Vascular anatomy of the maxillaries in relationship to bone regenerative procedures

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Introduction

Bone grafts have been the pillar of bone defect reconstruction for more than a century.[1]

The Research[2–8] has highlighted the advantages of graft vascularization. When compared with non-vascularized bone graft for reconstruction of critical size bone defects, the vascularized bone exhibits earlier blending and more solid biomechanical integrity,[2,4] as well as an improved resistance to a progressive resorption and higher chances to recover from local infection or from the irradiation. This can be learnt from the current understanding of osteogenesis, fracture healing and tissue perfusion.

Wagels and colleagues, in 2013,[1] specified that when a critical but not yet defined size of the defect is reached, the results of non-vascularized bone grafting are unpredictable.

After Taylor's description of the fibula flap technique in 1975,[6] numerous types of bone flaps have been described.

Yet, unlike when it happened for soft tissue reconstruction, it appears that anatomical models of bone vascularization have not, for a long time, typically been applied to the selection or manipulation of the bone component of a flap.

Subsequently, other researchers have put much effort[9–15] in performing anatomical studies that have facilitated understanding of the bone vascularization model. Designing reliably vascularized bone can often be neglected at the expense of intended reconstruction, leading to increased clinical failures.

From the aforementioned studies it could be inferred that success in reconstructing critical sized bone defects should require adequately vascularized and morphologically similar bone.

Thanks to the modern biomaterials and the autologous bone grafting, it is currently possible to undertake regenerative procedures even in patients with an important deficit of the same area, provided that suitable surgical techniques are used and favorable anatomical conditions are present. However, it must be considered that their removal is very invasive, sometimes not simple in the technique and very complicated to adapt to the recipient bone.

Other disadvantages are represented by both the quality of postoperative life and the resorption that usually occurs with the use of autologous bone blocks. In dentistry, except in rare cases of extreme bone dehiscences of the jaws, it is currently preferred to use grafts consisting of granules of bio-compatible materials (allografts or xenografts).

Many scientific researches have shown that these grafts are able to be vascularized by the angiogenesis that follows the operative trauma.[16,17]

This event is of the utmost importance for graft maturation and new bone formation. In addition, the particulate graft adapts to all surface irregularities.

Their use, however, is not without complication, since these grafts must be "immobilized" and often need to be completely covered with the use of membranes.[18] The membranes that are used, both resorbable and non-resorbable, with different resorption times, are designed to allow the passage of both regenerative cells and new vessels deriving from the new angiogenesis. Any uncovering of them during the regeneration phases may lead to a clinical failure and possible graft infections.

It must also be taken into account that the neo-vascularisation occurs and acts for few millimeters starting from the bone substrate and that the portion of biomaterial that most distracts will mature more slowly and often incompletely.[19]

For this reason, large granular grafts require adequate positioning, i.e. as much as possible between bone walls and close to the blood vessels.

Carotid artery

The common carotid artery has a different origin in the right and left side of the body. On the right side, it originates from the brachiocephalic artery, while on the left side it comes directly from the aortic arch. The common carotid artery begins laterally to the trachea and then to the larynx up to the height of approximately the superior margin of the thyroid cartilage, where it divides into the internal carotid artery and the external carotid artery. The internal carotid artery goes up to the "Rocca petrosa" of the temporal bone; here it enters the cranial cavity, passes through the cavernous sinus and ends under the anterior perforated substance. Its terminal portions are the anterior cerebral artery and the middle cerebral artery. During its course, it gives ramifications which also contribute to the vascularization of part of the nasal cavity and of some upper regions of the face.

Almost all the arteries of the oral cavity and neighboring regions are made up of branches deriving from the external carotid artery.

The external carotid artery begins between the third and fourth cervical vertebrae, below the anterior border of the sternocleidomastoid muscle; subsequently it moves upwards, reaches the lower margin of the digastric muscle and the stylohyoid muscle, crosses the most posterior part of the submandibular triangle and then enters the retromandibular fossa and, finally, near the angle of the mandible, it changes direction becoming ascending and running parallel to the posterior margin of the mandible, through the retromandibular fossa. At the level of the neck of the mandible, it bifurcates into its two terminal branches: the superficial temporal artery and the maxillary artery.

The branches of the external carotid are: anterior, posterior, medial and terminal. Those that mostly affect the vascularization of the grafts are the further branches of these vascular trunks and its terminal branch.[20]

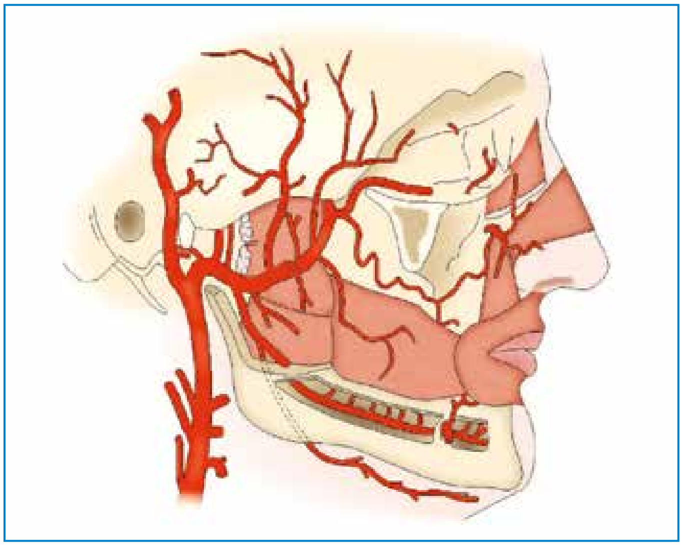
In this chapter those of greatest interest will be dealt with.

Maxillary artery

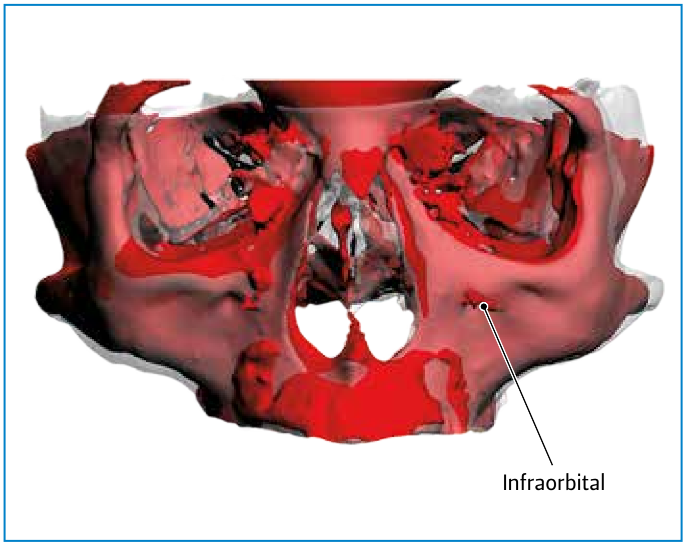
This artery originates from the external carotid artery under the mandibular neck, in the thickness of the parotid gland, then it follows a course in an anterior direction, slightly upward and medially, through the infratemporal fossa. This fossa, also known as the zygomatic fossa, is a space located in the lateral wall of the face, posterior to the jaw and located inferiorly and medially to the zygomatic arch, homologous to the subtemporal fossa (or window) of other vertebrates. It appears as the direct downward continuation of the temporal fossa. The artery, during its journey, is located on the internal surfaceof the mandible. The relationship with the external pterygoid muscle is variable; in fact, in half of the cases, it is found external to this muscle after it has passed between the mandible and the sphenomandibular ligament; in the rest of the cases it is found medial to the external pterygoid muscle. Once the artery has reached the antero-superior end of the infratemporal fossa, it passes through the pterygopalatine fissure, or pterygopalatine hiatus, entering its fossa and, consequently, dividing into its terminal branches.

In a schematic way, the maxillary artery can be divided into four parts.

- The first part is called the *mandibular tract* and corresponds to the short tract located medial to the neck of the mandible; between its collateral branches (the deep auricular artery, anterior tympanic, middle meningea), the *inferior alveolar artery*, which descends on the medial aspect of the mandible branch. It provides *a mylohyoid branch* for the muscle of the same name and penetrates, together with the inferior alveolar nerve, into the mandibular canal. It runs through this canal up to the height of the first premolar where it divides into an *incisional branch* that continues in the anterior portion of the alveolar canal and anastomoses with the homonymous branch of the opposite side providing *alveolar branches* and a *mental branch* that exits through the mental foramen distributing to the chin.
- The second tract is the *pterygoid or muscular artery* which is the longest among the four and it is related to the homonymous external muscle. Its collateral branches are: deep temporal arteries, irregular pterygoid branches, masseterin artery and bucinatory artery.
- The third part, also called *maxillary*, is related to the posterior surface of the maxillary bone (1.1). Numerous collateral branches, often considered in surgical procedures, originate from this branch. In fact, apart from the pharyngeal branch and the artery of the petrogopalatine canal, these are the following branches:
  - the *superior posterior alveolar artery*, which descends on the maxillary tuberosity and divides into numerous branches which penetrate the alveolar canals and are distributed to the roots of the upper molars and premolars, to the gums and to the maxillary sinus;
  - the *infraorbital artery*, which enters the orbital cavity through the inferior orbital fissure, runs through the sulcus and the infraorbital canal together with the infraorbital nerve, it emerges in the face through the infraorbital foramen and, behind the upper lip elevator muscle, it resolves into a tuft of slender branches;
  - in the infraorbital canal, the artery supplies the *orbithal branches* for the lower rectus and the lower oblique muscles of the eyeball and for the lacrimal sac and the *anterior superior alveolar branches* that descend into the anterior alveolar canals to distribute to the canines and the upper incisors, to the gums and to the mucous membrane of the maxillary sinus. Some terminal branches of this artery go up in the face, up to the inner corner of the eye and to the lacrimal sac; others descend towards the upper lip (1.2);
  - the *greater palatine artery* (or *descending palatine artery*), which descends through the pterygopala-



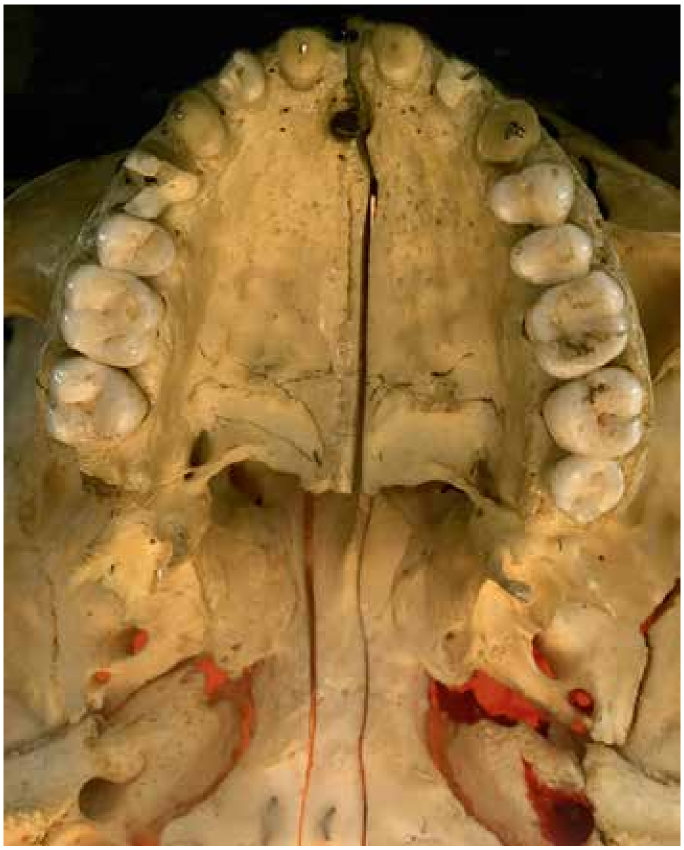
1.1 Course of the maxillary artery.



1.2 Infraorbital artery spraying area. (Image by S. Taschieri.)

tine canal with the posterior palatine nerve, originating from the sphenopalatine ganglion, and it supplies two or three minor palatine arteries which cross the palatine canals (1.3) and terminate in the soft palate and in the tonsil; it then emerges on the vault of the palate through the greater palatine foramen and it moves forward, along the alveolar process of the maxilla, to give branches to the bone and the palatine mucosa, to the minor glands in the palate and to the gums; it ends by anastomosing with a branch of the sphenopalatine artery that, through the incisive canal, descends into the palate.

- Finally, the fourth and last portion, also called terminal or sphenopalatine, divides into its terminal branches in the homonymous space from which it penetrates through its fissure, the sphenopalatine canal, into the nasal cavity where it divides into the *posterior medial nasal arteries* or *septum* and *posterior lateral nasal arteries*; the former are distributed to the nasal septum, the latter are carried to the horns, the walls of the foramina and the paranasal sinuses.[20]



1.3 Crossing of the palatine canals by the palatine arteries. (Image by S. Taschieri.)

Upper and lower jaw

The interest in dentistry is aimed at two structures: the upper jaw and the lower jaw (mandible).

The maxilla consists of a central body, comparable to a triangular pyramid with the base facing the nasal cavity and the apex that continues in the zygomatic process, and by four processes:

1. the *frontal process*, which rises from the anterior-medial angle of the body and moves upwards, joining with the frontal bone;
2. the *zygomatic process*, which corresponds to the lateral angle of the body and is joined to the zygomatic bone;
3. the *palatine process*, which originates from the lower edge of the medial face of the central body and runs horizontally, joining the homologous process of the other maxilla, thus constituting the main part of the anterior portion of the hard palate;
4. the *alveolar process*, which projects downwards and presents the alveoli for the teeth of the upper arch.

On the contrary, the mandible is made up of a horseshoe-shaped body that continues on each side in a branch directed upwards and backwards.

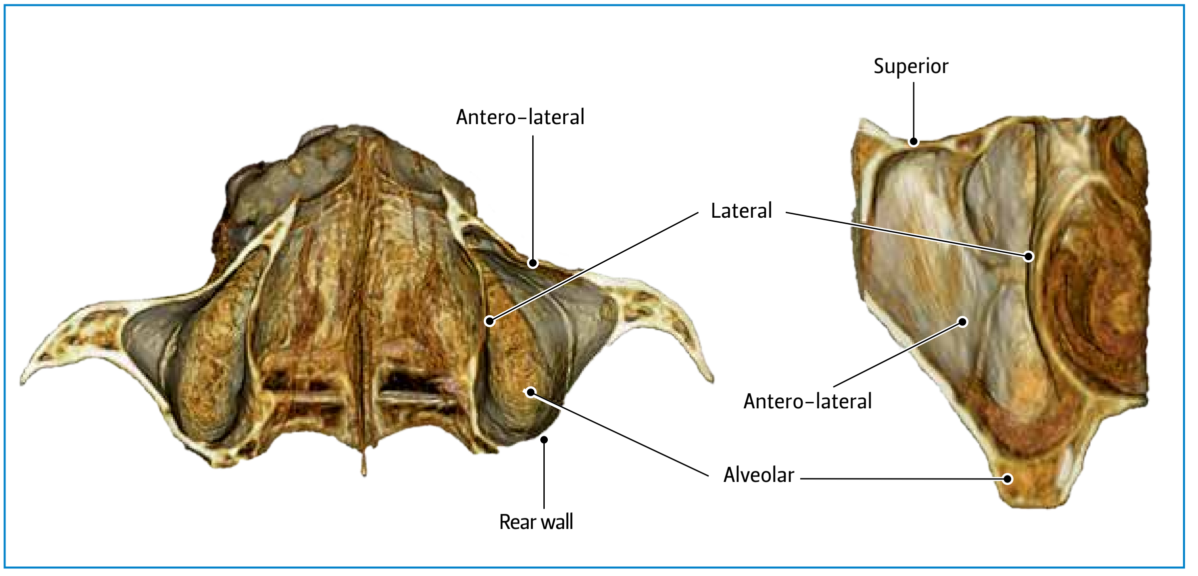
Both the anatomical structures mentioned above contain and are delimited by numerous noble anatomical structures, for example the arterial and the venous vessels, the nerve trunks and the cavities, which must be known in detail by the oral surgeons.

The regenerative techniques of the upper and lower jaw involve a sound knowledge of the vascularization of the relevant anatomical areas.

Vascularization of the maxillary sinus

The maxillary sinus is certainly one of the areas of greatest interest due to the tendency of the residual bone crest, especially following the loss of dental elements, to undergo a resorption process.

The maxillary sinus can be compared to a triangular pyramid with a base or internal wall corresponding to the lower half of the nasal cavity, an upper or orbital face, an antero-lateral face, a posterior or pterygopalatine face and a corresponding external part to the zygomatic process of the maxilla (1.4).



1.4 Maxillary sinus. (Image by S. Taschieri.)

The **antero-lateral wall** is depressed due to the presence of the canine fossa, it has a rectangular shape that looks forward and outward and corresponds, in turn, to the lateral wall of the maxillary bone. This wall is crossed by a partially intraosseous vascular anastomosis between the dental branch of the posterior-superior alveolar artery (PSAA), better known as the alveol-antral artery,[20–22] and the infraorbital artery (IOA).

Knowing this vascular anastomosis, detected in 100% of the cases (Solar and colleagues in 1999[23]) and in the dissective study by Rosano and colleagues, in 2009,[21] it is a clinically important consideration for all clinicians practicing oral surgery.

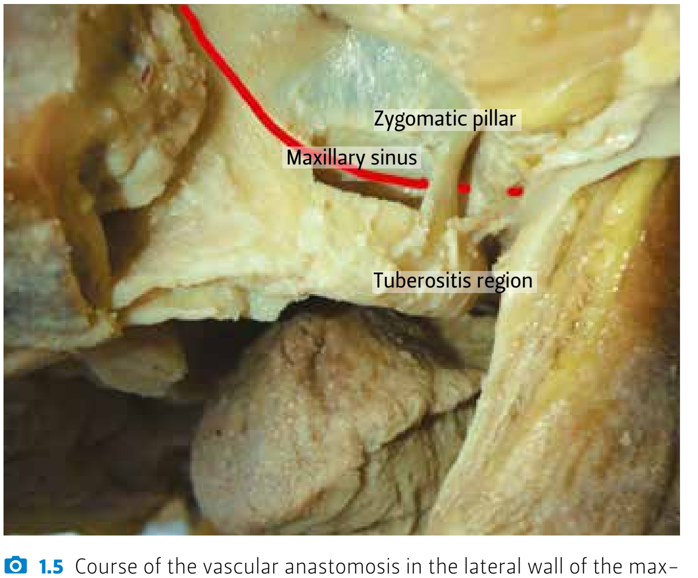
This anastomosis, when possible, should be preserved during the lateral sinus lift surgery, considering it as a vessel, albeit small in size (between 0.5 and 3 mm), capable of providing vascular support to the graft. This anatomical evidence is supported by its path which is often in the position in which the antrostomy is to be performed or in a neighboring position. Furthermore, this anastomosis is always intraosseous in the first millimeters of its course upstream and downstream, and then it continues at the vestibular level inside a channel formed in the bone wall and internally leaning directly on the Schneider's membrane (1.5).

The **upper or orbital wall** is triangular in shape and with the apex corresponding to the orbital process of the palatine bone; it constitutes a large part of the orbital floor.

This wall is bordered: anteriorly by the lower orbital edge and the lacrimal bone; inside, from the lower edge of the orbital lamina of the ethmoid; on the outside, from the zygomatic-maxillary suture in the anterior third and from the inferior orbital fissure in the posterior two thirds.

This wall, although optimally vascularized, is not important for the regeneration of any grafts aimed at increasing the bone volume within the maxillary sinus, but it has a higher value for the periodontal/periapical tissue regeneration of the upper jaw.

In fact, it is thanks to the lower orbital fissure that the infraorbital artery penetrates the orbit and then runs anteriorly, firstly contained in the infraorbital sulcus and then in the infraorbital canal. At this level, before



1.5 Course of the vascular anastomosis in the lateral wall of the maxillary bone. (Courtesy of A. Cardarelli.)

emerging at the infraorbital foramen, the infraorbital vessel gives off three branches or sometimes three groups of branches; these branches are the alveolar vessels (posterior, middle and anterior).

The **internal or nasal wall** has a rectangular shape and constitutes the bone septum that separates the maxillary sinus from the nasal cavity; its inferior portion corresponds to the inferior meatus of the nasal cavity.[24]

This wall, at a vascular level, is characterized by a multitude of small vascular tracts deriving from the posterior lateral artery of the nose, which perforate the wall and vascularize the mucous membrane of the maxillary sinus. The same wall is also vascularized by the posterior lateral arteries of the nose which, after having vascularized the superior and median concha, pass through the aforementioned wall with an antero-posterior direction supplying the sinus mucosa.[21] The presence of these numerous vascular branches makes this wall important for the angiogenesis of any graft placed. When it is possible and it is indicated based on the position of the graft, it is better that it is in contact or in a close proximity to this wall.

The **posterior wall** corresponds to the tuberosity of the maxilla and it is in relation to the infratemporal fossa, posteriorly and externally, and the pterygopalatine fossa posteriorly. The posterior-superior alveolar artery has a course extremely close to the maxillary tuberosity and many of its small vascular branches radiate into the complexity of its structure and participate in its vascularization. In addition, a close proximity can be seen between the posterior wall of the sinus, the descending palatine artery and the sphenopalatine artery.[21]

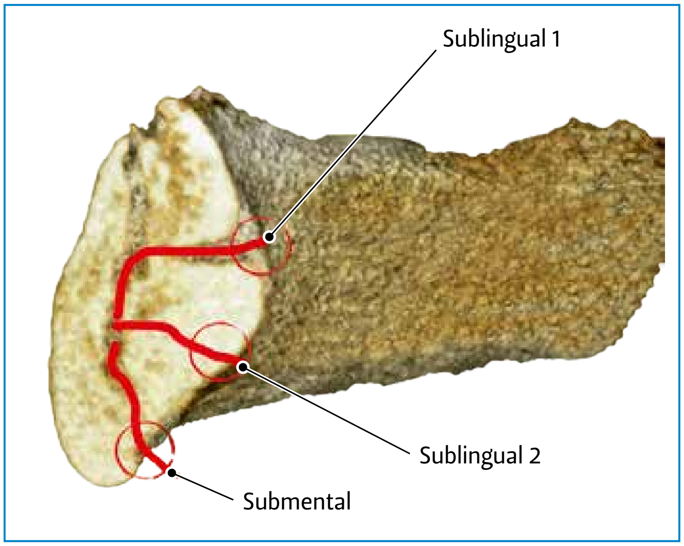
From what has been described, it is clear that the rich vascularization present in this anatomical area brings a consequent importance in the eventual angiogenesis for the maturation of a bone graft. It is therefore preferable that the graft positioning is performed by reaching the posterior wall either to give a correct and more suitable three-dimensional volume to accommodate the implants grafted in the right position or for its maturation.

Vascularization of the anterior jaw

Surgical procedures at the level of the anterior mandible require a high level of knowledge of its vascularization. In fact, any neurovascular damage can lead to serious postoperative sequelae. In the literature there are many cases of bleeding complications in the hours following surgery, especially implant surgery. The resulting hematoma expanding in volume, causes the lingual floor and the tongue itself to rise over time, sometimes so broadly that it obstructs the respiratory tract with consequent danger to the patient's vital parameters. To understand the possible hemorrhagic event, it is necessary to consider the presence of the rich para-symphyseal plexus to which the branches deriving from the anastomosis of the sublingual arteries coming from the right and left side belong. These arteries, which derive from the lingual arteries, penetrate inside the anterior area of the mandible both above and below the genus apofix in a variable number (in the literature there are up to 4/5 foramina with a common average of 1 to 3). Before their penetration, they often anastomose. Once penetrated, they are distributed within intrabony terminal branches giving support to the bone and dental vascularization by anastomosing with the central alveolar vessels between the two lower canines.

The presence of the genii apophyses prevents the formation of the anastomosis between the sublingual arteries and the inferior alveolar arteries.[20]

However in some studies an important presence at the level of vascularization that originates from the terminal derivation of the submental artery is reported, although with a wide variability in percentage. The artery penetrates through the mylohyoid muscle and it anastomoses itself in the same anatomical region.



1.6 Course of the sublingual arteries and the submental artery in the anterior area of the mandible. (Image by S. Taschieri.)

In the literature its importance in the vascularization of the anterior area of the mandible varies considerably, from being the main one to being supplementary to that deriving from the sublinguals. Nakajima and colleagues, in 2014,[25] highlighted the wide variability with which the submental and the sublingual artery, respectively derived from the facial and lingual arteries, can originate from the main vascular trunks above mentioned, an origin which may be sometimes common. This subdivision essentially derives from the relationship that these vascular branches have with respect to their passage through the mylohyoid muscle (1.6).

The above mentioned complexity and the vascular number gives an idea of how complicated it is, on a surgical emergency level, to be able to stop the bleeding with ligatures up to the vascular derivation, but also it gives an idea of the angiogenic possibilities of this anatomical portion.[26]

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