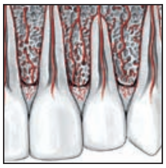
Review of Intraoral Vasculature and Implications on Incision Designs of Periodontal and Implant Surgeries



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Currently, the incision design for periodontal and implant surgeries is mainly based on the surgeon's personal preference. The primary aim of this study is to review the intricate periodontal microvascular system and to illustrate the potential impact of commonly applied flap designs on the integrity of this system. A complete literature electronic search resulted in 37 relevant articles. The maxillary, facial, and lingual arteries supply the microvasculature system, including the supraperiosteal, intraligamental, and intraosseous arterioles. These arterioles have their own territories yet are extensively interconnected. The impact of common papilla management techniques are discussed, including tunneling; papilla base, incision, and preservation; and flap-releasing incisions. Flap design can impact reperfusion and blood inflow in the early healing phase, which eventually influences wound closure probability, healing speed, surgical predictability, tissue volume change, and postoperative morbidity. Future studies on the three-dimensional distribution of microvasculature and clinical impact of various flap designs on tissue reperfusion can lead to evidence-based incision selection and improved wound-healing outcomes.
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Intraoral surgical wound healing is mediated by a series of vascular events that begin as early as local anesthetic delivery and incisions. A few hours after surgery completion, an avascular zone is formed at the incision line and the elevated mucoperiosteal flap is observed with variable extension.[1–3] Extensive incisions can result in intraoperative bleeding, wound healing disturbance, flap necrosis, crestal bone resorption, gingival recession, and scar tissue formation.[2,4–11]

Incisions, which are primarily used to access alveolar bone and for flap mobilization, inevitably disrupt vascular integrity. The incisions are based on the principles of preserving the vascular supply.[12] A paradigm shift occurred with the advent of periodontal regenerative surgery characterized by minimally invasive flap designs to maximize healing potential.[12–18] In regenerative and periodontal procedures, releasing incisions are also made to enhance flap mobility for primary wound closure.[19]

Currently, selecting a particular incision design for periodontal and implant surgeries is largely anecdotal and depends on the surgeon's personal preference. Knowledge of vascular anatomy could improve incision and flap designs by utilizing clinical, evidence-based selection to achieve surgical predictability. The primary aim of this study is to review

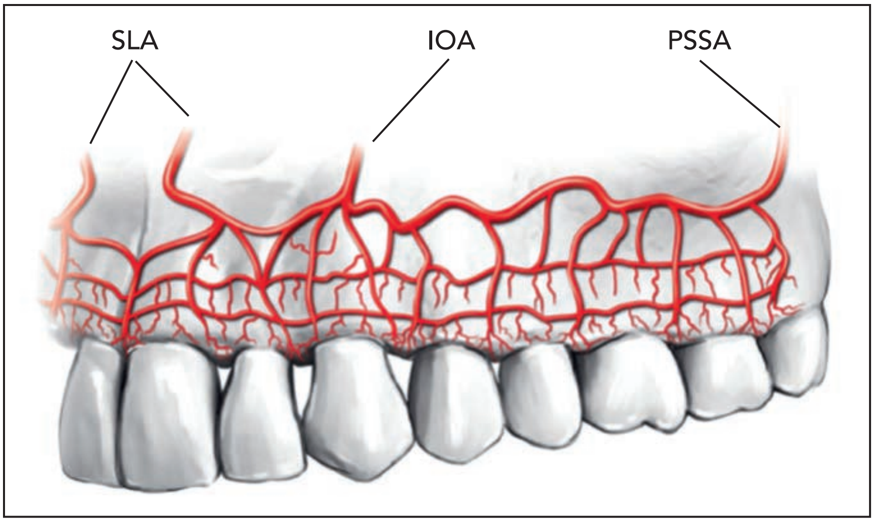

Fig 1 *Macrocirculation of the facial maxilla is mainly provided by three arteries: the posterior superior alveolar artery (PSAA), the infraorbital artery (IOA), and the superior labial artery (SLA).*

the intricate periodontal microvascular anatomy and to illustrate the potential clinical impact of commonly applied flap designs on the integrity of this system in periodontal and implant surgeries.

Materials and Methods

A complete literature electronic search was conducted by two reviewers (A.R., H.C.) using five databases (OvidMedline, Elsevier Embase, EBSCOhost Dentistry and Oral Sciences Source, Clarivate Web of Science, and EBSCOhost CINAHL) from August 2021 to January 2022 to generate a comprehensive review. The screening processes used Mesh terms, keyword combinations, and logic operators selected based on the controlled vocabularies of specific database using keywords: (exp surgical flaps/ or (flap* adj3 design) or ((dent* or periodontal) adj5 (incision* or surger*)).tw.) and (bs.fs. or (arter* or blood or macrocirculat* or microcirculat* or vascular*).ti.) and (exp *jaw/ or (mandib* or maxill* or mucosa or soft tissue*).ti.) and english.la. There was no restriction on the date or type of publication. Repeated articles and those that were irrelevant to the review were excluded. A total of 1,635 articles were retrieved, and 37 relevant articles were finally included.

Results

Macrocirculation

In the maxillofacial region, there is extensive collateral circulation among the major arteries, and thus their boundaries may not be clearly defined. Nevertheless, this knowledge is essential for a thorough understanding of microcirculation and will be briefly summarized here.

The blood supply to the facial maxilla is mainly provided by three arteries: the posterior superior alveolar artery (PSAA), the infraorbital artery (IOA), and the superior labial artery (SLA)[20–22] (Fig 1 and Table 1). The PSAA supplies the retromolar, molar, and premolar regions. The IOA supplies the premolar and incisor–canine regions. The transverse artery, an anastomosis between PSAA and IOA (as the name implies), travels horizontally along the posterior maxilla. The incisor–canine region is also supplied by the SLA. The palatal mucosa is mainly supplied by the greater palatine artery (Fig 2 and Table 1). The nasopalatine artery and the lesser palatine artery supply the premaxilla and retromolar regions, respectively. Penetrating transverse intraosseous arteriole (TA) branches are present from the facial to the palatal sides at the premolar-canine area[2,8,10,23,24] (Fig 2).

In the mandible, the facial mucosa in the incisor–premolar sites is mainly supplied by the inferior labial artery and the mental artery[11,25] (Fig 3 and Table 1). The facial mucosa in the molar region is supplied by the facial artery. On the lingual aspect, the mucosa is supplied by the submental and the sublingual arteries, which are branches of the lingual artery. The inferior alveolar artery supplies the periodontium of premolars and molars.[1,2,8,10,11,24]

Microcirculation

The supraperiosteal (SPA), intraosseous (ITOA), and intraligamental (ITLA) arterioles, which branch off from the macrocirculation approximately at the level of the root tip

Table 1 Macrocirculation of the Maxillary and Mandibular Mucosa and Periosteum

	Maxilla		Mandible	
Location	Facial	Palatal	Facial	Lingual
Incisor-canine	IOA and SLA	GPA and NPA	MA and ILA	SMA and SLA
Premolar	IOA and PSAA	GPA	MA and ILA	SMA and SLA
Molar	PSAA	GPA	FA	SMA and SLA
Retromolar	PSAA	GPA and LPA	FA	SMA and SLA

FA = facial artery; GPA = greater palatine artery; ILA = inferior labial artery; IOA = infraorbital artery; LPA = lesser palatine artery; MA = mental artery; NPA = nasopalatine artery; PSAA = posterior superior alveolar artery; SL = sublingual artery; SLA = superior labial artery; SMA = submental artery.

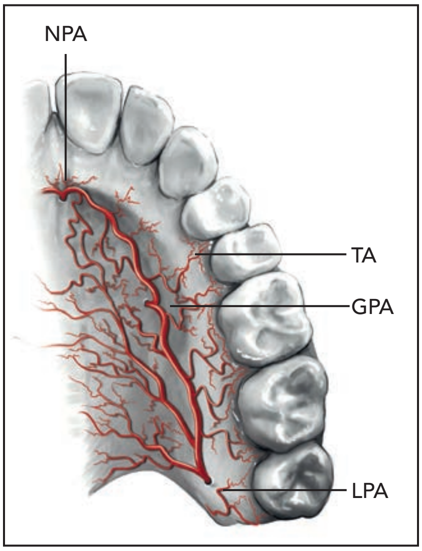

Fig 2 *Macrocirculation of the palatal mucosa is mainly supplied by the nasopalatine artery (NPA), the greater palatine artery (GPA), the lesser palatine artery (LPA), and the penetrating transverse intraosseous branches (TA).*

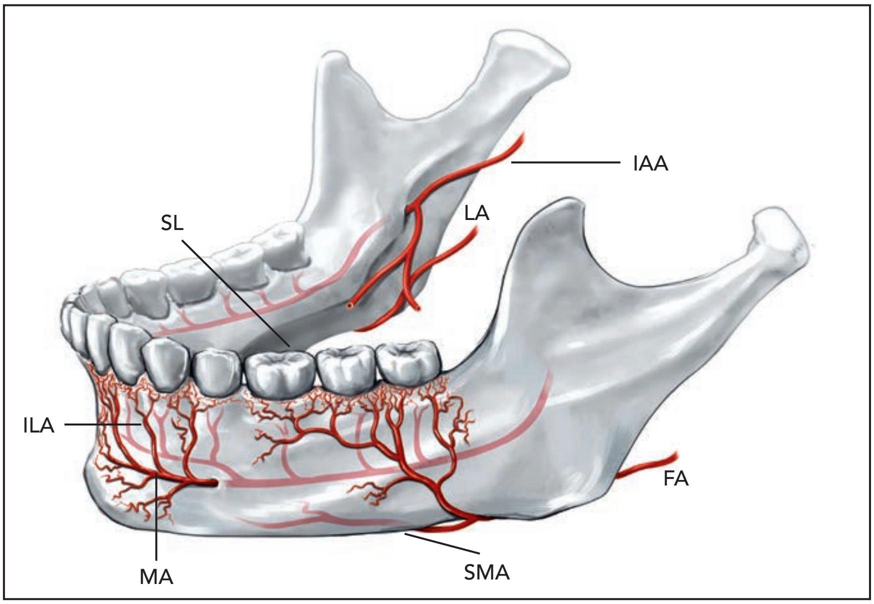

Fig 3 *Macrocirculation of the mandible facial mucosa is mainly supplied by the inferior labial artery (ILA), mental artery (MA), and facial artery (FA). The lingual aspect is supplied by the submental (SMA), sublingual artery (SL), and a branch of the lingual artery (LA). The inferior alveolar artery (IAA) supplies the periodontium of premolars and molars.*

apicocoronally, support the more coronally located oral mucosa and the periodontium. These relatively vertically (apicocoronally) oriented arterioles have their own main territories reflected by the relative independence of the gingival and periodontal ligament (PDL) blood supplies, and yet are extensively interconnected. Occlusion of vessels in the PDL does not significantly affect the gingival blood supply and vice versa (Fig 4). As for their interconnections, these arterioles, which travel in an apical-to-coronal direction, anastomose at the interdental papilla and marginal gingiva[2,26] (Fig 4). In addition, the ITOA anastomose to each other horizontally through Volkmann's canals, thus contributing to the periodontal vascular network.[27–29]

The microvascular architecture of the mandibular facial periosteum has two layers: outer and inner. The outer fibrous layer contains arterioles/venules that infrequently anastomose with each other, and the inner osteogenic layer contains a venous network.[30] In the maxilla, transversal (horizontal) anastomoses were found between the SPA and ITOA,[9,10] and some transversal connections cross

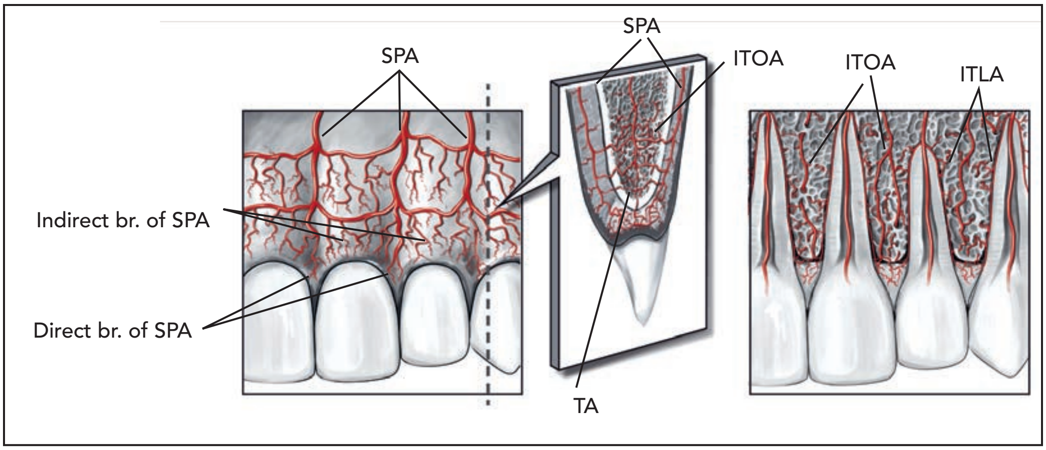

Fig 4 *Microcirculation of the mucosa and the periodontium is supplied by direct and indirect branches of the supraperiosteal (SPA), intraosseous (ITOA), intraligamental (ITLA), and transverse (TA) arterioles.*

Table 2 Microcirculation of the Maxillary Facial Gingiva

Facial gingiva	Interdental papilla	Marginal gingiva
SPA directly (from microcirculation)	Yes	No
SPA indirectly (from horizontal anastomoses of microcirculation)	Yes	Yes
ITOA	Yes	Yes
ITLA	Yes (from both mesial and distal PDL spaces)	Yes (from facial PDL space)
TA	Yes	No

ITLA = intraligamental arteriole; ITOA = intraosseous arteriole; PDL = periodontal ligament; SPA = supraperiostal arteriole; TA = transverse intraosseous arteriole.

between facial and palatal arterioles in the papillary regions and also in the interdental alveolar septum[9] (Figs 2 and 4). These arterioles then branch further, eventually connecting to numerous capillary loops, which then connect to venules.[26] For example, SPA in the oral submucosa divides into smaller branches that enter the lamina propria, forming net-arteries with numerous anastomoses with an average diameter < 100 µm. On the other hand, large arteries (diameter size > 200 µm) in the deep layer of the attached gingiva may not anastomose with arterioles of the attached gingiva and move toward the papilla.[1,2]

There are few differences in the blood supply between the interdental papilla and marginal gingiva that may have clinical ramifications (Fig 1 and Table 2). First is the diameter and distribution of the SPA. The SPA in the interdental papillae are vertical branches with larger diameters directly arising from the major artery.[2,9] On the other hand, SPA of the facial gingival margin are branches with smaller diameters that come from horizontal anastomoses of the major arteries.[2] A clinical case demonstrated these findings (Fig 5). Second, the papillae receive supplies from both the mesial and distal ITLA, while the facial gingival margin only receives blood supply from facial ITLA arterioles. Third, the interdental papillae also have TA traveling between the facial and palatal mucosa.

Incision Design and Possible Impact on Microcirculation

Based on the prior knowledge of periodontal macro- and microcirculation, it becomes clear that incisions and flap reflection interrupt these intricate vasculature systems,[1,2] which might partially explain variations in the clinical healing outcomes of different flap designs. It is very common for gingival recession to occur after an incision is made in the papilla.[31] The amount of recession varies and depends on the amount of papillary tissue removed, the level of the underlying alveolar crest, the tissue phenotype, and the degree of surgical trauma. Studies on flapless, papilla-preserving implant placement suggest less soft tissue and hard tissue dimension changes.[7,12,31] Most flap designs focus on the interdental papilla[32] and flap-releasing incisions; therefore, the potential impact on vasculature integrity of some common flap designs for surgical papillary management or flap-releasing is discussed herein.

Four common incision designs involving the papilla and neighboring tissues are tunneling, papilla base, simple papilla preservation, and traditional papilla incision (Table 3). In the tunneling approach, because the incisions stop at the line angle of the boundary teeth, the TA from the palatal branches could be preserved.[24] Supply of SPA to the papilla can be preserved because no incision is made in the papilla. Depending on the degree of papilla elevation from the underlying crestal bone and adjacent teeth, the ITOA and ITLA might be affected.[9,31] Anastomoses between SPA and ITOA can be compromised once a flap is elevated. The papilla base incision is advocated by endodontic specialists to reduce papilla loss after endodontic surgeries.[28] In this approach, a facial horizontal incision is made between the line angles of the adjacent teeth.[6,22,24,29] Because the papilla is not elevated, ITOA from the alveolar crest and TA could be preserved. On the other hand, SPA, ITLA, and SPA-ITOA anastomose can be impaired due to the incision and flap reflection. Simplified papilla preservation incision has been commonly used for guided tissue regeneration with the aim to increase the potential for primary wound closure and consequently undisturbed wound healing. Because of an incision and reflection of the papilla, all the arterioles and anastomoses discussed earlier are affected. The traditional papilla incision can compromise the whole microcirculation as well.

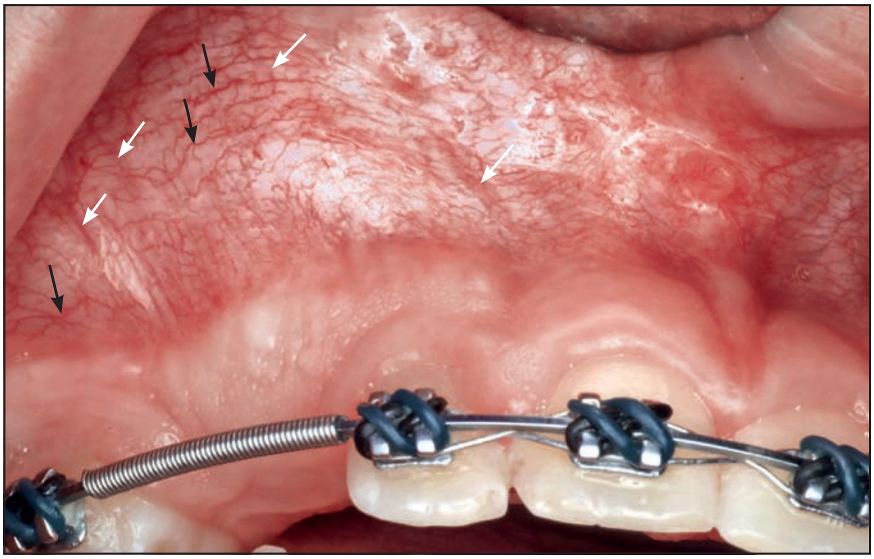

Fig 5 *Clinical case of microcirculation in the maxilla. White arrows indicate direct vertical branches, whereas black arrows indicate indirect horizontal branches of the supraperiosteal (SPA) arterioles.*

To achieve primary tension-free closure of soft and hard tissues after regenerative procedures, flap-releasing procedures are used.[11,33,34] The linear incision (periosteal releasing), pouch releasing, and vertical incision could incur trauma to SPA arterioles and their anastomoses to the alveolar bone (ITOA).[3,35] For horizontal releasing incisions, their depth and the mesiodistal length determine the degree of vascular interruption. Split-thickness flaps in different layers could play a key role in preserving the integrity of SPA arterioles.[35] For vertical incisions, their apicocoronal length and location in relation to the arterioles determine the circulation impairment. Table 4 shows the flap releasing types and their possible vascular disruptions that can occur.

Discussion

The impact of incision designs on microvasculature systems is conceptually based on anatomical knowledge; how this can translate into clinical outcomes is not known. Proper incision tracing and flap design and manipulation, characterized by minimally interrupted postoperative mucosal and periosteal microcirculation, will result in more predictable wound healing and could influence the probability of wound closure, healing speed, surgical predictability, and postoperative morbidity. Tissue recession and loss is in direct relation to flap elevation and microvascular anastomosis disruption.[2,7] A clinical case

Table 3 Surgical Papilla Management and Possible Microvascular Interruptions to the Papilla

Illustration	Technique	Apicocoronal direction			Faciopalatal direction	
		SPA	ITOA	ITLA	Anastomosis between SPA & ITOA	TA
	Tunneling	No	Yes, if papilla elevated	Yes, if papilla elevated	Yes	No
	Papilla base incision	Yes	No	Yes	Yes	No
	Simple papilla preservation incision	Yes	Yes	Yes	Yes	Yes
	Papilla incision	Yes	Yes	Yes	Yes	Yes

ITLA = intraligamental arteriole; ITOA = intraosseous arteriole; SPA = supraperiostal arteriole; TA = transverse intraosseous arteriole.

Table 4 Flap Releasing Types and Possible Vascular Disruption to the Flap

Technique	Major artery	SPA and branches	Anastomosis between SPA & ITOA
Horizontal (mesiodistal)			
Coronal linear release (periosteal scoring)	No	Possible with deep incision	Yes when a full-thickness flap is elevated
Apical linear release	Possible if too apically placed beyond the vestibule depth		
Layered release (pouch)			
Vertical (apicocoronal)	Possible if too apically placed beyond the vestibule depth	Possible	Yes when a full-thickness flap is elevated

ITOA = intraosseous arteriole; SPA = supraperiostal arteriole.

is presented in Fig 6, showing the intricate microcirculation on the mandibular facial anterior region in a patient with a thin phenotype (Fig 6a). To treat a gingival recession on the left central incisor and improve tissue thickness of the remaining incisors that are developing recession, a tunneling procedure with connective tissue graft was performed to minimize microvascular interruption (Fig 6b). Regardless of the location of the incision, an ischemic area forms, followed by hyperemia and revascularization that primarily begins laterally from arteriole anastomoses of major vertical branches. Major disruption of the microvasculature system could be the reason for negative surgical outcomes, dehiscent bone, and significant alterations to ridge

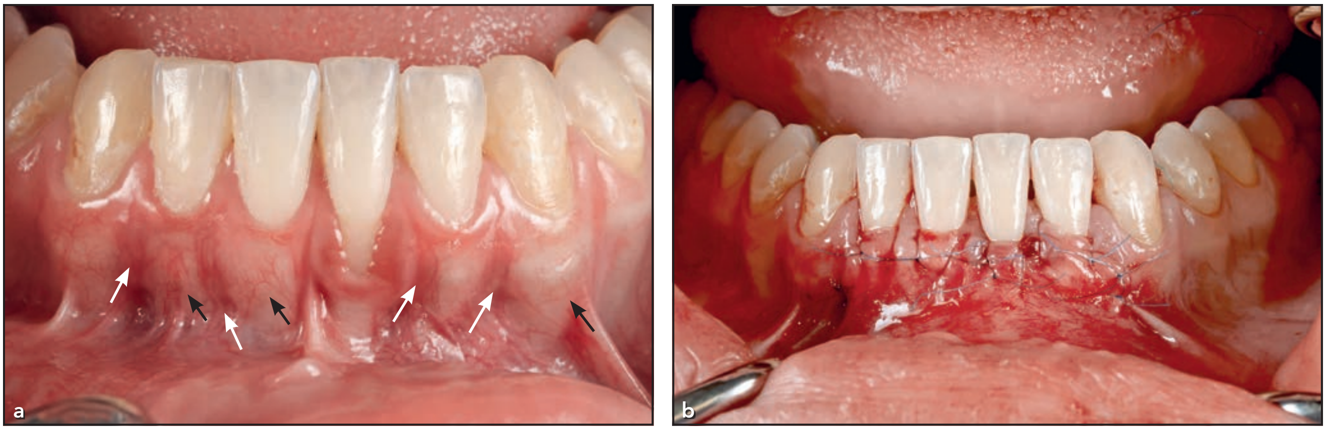

Fig 6 *Clinical case of microcirculation in the anterior mandible of a patient with a thin phenotype.* (a) *White arrows indicate direct vertical branches, whereas black arrows indicate indirect horizontal branches of the supraperiosteal (SPA) arterioles.* (b) *Surgical papilla management (SPM) was applied to treat the gingival recession on the left central incisor. A tunneling procedure with connective tissue graft was performed to minimize microvascular interruption.*

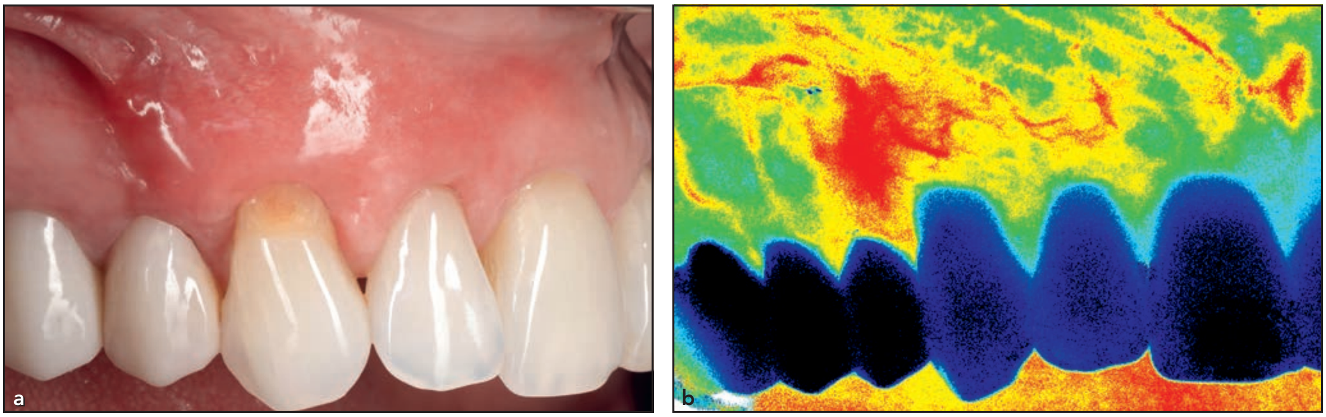

Fig 7 (a) *Clinical and* (b) *three-dimensional laser imaging of the microvasculature system of the maxillary right side. The three-dimensional depiction uses laser speckle contrast imaging, quantifying the magnitude of the superficial tissue perfusion by analyzing the speckle pattern of scattered light. Superficial tissue perfusion (~1 mm) was expressed in laser speckle perfusion units and coded by color: blue-cyan (low perfusion), green-yellow (moderate perfusion), and orange–red (high perfusion).*

morphology.[1,2,7] For periodontal regeneration, papilla preservation procedures have positive outcomes and may be related to the preservation of tissue as well as vascular integrity in the papillary region.[14,17] Therefore, understanding the papillary microvasculature could encourage more clinical research and an evidence-based selection of the appropriate surgical papilla management (Fig 7).

Surgical flap designs are based on the amount of flap advancement and a varying number and length of vertical, horizontal, and periosteal incisions. Circulation reduces by about 50% in full-thickness flaps.[27] Horizontal linear or pouch releasing techniques are essentially partial-thickness flap preparation.[35,36] Therefore, the incision depth plays a key role in preserving he integrity of the SPA arterioles. Partial-thickness flaps that are closer to bone have been recommended as they avoid injury to SPA, especially when flap tension is created for bone regeneration procedures[37] as opposed to a more superficial layer for soft tissue procedures.[18] Currently, the three-dimensional location of SPA arterioles is not well defined in the literature and deserves further investigation.[30] For example, on ultrasound images, SPA can be shown in cross-sectional view (Fig 8). This imaging modality can be very beneficial to understanding the SPA location.

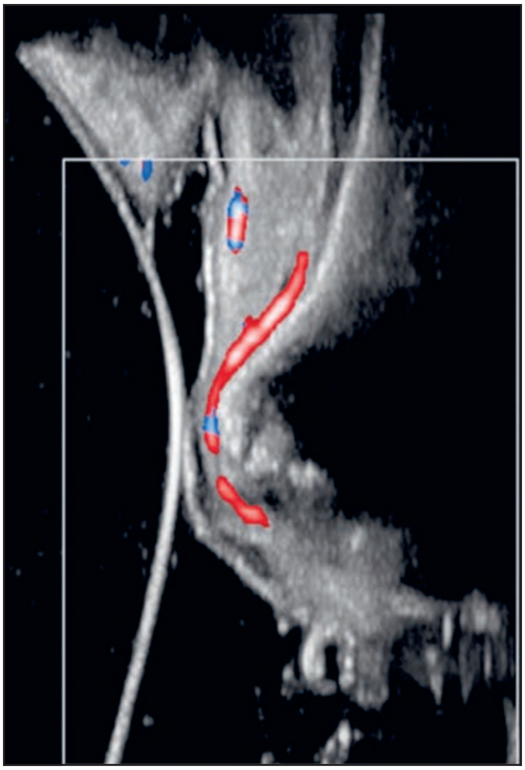

Fig 8 *Example of blood-flow visualization using an ultrasound image and color flow mode of an edentulous crest from a facial (cross-sectional) view. Red and blue pixels are superimposed on gray brightness-mode pixels to detect the velocity of the blood flow. A positive velocity toward the transducer is typically displayed in red/yellow. Blue/cyan pixels are labeled as negative and indicate a velocity moving away from the transducer. Ultrasound imaging can be useful for locating supraperiosteal arterioles (SPAs), viewed as red or blue hues.*

As for vertical releasing incisions, these resulted in poorer revascularization and created triangular, cleft-like tissue loss at its margin.[26] Therefore, they should be used cautiously and only for gaining access, knowing that horizontal releasing incisions are efficient at flap advancement.[34] In this regard, it might be beneficial to utilize an operating microscope for improved magnification (visual access) to avoid a vertical incision. These should be performed only on the mesial border of flap to avoid incising the major vessels traveling from the posterior to the mesial tissues.[1] Intricate small anastomoses between small-sized arteries and variations in ischemic responses after vertical incisions might be the reason for variable and unexpected surgical healing outcomes.[2]

Conclusions

Tissue reperfusion is an essential part of wound healing, though other systemic, local, and environmental factors can also influence wound healing. This article reviewed the periodontal macro- and microvasculature and hypothesized the impact of various commonly applied incision designs on the integrity of microcirculation. This critical information could lay the foundation for studying microvasculature systems in three dimensions using modern technology and evidence-based incision designs. This review suggests that minimally invasive and customized incision design and flap management (eg, the selective use of vertical incisions, prudent horizontal flap extension, conservative papilla handling, and vessel-inclusive partial-thickness flaps) can preserve the microvasculature and encourage expedited wound healing. Whether these benefits can improve clinical and patient-centered outcomes deserve further research. Eventually, this could help shed light on evidence-based selection of incision and flap designs.

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