced asymmetry with a unilateral dominant SLA. The dominant SLA supplied the ipsilateral nostril as well as the contralateral nasal septum. In this type the SAB originated from the SLA and SLA sub-branches to the contralateral nasal sill and alar base were observed. On the weak SLA side, the ala and the nasal sill were instead supplied by branches of the FA.

- In type C (21.4%), the asymmetry of the SLA was even more pronounced. On one side the FA/SLA was only rudimentary and did not contribute to the vascularization of the ala and nostril area. In contrast, the contralateral FA/SLA was dominant and followed the distribution patterns described in type A or type B. This dominant FA/SLA side supplied the contralateral nasal septum and nasal sill and additionally gave branches to the alar base. In two specimens, the dominant SLA ended as the contralateral angular artery. On the side where the FA/SLA was only rudimentary built, the IOA acted as a compensatory role, providing a more substantial contribution to the vascular supply of the region. As a result, the supply of the deep portion of the alar base relied on the IOA. The IOA branches coursed from deep to superficial muscular planes, while FA branches penetrated from superficial to deep muscular planes and created several anastomoses. The pathways of these two vascular entities created multiple compensatory anastomoses.
- In type D (7%), the IOA and DNA (branch of the ophtalmic artery) supplied the ala on the weak SLA/FA side. Notably, both the IOA and DNA gave rise to lateral nasal branches which coursed through dense connective tissue to reach the internal aspect of the piriform aperture. SABs were derived predominantly from the IOA. The contralateral arterial distribution was consistent with the patterns described in previous types A–C.

Our findings revealed that the SABs of the FA were distributed superficially to the LLSANM, whereas the SLA coursed under the OOM and gave rise to several deep and superficial vertical and oblique PSBs. The deep branches pierced the OOM to reach the nostril surface. Constantly superficial and deep branches continued through the columella to the nasal tip. At this point they anastomosed with lateral nasal branches of the FA, the DNA and IOA branches, forming a dense vascular network around the nostrils.

Meanwhile, IOA branches coursed in a predictable manner under the LLSANM and superficial to the NM. The main IOA branch followed a medial path and the terminal artery perforated at the medial border of the LLSANM emerging to the surface and then accompanying the DSNM en route to the nasal septum. In multiple specimens, numerous IOA branches were observed to perforate the LLSANM, NM, or the MM before running on top of the periosteum.

Inside the floor of the nasal sill, two vascular arcades were detected. A superior arcade was composed by branches of either the FA or IOA, which followed the nostril rim from lateral to medial. The branches were situated superficially to the periosteum at the level of the piriform aperture and coursed deeply from the lateral alar cartilage to the medial cartilaginous septum. The inferior arcade, however, was mainly built by SLA branches. In specimens where the SLA was rudimentary, this inferior arcade exhibited variabilities in its configuration or was absent. In addition, a dense band of connective tissue was observed linking the lateral nasal cartilages to the internal bone surface of the piriform aperture. This band was situated in the deepest layer of the lateral nostril and was supplied by mainly branches of the FA or IOA, depending on the above occurring type.

5. Conclusions

Successful cleft surgery is fundamentally dependent on precise morphological understanding to achieve optimal functional and aesthetic outcomes while minimizing complications. Various intra- and extraosseous collateral networks were identified in normal adult palates. However, in the hard palate cleft fetus, the GPA appeared enlarged and laterally displaced, forming alternative anastomotic patterns. The findings indicated that, although vascular continuity was reduced within the cleft zone, arterial configurations in the non-cleft regions largely preserved normal circulation, with maintained anastomotic networks. In contrast, the reduced microcirculation within the cleft area underscored the critical importance of preserving existing vascular pathways—particularly in the regions of the incisive canal, alveolar ridges, and retrotuberal area—to ensure adequate perfusion.

In the myrtiform study, the MMS demonstrated a W- or V-shaped configuration with considerable vascular variability, characterized by unilateral dominance of the SLA and compensatory supply from adjacent arterial systems. Vascular mapping further identified four distinct patterns (types A–D). Intraoperative observations revealed that, although muscular attachments resembled normal anatomy, cleft-related displacement led to distortion of muscular vector orientation. These findings clarified the musculovascular morphology in relation to the surgical intervention and demonstrated that restoration of a natural alar-facial groove in cleft lip-nose repair could be achieved by detaching and repositioning the origin of the MMS, hence correcting cleft-induced muscular vector distortion while omitting extensive dissection.

Overall, these results highlight the importance of adapting surgical techniques to the underlying vascular and muscular anatomy. Preservation of critical anastomotic pathways and careful consideration of muscle vector orientation are essential for maintaining tissue perfusion, thereby enhancing wound healing and reducing complications in cleft repair.

6. Bibliography of the candidate's publications

1) Shahbazi A, Sculean A, Baksa G, **Gschwindt S**, Molnár B, Vág J, Bogdán S. Intraosseous arterial alteration of maxilla influencing implant-related surgeries. Clin Oral Investig. 2023;27(9):5217-5221.
   (Journal: Clinical Oral Investigations; Rank: D1; Impact factor: 3,1)

2) Shahbazi A, Mueller AA, Mezey S, **Gschwindt S**, Kiss T, Baksa G, Kisnisci RS. Is the collateral circulation pattern in the hard palate affected by cleft deformity? Clin Oral Investig. 2024;28(5):277.
   (Journal: Clinical Oral Investigations; Rank: D1; Impact factor: 3,1)

3) **Gschwindt S**, Mueller AA, Benitez BK, Baksa G, Kisnisci RS, Chong DK, Shahbazi A. Musculovascular pattern in the myrtiform area: implications for cleft lip reconstruction. Int J Oral Maxillofac Surg. 2026 Mar 25:S0901-5027(26)00092-5.
   (Journal: International Journal of Oral and Maxillofacial Surgery; Rank: Q1; Impact factor: 2,7)