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XXVI CICLO

Vascularization of the facial bones by facial artery: implications for full face allotransplantation

Direttore della Scuola : Ch.ma Prof.ssa Maria Teresa Conconi

Supervisore :Ch.mo Prof. Franco Bassetto

Dottorando : Antonio Rampazzo

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Riassunto

Introduzione- L'arteria mascellare è riconosciuta da sempre come il principale supporto vascolare delle ossa facciali. L’evidenza clinica tuttavia sostiene un ruolo codominante dell'arteria faciale . Questo studio esplora quanto dello scheletro di un allotrapianto facciale possa essere vascolarizzato dall’arteria faciale.

Metodi- Ventitre’ teste di cadavere sono state utilizzate in questo studio. In 12 teste l’arteria faciale, temporale superficiale e mascellare destra sono state iniettate. In una testa è stata eseguita l’angiografia dell’arteria faciale. Dieci allotrapianti di faccia contenenti la mandibola , il complesso naso-orbito-maxillo-zigomatico e la lingua sono stati allestiti. I tessuti molli sono stati dissezionati per mostrare le connessioni anastomotiche tra i diversi vasi e successivamente tutti I tessuti molli ad eccezione del periostio sono stati rimossi. Sono state eseguite radiografie standard e TAC.

Risultati- Anastomosi costanti tra l’arteria faciale, l’arteria alveolare inferiore e l’arteria infraorbitaria sono state trovate a livello del forame mentale e infraorbitale. L’arteria faciale vascolarizzava il corpo, il ramo e la sinfisi mandibolare omolaterale. Il condilo e il processo coronoideo erano vascolarizzati nel 67% dei casi. La mascella omolaterale era contrastata in tutti i trapianti ad eccezione dei processi alveolari e palatini che contenevano il contrasto nell’83% dei campioni. Il processo mascellare dell'osso zigomatico era perfuso in tutti gli allotrapianti, seguito dal corpo, il processo frontale (83%) e il processo temporale (67%). La parete nasale laterale ed il setto erano vascolarizzati nell’83% dei casi. Le pareti orbitali mediali e laterali e il pavimento dell’orbita erano vascolarizzati in tutti i trapianti. Il processo zigomatico dell'osso temporale era il meno perfuso.

Conclusioni- Un allotrapianto composito facciale contenente il 90-95% delle ossa facciali può essere vascolarizzato dalle due arterie faciali.

Abstract

Background-The maxillary artery is recognized as the main vascular supply of the facial bones; nonetheless clinical evidence supports a co-dominant role for the facial artery. This study explores the extent of the facial skeleton within a facial allograft that can be harvested based on the facial artery.

Methods-Twenty-three cadaver heads were used in this study. In 12 heads, the right facial, superficial temporal and maxillary arteries were injected. In 1 head, facial artery angiography was performed. Ten facial allografts containing the mandible, naso-orbito-maxillo-zygomatic complex and tongue were raised. The soft tissues were dissected to show the arterial anastomotic connections and thereafter removed. Radiograms and CT scans were performed.

Results-Constant anastomosis between the facial, inferior alveolar and infraorbital arteries at the mental and infraorbital foramina were found. Facial artery vascularized the homolateral mandibular symphysis, body and ramus. The condylar and coronoid processes were vascularized in 67% of the allografts. The homolateral maxilla was contrasted in all allografts with the exception of the alveolar and palatine processes which contained the contrast in 83% of specimen. The maxillary process of the zygomatic bone was perfused in all allografts, followed by the body, frontal (83%) and temporal processes (67%). The nasal lateral wall and septum were vascularized in 83% of the allografts. The medial and lateral orbital walls and the orbital floor, were stained in all specimens. The zygomatic process of the temporal bone was the least perfused bone.

Conclusions-A composite allograft containing 90-95% of the facial bones can be based on bilateral facial arteries.

Introduction

In the past 8 years, a total of 27 facial allotransplants have been performed worldwide [1]. With increased confidence in the favorable outcome of the procedure [2, 3], there has been a consistent progress towards more complex allografts including all facial soft tissues and increasing amounts of the craniofacial skeleton. To ensure the viability of all components in these composite allografts, the selection of the vascular inflow is of utmost importance [4].

Maxillary artery has been traditionally considered the main blood supply to the maxilla and mandible [5]. The role of this artery for inclusion of the maxilla in facial allotransplantation was supported in an anatomical study by Yazici et al. [6, 7] who presented a maxillary allograft based on the maxillary artery. The authors demonstrated that the branches necessary for nutrition of the bone originated from the pterygopalatine portion of the artery.
Banks et al. [8] studied the circulatory patterns of the composite midface allografts and concluded that inclusion of the maxilla demands bilateral vascular pedicles based on the maxillary arteries. However, the deep course of the maxillary artery, medial to the inner surface of the mandibular ramus in the infratemporal and pterygopalatine fossae, makes this vessel difficult to dissect and prone to injury during the osteotomies required to harvest a composite maxillo-mandibular complex in facial transplantation [4, 9].
Therefore, most of the osteomyocutaneous facial allografts were based on the facial artery [10]. The clinical experience with these allografts supported the possible co-dominant role of the facial artery in providing a physiological perfusion to the bone component of the flap [9, 11].

The aim of the present study was to assess the role of the facial artery in the vascularization of the facial bones and to determine the extent of the facial skeleton that could be safely harvested based on the facial artery as the main arterial supply.

Materials and Methods

A total of twenty-three fresh cadaver heads were studied.

Selective artery injections

Twelve cadaver heads were drained of blood and flushed with normal saline. The external carotid artery was isolated through an 8 cm longitudinal incision along the anterior border of the sternocleidomastoid muscle. The superior thyroid, ascending pharyngeal and lingual arteries were ligated. The right facial artery (6 heads), superficial temporal (3 heads) and maxillary arteries (3 heads) were isolated and cannulated after ligating the external carotid artery distally.

Lead oxide gel was prepared adding one hundred milliliters of warmed normal saline (70ºC) to 3 g of powdered gelatin (Aldon Corp., Avon, NY), and 65 g of lead oxide powder (Science Stuff, Austin, Tx). Each vessel was injected with 60 ml of lead oxide gel using a 60 ml syringe and injecting in a pulsatile fashion. The bodies were refrigerated at 4ºC for 24 hours [12].

Full Facial Allograft Harvest

Ten facial allografts containing the mandible, naso-orbito-maxillo-zygomatic complex and tongue were raised based on the facial artery (6) and maxillary artery (4).

The external carotid artery was isolated as above. Hypoglossal nerve was exposed and transected. The digastrics muscle was divided at the level of the intermediate tendon exposing the facial artery. The external carotid artery was ligated distal to the origin of the facial artery. The contralateral side was prepared in the same manner; however the facial artery was ligated. Thereafter, a coronal incision was performed and the dissection continued subperiosteally over the frontal bone until the orbital rim was encountered. The supraorbital and suprathroclear pedicles were dissected and divided. Laterally, the dissection was continued under the deep temporal fascia up to the zygomatic arch. The temporalis muscle was removed from the temporal fossa. The coronal incision was extended along the posterior auricular groove to include the ears in the flap. Caudally, the skin incision was performed 2cm inferior to the jaw line and crossed over the midline to the controlateral side.

On both sides, conjunctival incisions were performed at the tarsal margins of the upper and lower palpebral fornix to include the eyelids within the flap.

A modified Le Fort III osteotomy was made with an oscillating saw. The osteotomy was carried down the lateral orbital wall from the zygomatico frontal suture to the inferior orbital fissure, across the floor of the orbit to the medial orbital wall extending behind the nasolacrimal fossa, and finally across the frontonasal junction. Most of the orbital floor was preserved. The zygomatic arch was cut at its base. Next, the muscles of mastication were released and removed to allow for complete disarticulation of the mandible. The attachment of the pterygoid plates to the basicranium was fractured with an osteotome. The soft tissue dissection was completed above the hyoid bone (Figures 1-12).

Figure 1- Marking of the skin incisions to harvest the allograft

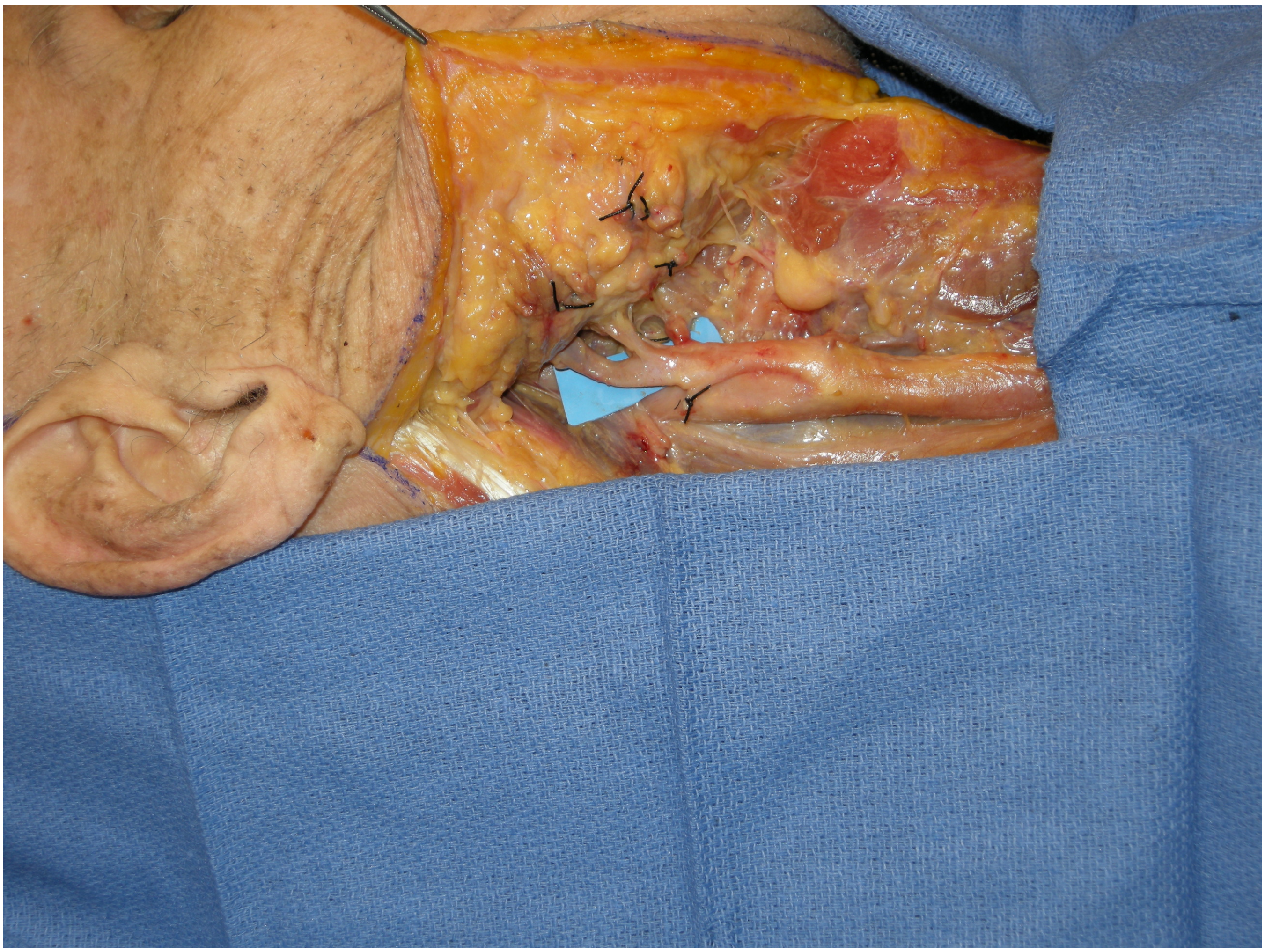


Figure 2- Dissection of the common, internal and external carotid artery and its branches

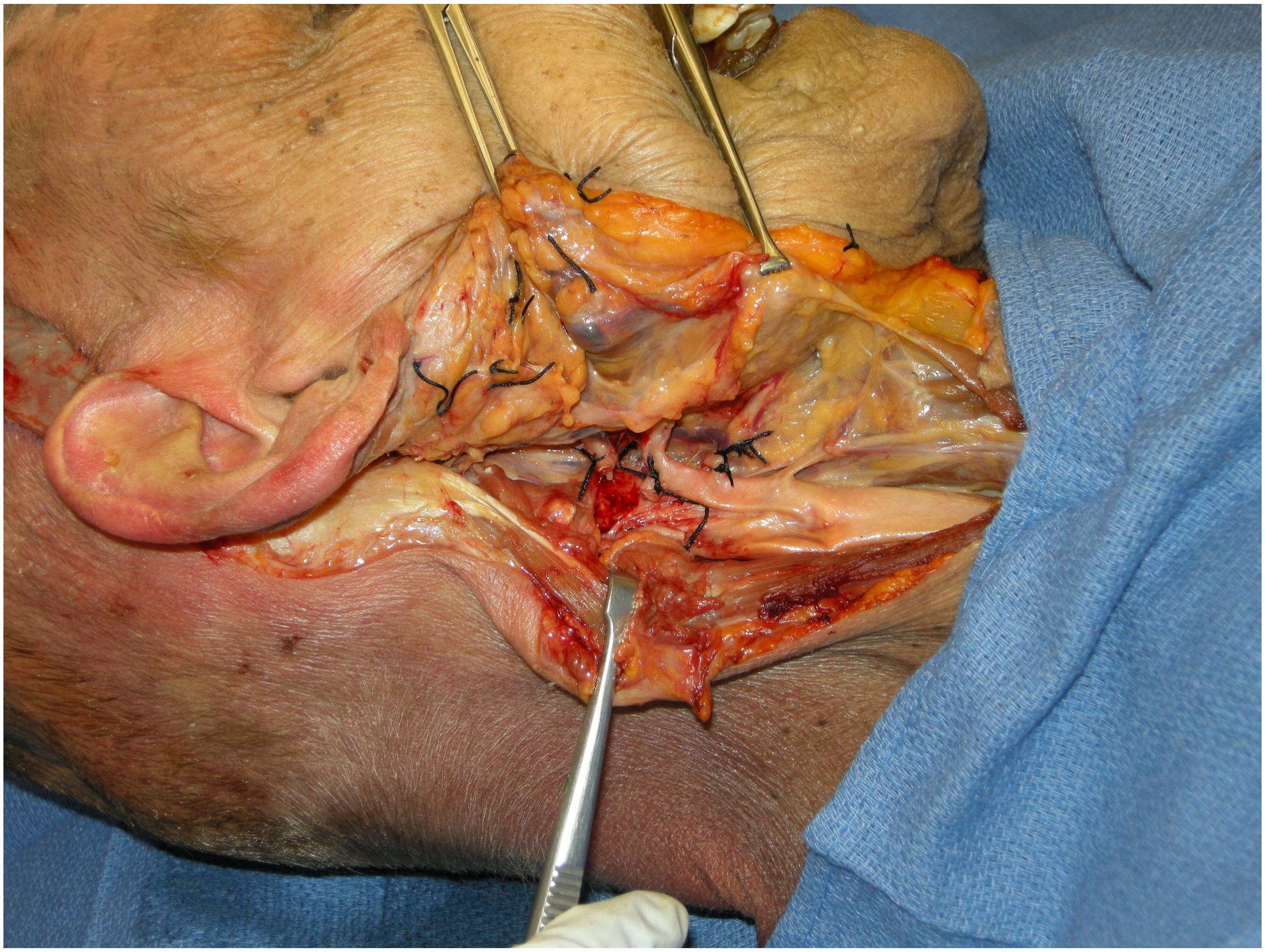


Figure 3- All the external carotid artery branches but the facial artery are divided

Figure 4- Coronal incision used to harvest the flap

Figure 5- Exposure of the orbital rim, zygoma and nasofrontal suture to allow the osteotomies

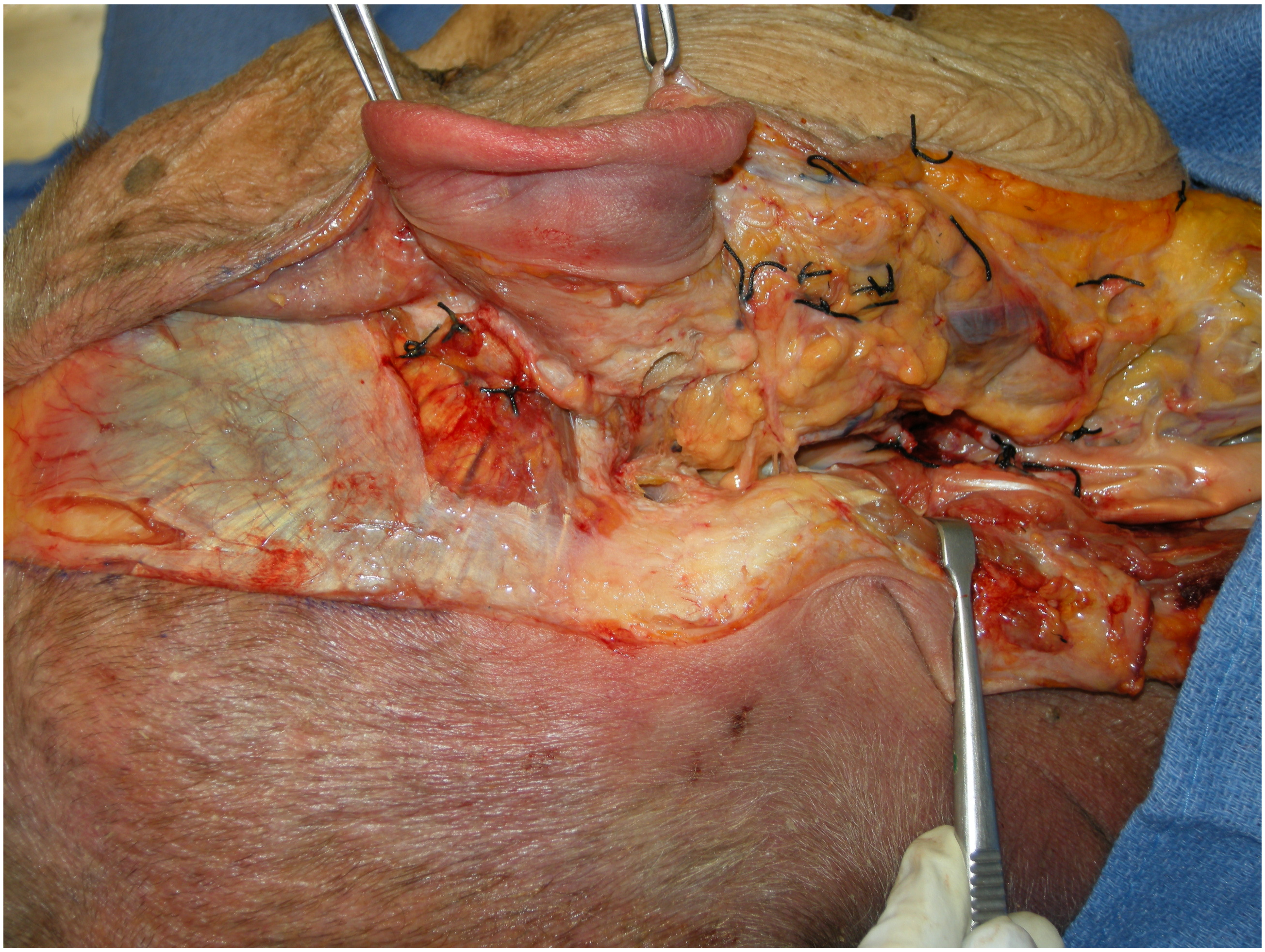


Figure 6- The ear is lifted with the flap and access is created to the condyle. The dissection carries on just over the skull base

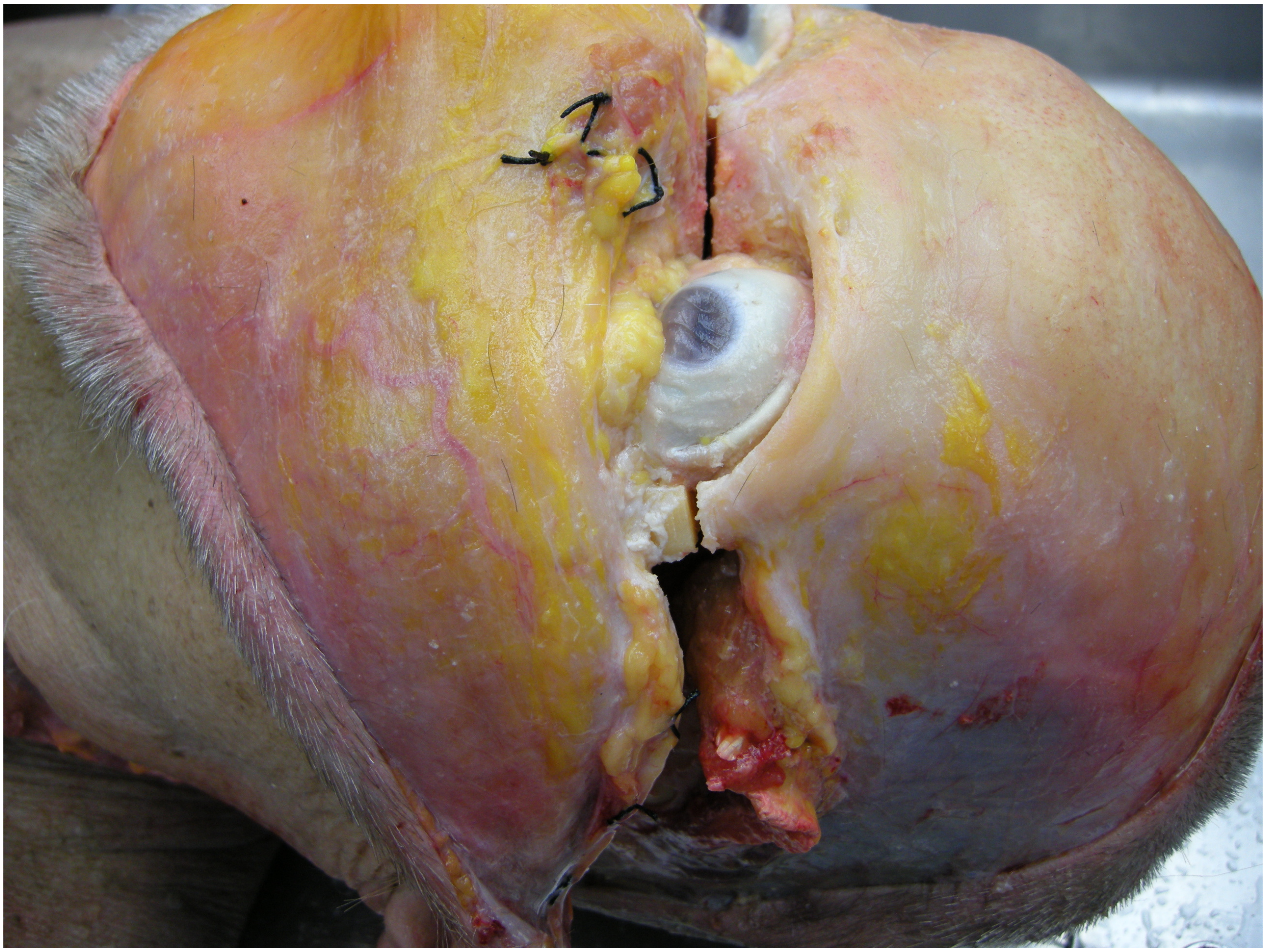


Figure 7- Osteotomies at the nasofrontal and zygomaticofrontal sutures are performed

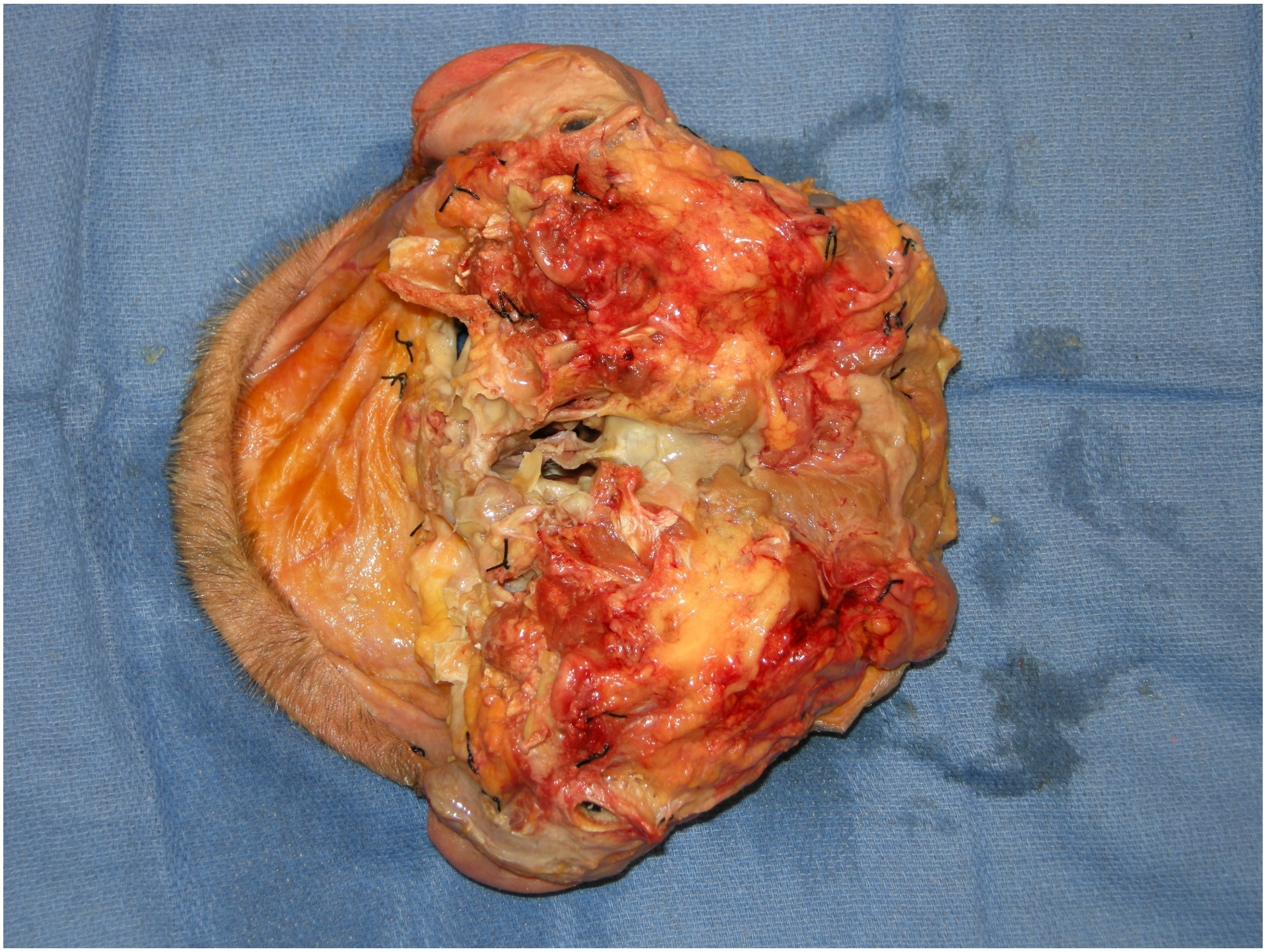


Figure 8- Full facial allotransplant harvested

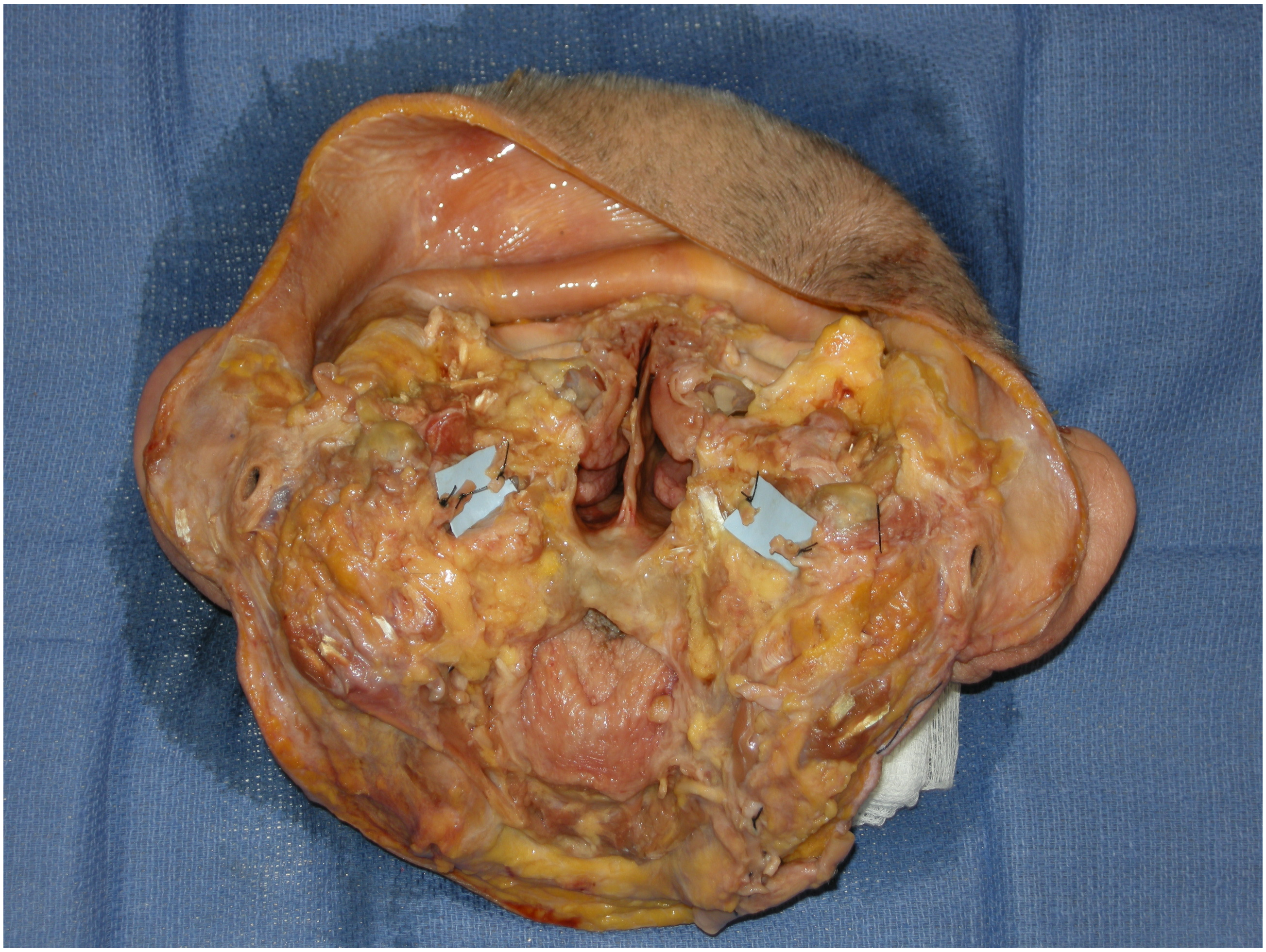
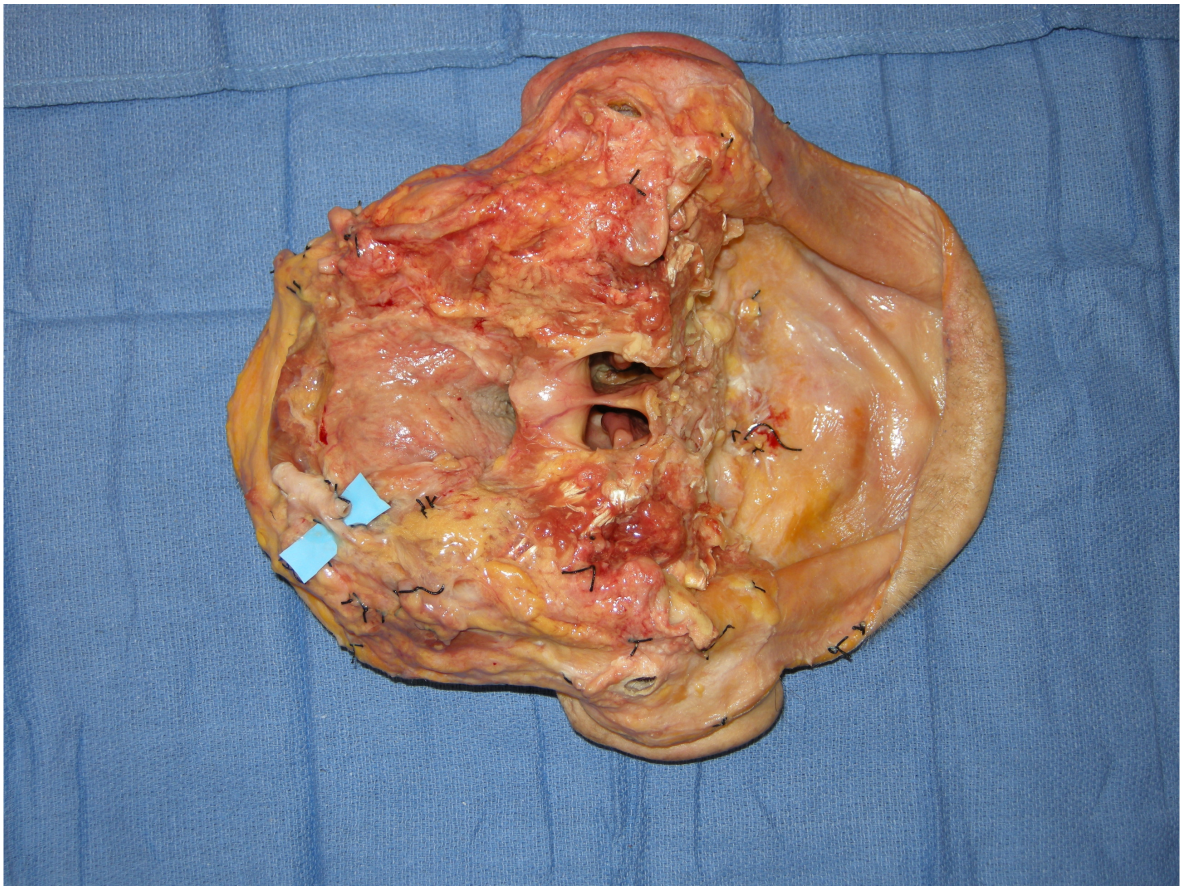


Figure 9- Both internal maxillary arteries are divided

Figure 10- Bony and soft tissue defects left after the dissection of the flap

Figures 11- A full facial allograft containing mandible and naso-orbito-maxillo-zygomatic complex is shown again. The injection cannula is inserted in the right facial artery.



Figures 12- The deep aspect of the full facial allograft: choanae, soft palate and base of the tongue are visible. Background is placed under the right facial artery.

The right facial artery was flushed with normal saline and injected with 60 ml of lead oxide gel. The flap was preserved at 4°C for 24 hours.

In four heads, the allograft was based on the maxillary artery. After exposure of the external carotid artery, the superior thyroid, ascending pharyngeal, lingual, facial and superficial temporal arteries were ligated. The rest of the procedure was similar to that described above. After the dissection and the osteotomies were completed, the allografts were inspected to assess the integrity of the maxillary artery.

Angiography of the facial artery

In one head, 60 milliliters of lead oxide gel were injected in the facial artery while the angiogram (Artis Zeego, Siemens Digital Angiography, Erlangen, Germany) was recorded.

Soft tissue dissection

The soft tissues were dissected in all heads that received selective artery injection (13) and the facial allografts (10), to show the anastomotic connections between the terminal branches of the facial, superficial temporal and maxillary arteries.

Radiograms and Computed Tomography

At the end of dissection, all soft tissues, with the exception of gingival and mucosal layers of the maxillary sinus, palate and nasal cavities, were removed (Figure 19).

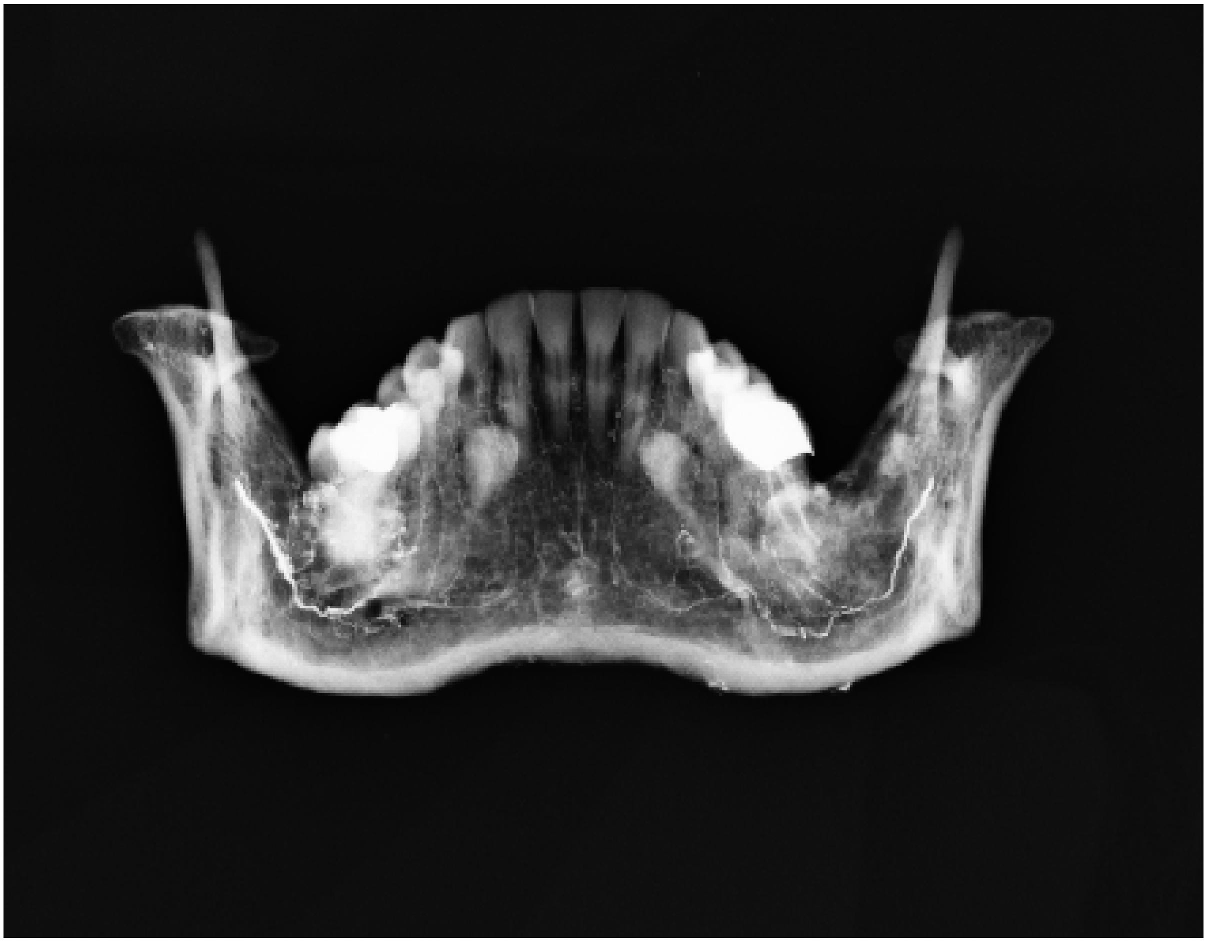


Figure 13- Anteriorposterior X-ray view after injection of the right facial artery, note that both inferior alveolar arteries contain contrast.

Figure 14- Oblique X-ray view shows again contrast in the bilateral inferior alveolar arteries.

Figure 15- Cranio-caudal X-rays view of the mandible.

Figure 16- Anteroposterior X-ray view of the middle third of the face, the contrast is present in both inferior alveolar arteries after injection of the right facial artery.

Figure 17- The greater palatine artery is contrasted bilaterally.

Figure 18- The contrast is also present in the most posterior part of the flap.

Figure 19- Naso-orbito-maxillo-zygomatic complex (frontal and superior aspect) harvested through the modified Le Fort III osteotomy and the mandible after removal of the soft tissues.

Traditional radiograms were used to screen the mandible and the midfacial complex for the presence of the contrast (figures 13-18). Thereafter in all specimens, CT scans (GE 64 slice Lightspeed VCT, General Electric Company, Waukesha, WI) of the mandible and the naso-orbito-maxillo-zygomatic complex were performed (slice thickness 0.6 mm).
Three-dimensional images and videos were reconstructed by GE Advantage workstation 4.2 software (General Electric Company, Waukesha, WI).
The CT scan images were used to investigate the presence of contrast in the different segments of the facial bones and in the following arteries: inferior alveolar, superior alveolar, infraorbital, major palatine, sphenopalatine (posterior septal branches, postero-lateral nasal branches) and anterior ethmoidal (anterior septal branches, antero-lateral nasal branches).

Results

Maxillary Artery Based Allografts

The origin of the inferior alveolar artery and the main trunk of the maxillary artery located within the infratemporal fossa were preserved. However, the terminal bifurcation in infraorbital and sphenopalatine arteries was damaged in bilaterally in 3 allografts. All of the branches to the cranial base were severed.

Soft Tissue Dissection

Constant anastomoses were apparent between the terminal branches of the facial artery and inferior alveolar artery, and between the facial artery and infraorbital artery (Figure 20-31).

Figure 20- Following injection of the lead oxide in the facial artery, an anastomotic connection with the inferior alveolar artery is evidenced at the level of the mental foramen. This artery runs along a branch of the mental nerve. Posteriorly, 2 branches of the facial artery supplying the parasymphyseal periostium are visible.

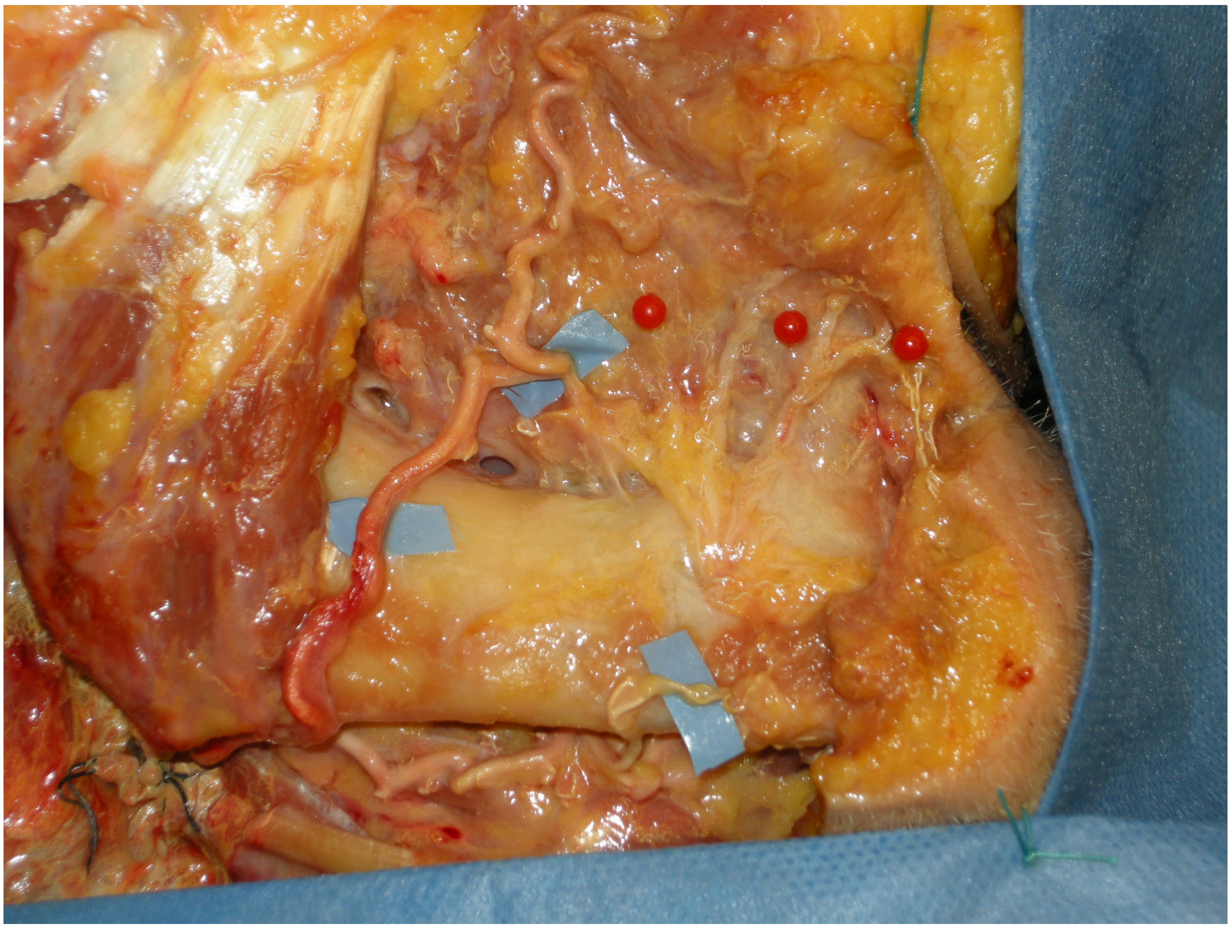


Figure 21- Multiple connections are present between the facial artery and the inferior alveolar artery at the level of the mental foramen.

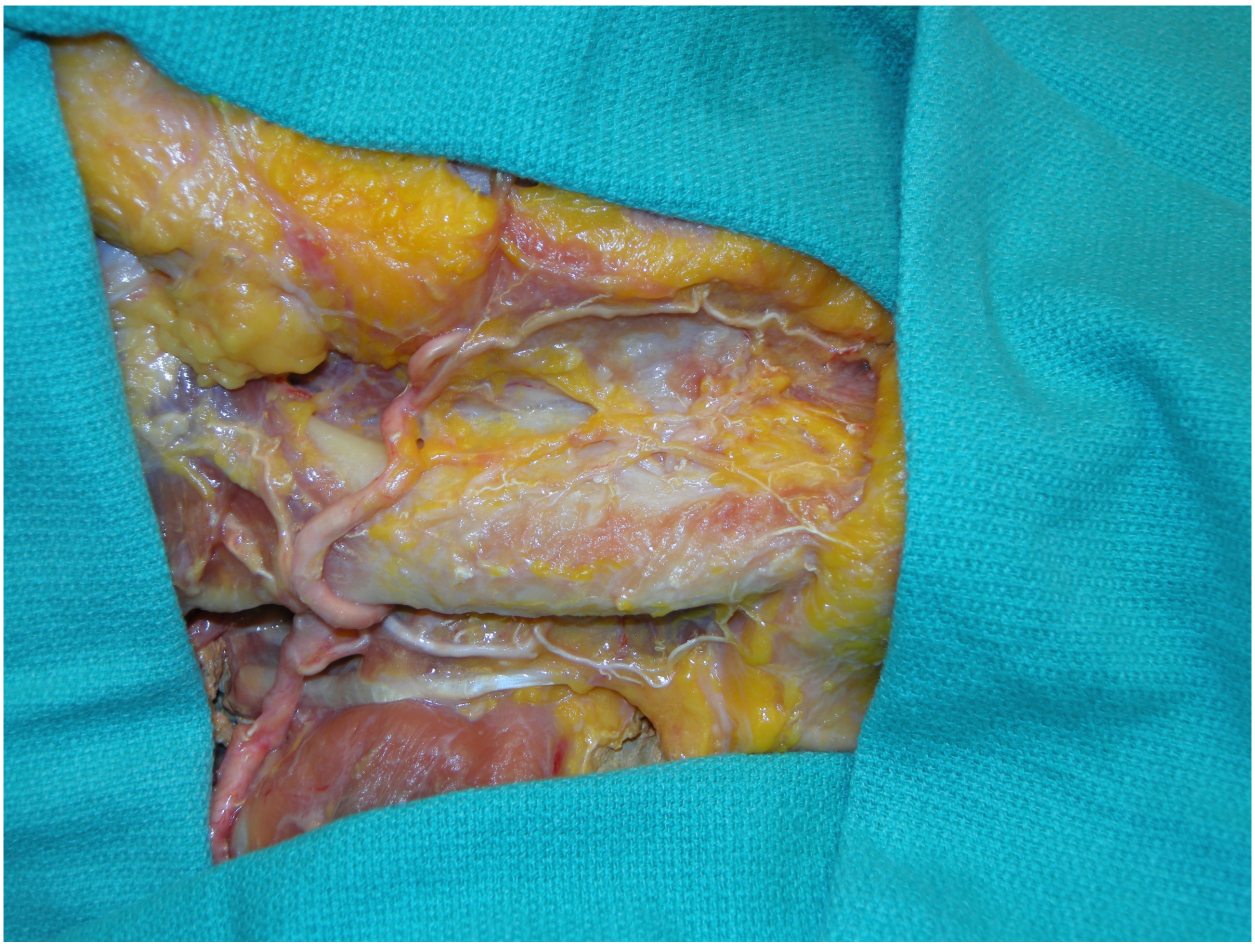


Figure 22- The submental artery in this case was also directly anastomosed with the inferior alveolar artery through the mental foramen.

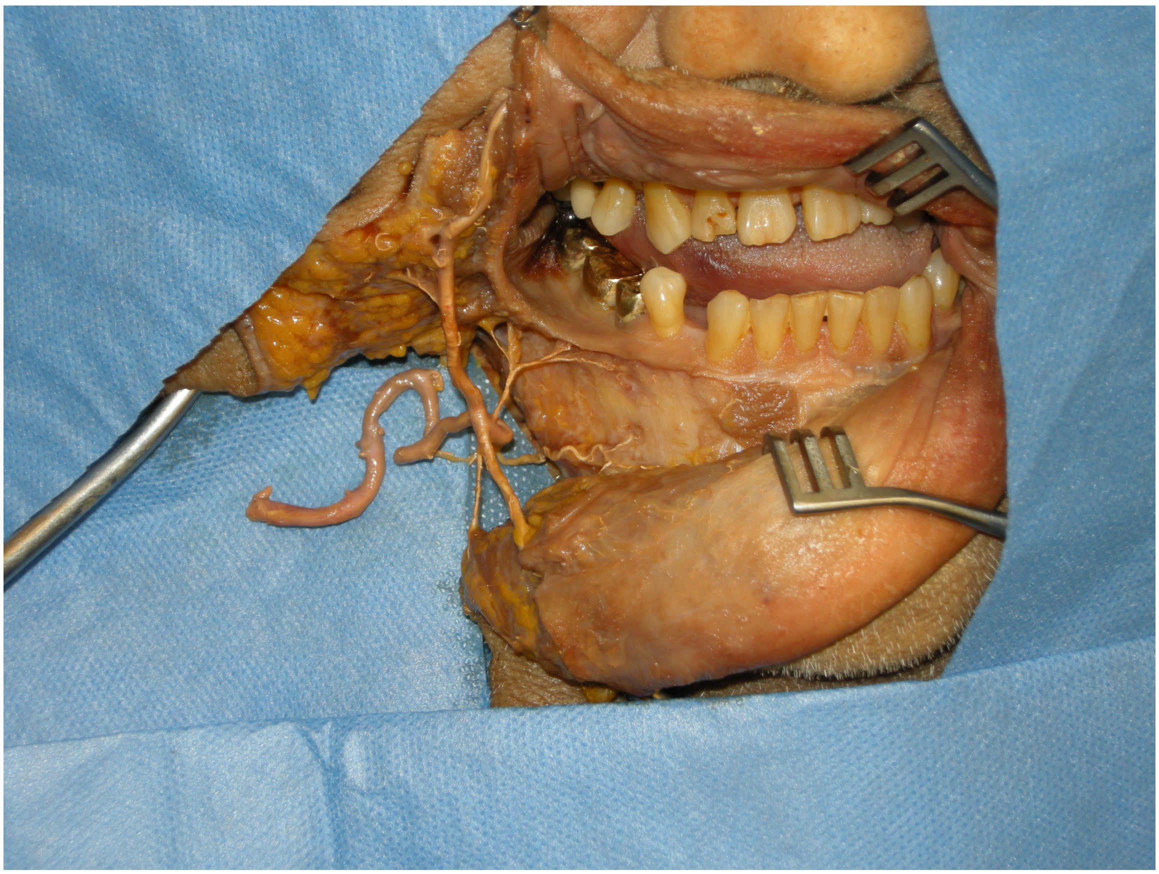


Figure 23- Facial artery is shown bifurcating into superior and inferior labial arteries. The anastomotic connection with the inferior alveolar artery at the mental foramen and a periosteal branch arise just before the bifurcation.

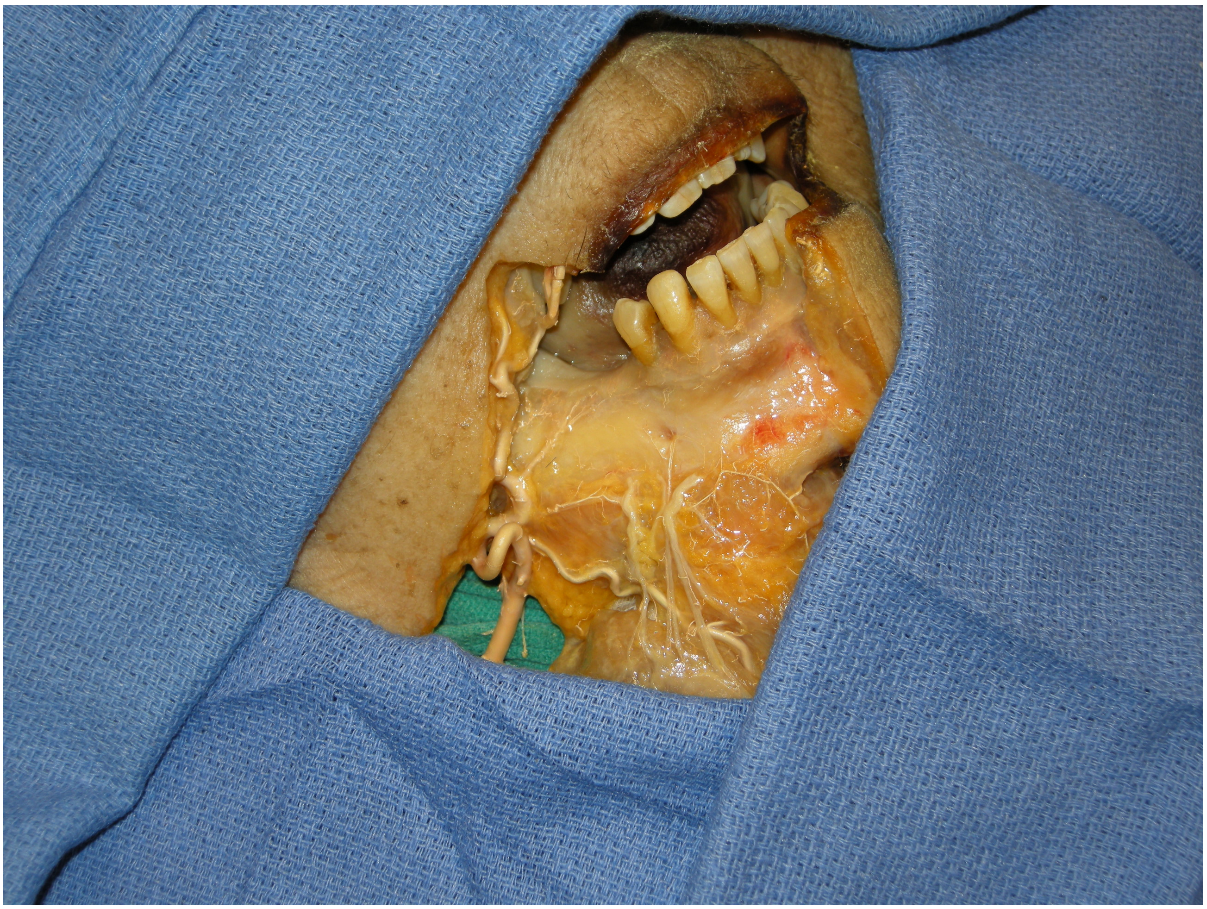


Figure 24- The facial artery branches are tightly interconnected with the mental nerve branches.

Figure 25- Multiple branches of the facial artery supply the vascularization to the periostium of the inferior part of the maxilla and alveolus.

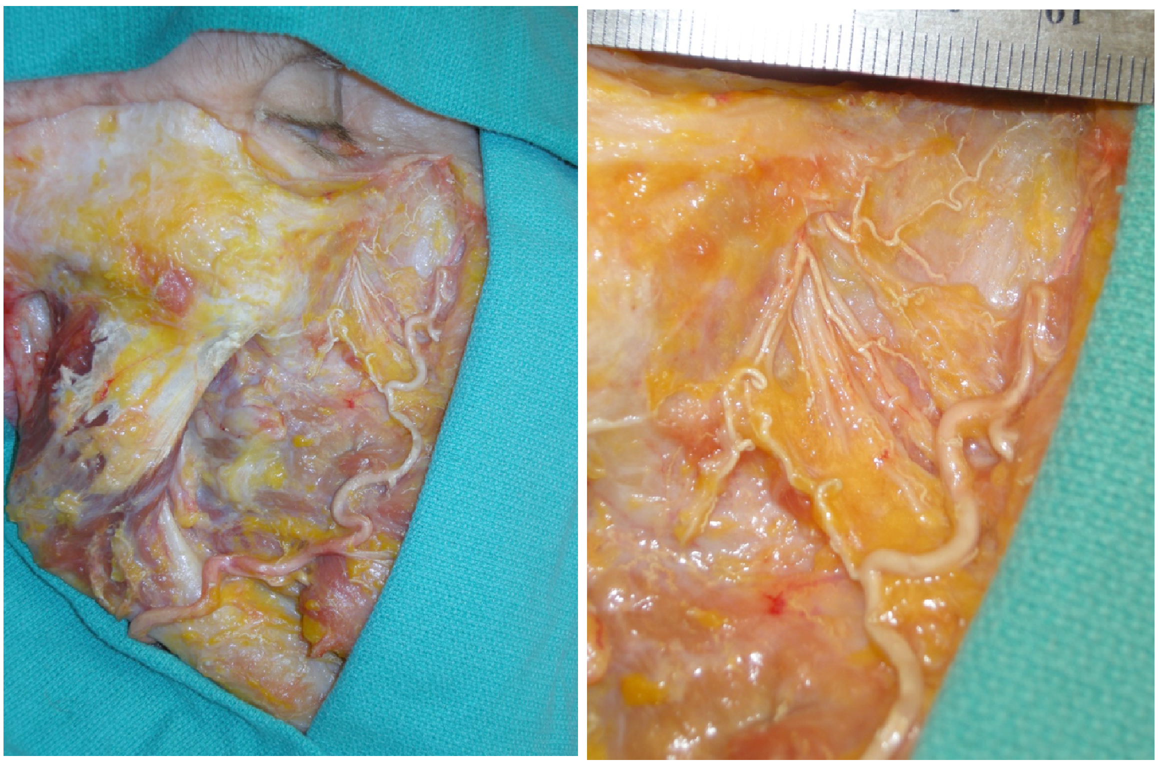


Figure 26- Multiple anastomotic connections are seen between the angular artery and the terminal branches of the infraorbital artery, running along the infraorbital nerve branches.

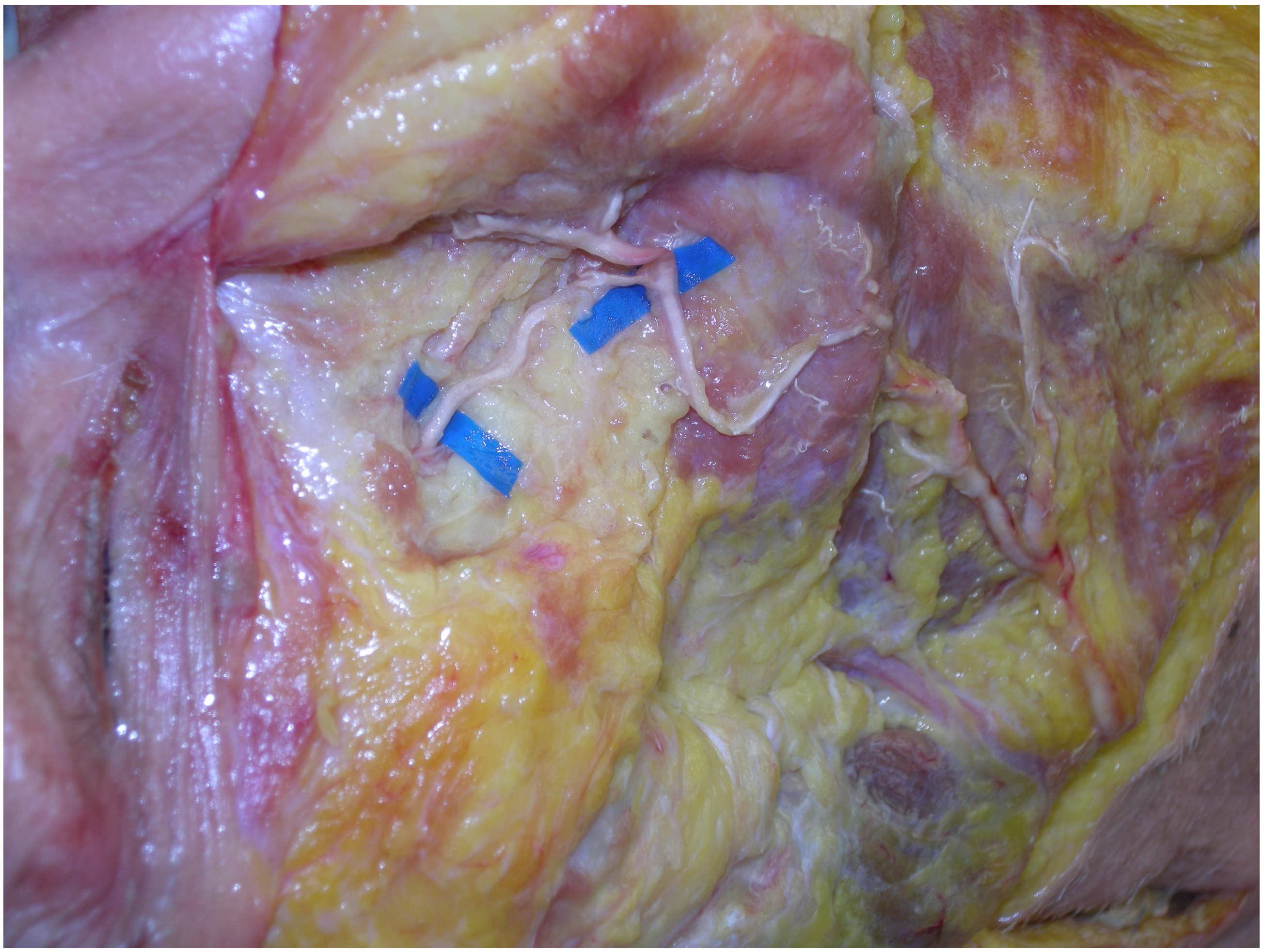


Figure 27- Connection between the facial artery and the infraorbital artery at the infraorbital foramen (the size of the connection is over 1 mm in this case).

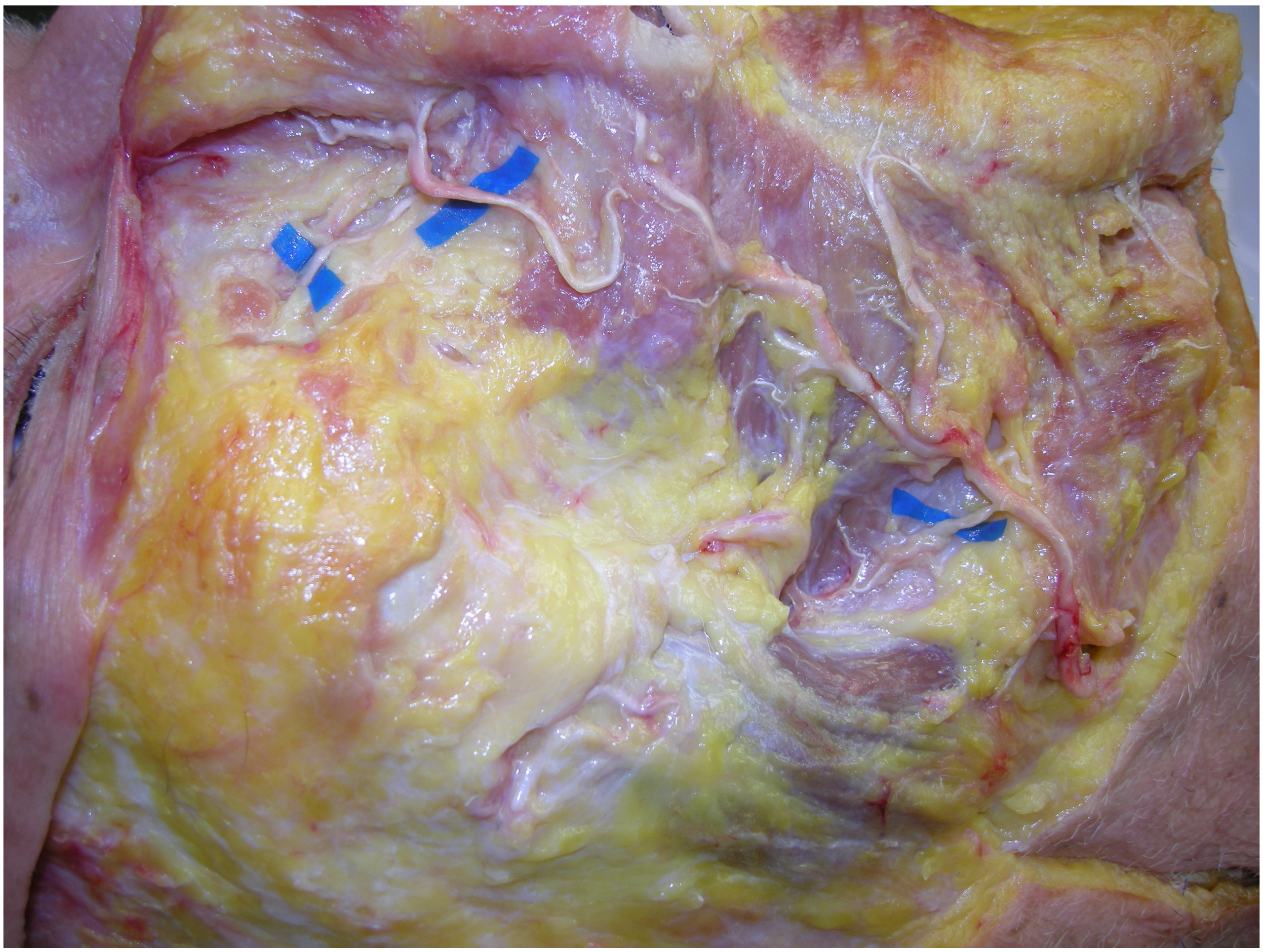


Figure 28- The facial artery was giving off a branch which was supplying directly the ramus and condyle of the mandible.

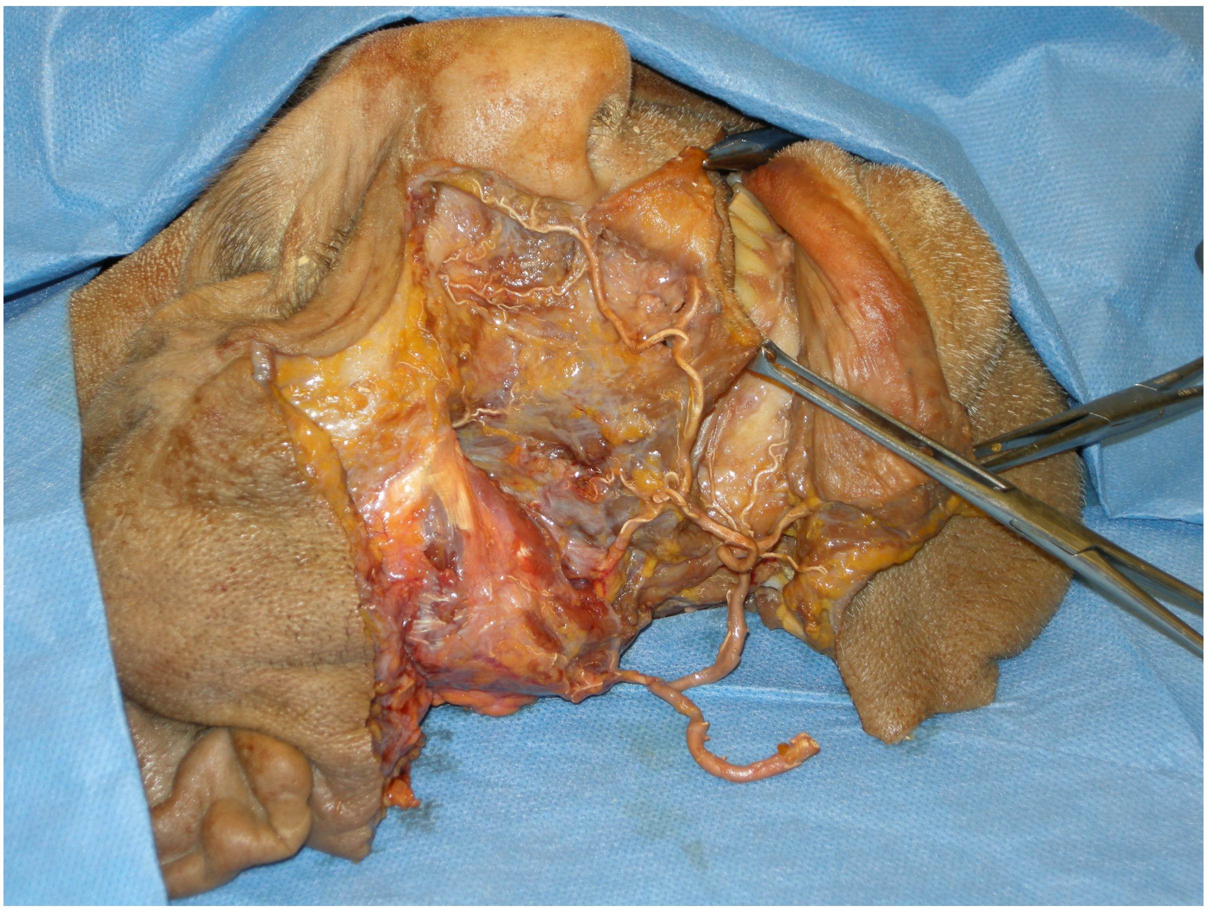


Figure 29- Facial artery course through the soft tissues with the different branches going to the bone.

These communications were at the level of the mental foramen (1-2 anastomotic branches, 0.2-1 mm in size) and at the level of the infraorbital foramen (2-3, 0.2-1 mm). The anastomotic branches communicating with the inferior alveolar artery originated from the facial artery just prior to its bifurcation into superior and inferior labial arteries or from the inferior labial artery. The branches communicating with the infraorbital artery arose from the superior labial artery, angular or lateral nasal arteries. All anastomotic branches followed the terminal divisions of the mental nerve and infraorbital nerve.

Periosteal branches originating from the facial artery were constantly present and were supplying the anterior cortex of the mandibular symphysis, body, angle and ramus, and the anterior cortex of body of the maxilla and nasal bones.

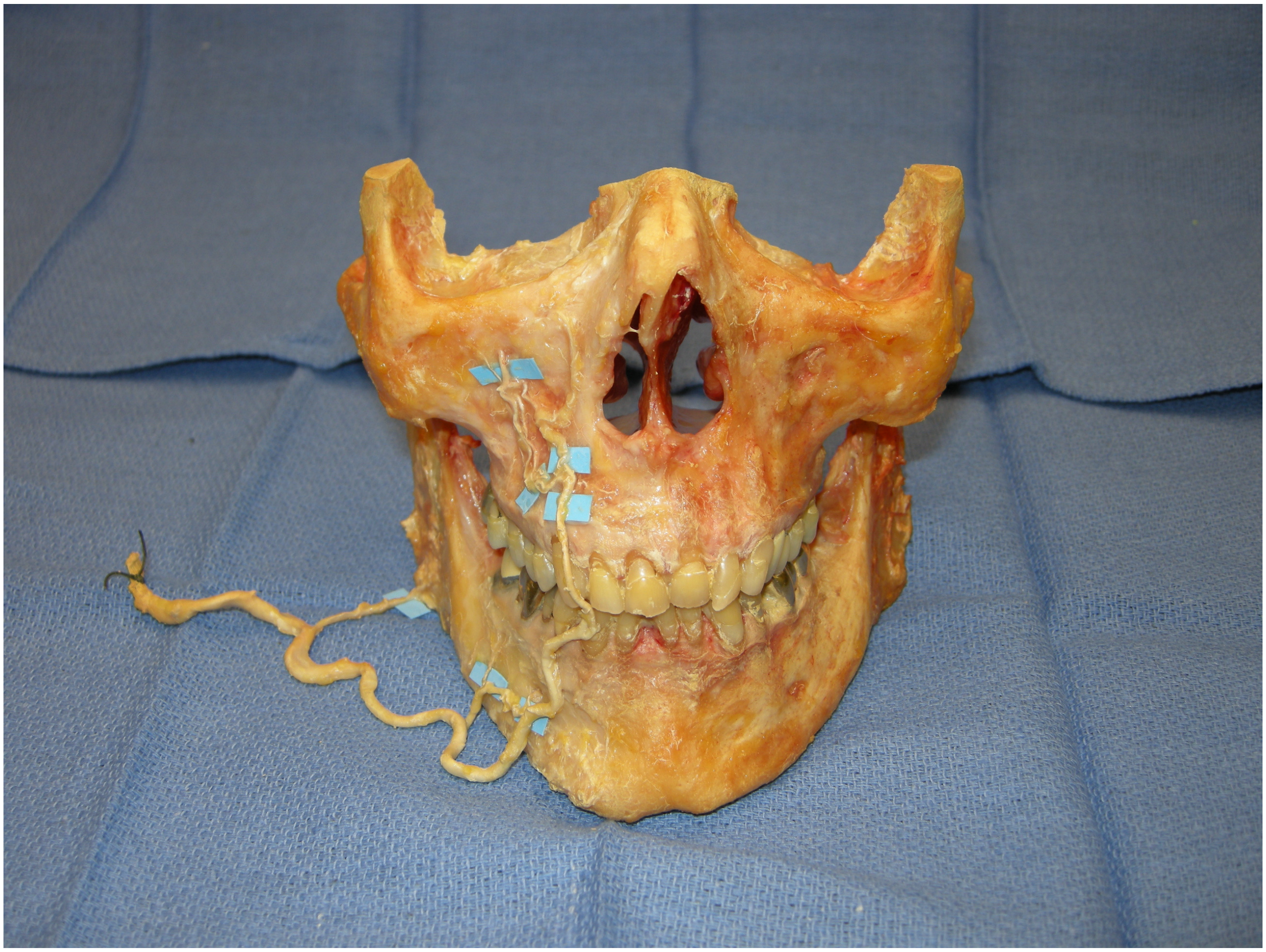


Figure 30- Both anastomotic connections between facial artery and inferior alveolar and infraorbital arteries and some of the periosteal branches to the mandible and maxilla are dissected (frontal view).

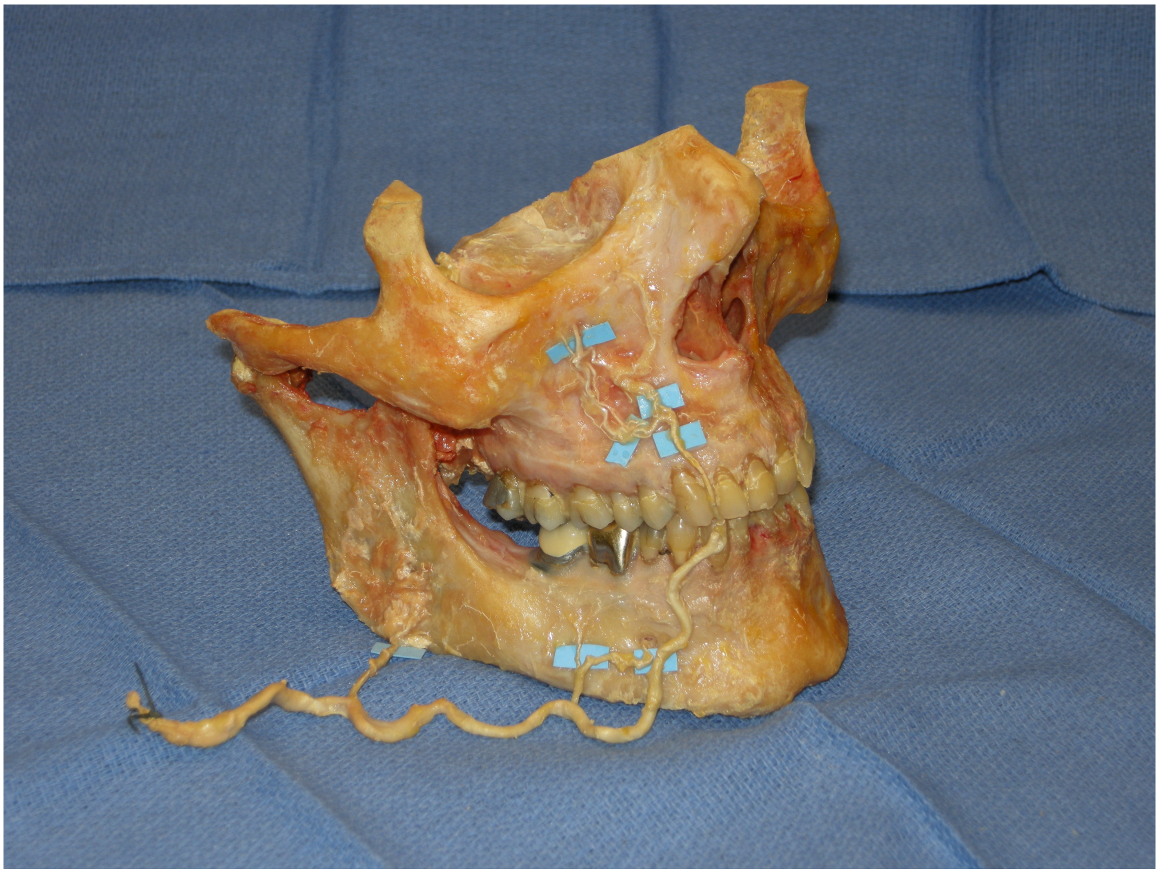


Figure 31- Both anastomotic connections between facial artery and inferior alveolar and infraorbital arteries and some of the periosteal branches to the mandible and maxilla are dissected (lateral view).

Consistent anastomoses were observed between the transverse facial artery and branches of the facial and infraorbital arteries.
The facial artery supplied branches to the buccal mucosa and the deep fat pad.

Radiograms and Computed Tomography Scans

In the following description, “head” indicates where only a selective injection of one of the 3 arteries was performed as opposed to “allograft” where the injection was performed after the flap was raised. Perfusion data are summarized in Tables 1 and 2.

Mandible

Facial artery vascularized the homolateral symphysis, alveolar process, body and ramus in all heads and allografts. The homolateral condyle was vascularized in 57% of the heads and 67% of the allografts. The homolateral coronoid process was perfused in 43% of the heads and 67% of the allografts. Contrast was present at the mental foramen, in the inferior alveolar artery and in the branches ending in the central foramina and central canals of the teeth as well as in the periodontal dentogingival plexus (Figure 32-33).
Facial artery vascularized the controlateral symphysis (100%), body, ramus and alveolar process (71%) of the heads. In the allografts, the contrast was present in 100% of the symphysis and mandibular bodies and 83% of the

rami and alveolar processes. The condylar and coronoid processes of the controlateral side were the least perfused (figure 38-44)

The maxillary artery did not perfuse the controlateral mandible.

	Mandible						Maxilla						Zygomatic Bone				Palate	Nasal cavity		Orbit			Temporal Bone
Injected Artery	Symphysis	Body	Ramus	Condyle	Coronoid Process	Alveolar Process	Alveolar Process	Zygomatic Process	Frontal Process	Orbital Plate	Palatine Process	Sinus	Frontal Process	Temporal Process	Maxillary Process	Body	Palate	Lateral Wall	Septum	Medial Wall	Floor	Lateral Wall	Zygomatic Process
Maxillary Artery	67.7	67.7	67.7	100	100	67.7	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Superficial Temporal Artery	0	100	100	67.7	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Facial Artery (Head)	100	100	100	57.1	42.9	100	85.7	71.4	71.4	100	100	100	42.9	42.9	85.7	57.1	71.4	85.7	85.7	57.1	100	57.1	42.9
Facial Artery (Allograft)	100	100	100	66.7	66.7	100	71.4	100	100	100	71.4	100	71.4	66.7	100	71.4	71.4	71.4	71.4	100	100	100	50

Table 1- The presence of the contrast in the different **homolateral** bone segments was expressed as the percentage of the specimens which contained the contrast over the total number of injected specimen.

Injected Artery	Symphysis	Body	Ramus	Condyle	Coronoid Process	Alveolar Process	Alveolar Process	Zygomatic Process	Frontal Process	Orbital Plate	Palatine Process	Sinus	Frontal Process	Temporal Process	Maxillary Process	Body	Palate	Lateral Wall	septum	Medial Wall	Floor	Lateral Wall	Zygomatic Process
Maxillary Artery	0	0	0	0	0	0	100	0	100	66.7	100	66.7	0	0	0	0	100	66.7	100	0	66.7	0	0
Superficial Temporal Artery	0	0	66.7	0	0	0	0	0	66.7	66.7	66.7	0	66.7	0	0	0	0	0	66.7	66.7	100	66.7	0
Facial Artery (Head)	100	71.4	71.4	0	0	71.4	71.4	28.6	57.1	71.4	71.4	85.7	28.6	14.3	28.6	14.3	71.4	57.1	57.1	28.6	71.4	14.3	14.3
Facial Artery (Allograft)	100	100	83.3	16.7	33.3	83.3	83.3	83.3	100	100	83.3	83.3	83.3	83.3	83.3	83.3	83.3	83.3	83.3	83.3	100	83.3	50

Table 2- The presence of the contrast in the different **controlateral** bone segments was expressed as the percentage of the specimens which contained the contrast over the total number of the injected specimen.

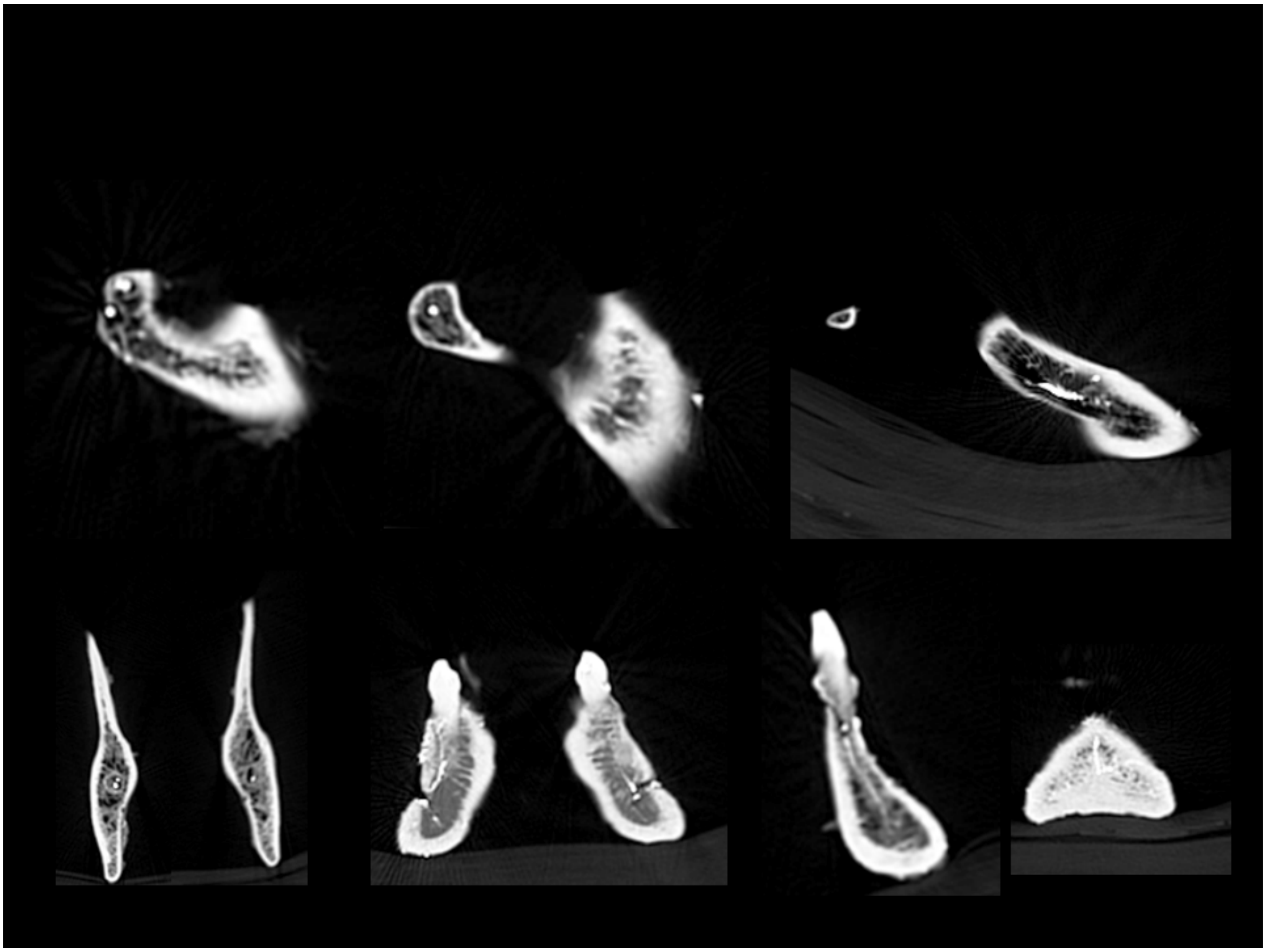


Figure 32- CT scan of the mandible after injection of the lead oxide gel in the right facial artery confirms the presence of contrast at the level of condyle, coronoid process, ramus, angle (within the inferior alveolar canal), mental foramen and symphysis (*From top left to bottom right*). Central canal arteries to the teeth and affluents to the periodontal dentogingival plexus contained the contrast.

Maxilla

The contrast was present in all components of the maxilla in more than 71% of the heads and allografts and in the mucosa of the maxillary sinus (100%). The controlateral maxilla was well perfused in the allografts based on facial artery (>83%). In the injected heads, the zygomatic and the frontal processes of the maxilla represented areas of weakness with contrast being detected in 28% and 57% of the cases respectively (Figure 34).

The maxillary artery contributed to the vascularization of the controlateral palatine process. The orbital process and the body of maxilla were less perfused when compared to the facial artery (figure 45-53).

Zygomatic Bone

The body (57%), the frontal and temporal processes (43%) of the zygomatic bone were the least vascularized parts in the injected heads. The allografts contained the contrast in at least 71% of the specimen (Figure 37).

The facial artery perfused well the controlateral zygomatic bone (>83%) in the allografts. The maxillary artery did not contribute to the vascularization of the controlateral zygomatic bone.

Palatine bones and nose

The palatine bones and all components of the nasal cavity were well perfused (>71%). (Figure 35-36).

The controlateral palatine and nasal bones contained the contrast in at least 83% of the allografts. The perfusion was less in the injected heads (71% of the palatine bones and 57% of the septa and lateral nasal walls).

The contribution of the maxillary artery to the controlateral nose was slightly better than the facial artery in the palatine and septal components (100%) and slightly worse in the lateral components (67%).

Orbit

The orbital floor contained the contrast in 100% of the injected heads and allografts. In the allografts, the medial and lateral walls of the orbit contained the contrast in all cases, while in the injected heads the vascularization decreased to 57%.

Facial artery vascularized the controlateral orbital walls and floor in the allografts. In the injected heads, the orbital floor contained the contrast in 71% of the cases, while the lateral and medial orbital walls were less perfused (14% and 28%).

Maxillary artery perfused 67% of the controlateral orbital floors, while the lateral and medial orbital walls did not contain the contrast.

Zygomatic Process of the Temporal Bone

This bone presented the lowest perfusion values: 43% of the injected heads and 50% of the allografts were stained.

Facial artery contributed to the vascularization of the zygomatic process of the temporal bone in 50% of the allografts. This contribution was less in the injected heads (14%).

The maxillary artery did not perfuse the controlateral zygomatic process of the temporal bone.

Presence of the Contrast in the Intraosseus Arteries

Following injection of the lead oxide gel in the facial artery, the main homolateral arteries were stained in more than 83% of the allografts (Table

3). The injected heads presented a similar pattern of perfusion with exception of the posterior septal branches of the sphenopalatine artery. Controlaterally, the staining was consistently less and paralleled the observed perfusion of the bones.

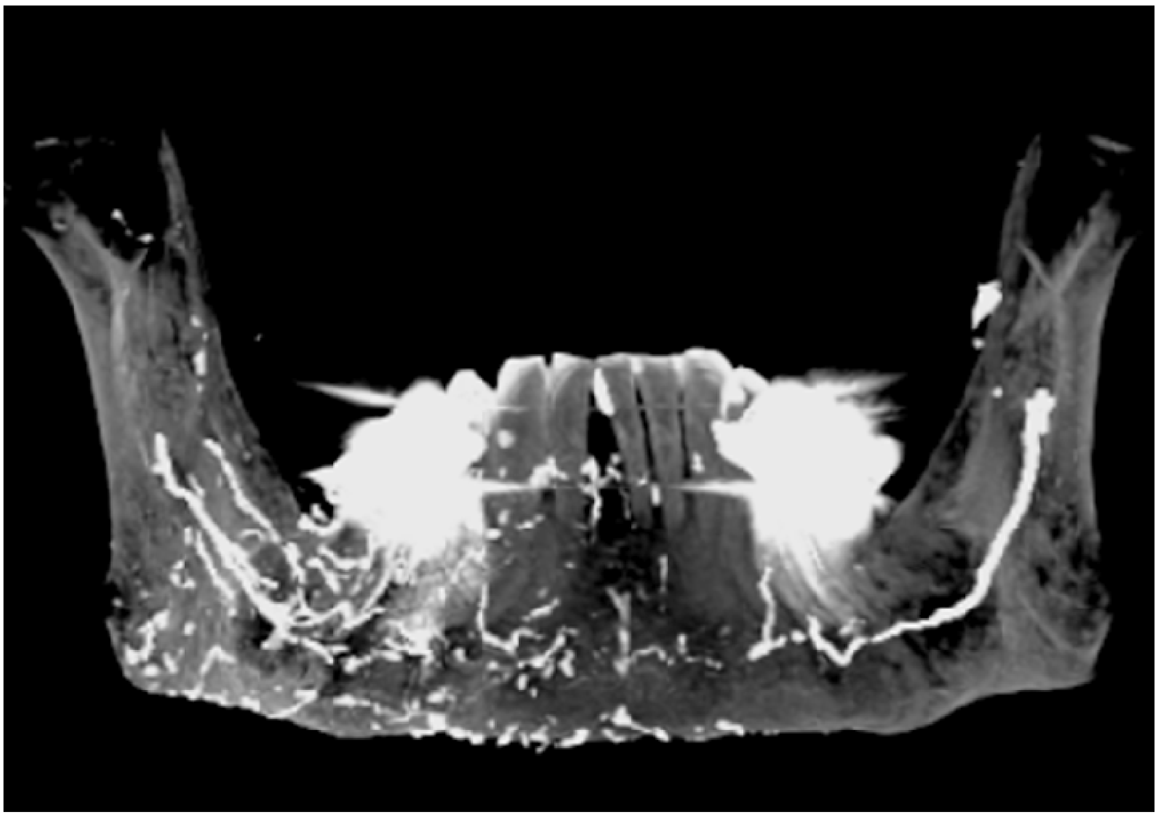


Figure 33- The contrast is present in both homolateral and controlateral inferior alveolar arteries. The right side of the mandible contains more contrast than the left side at the level of the periostium.

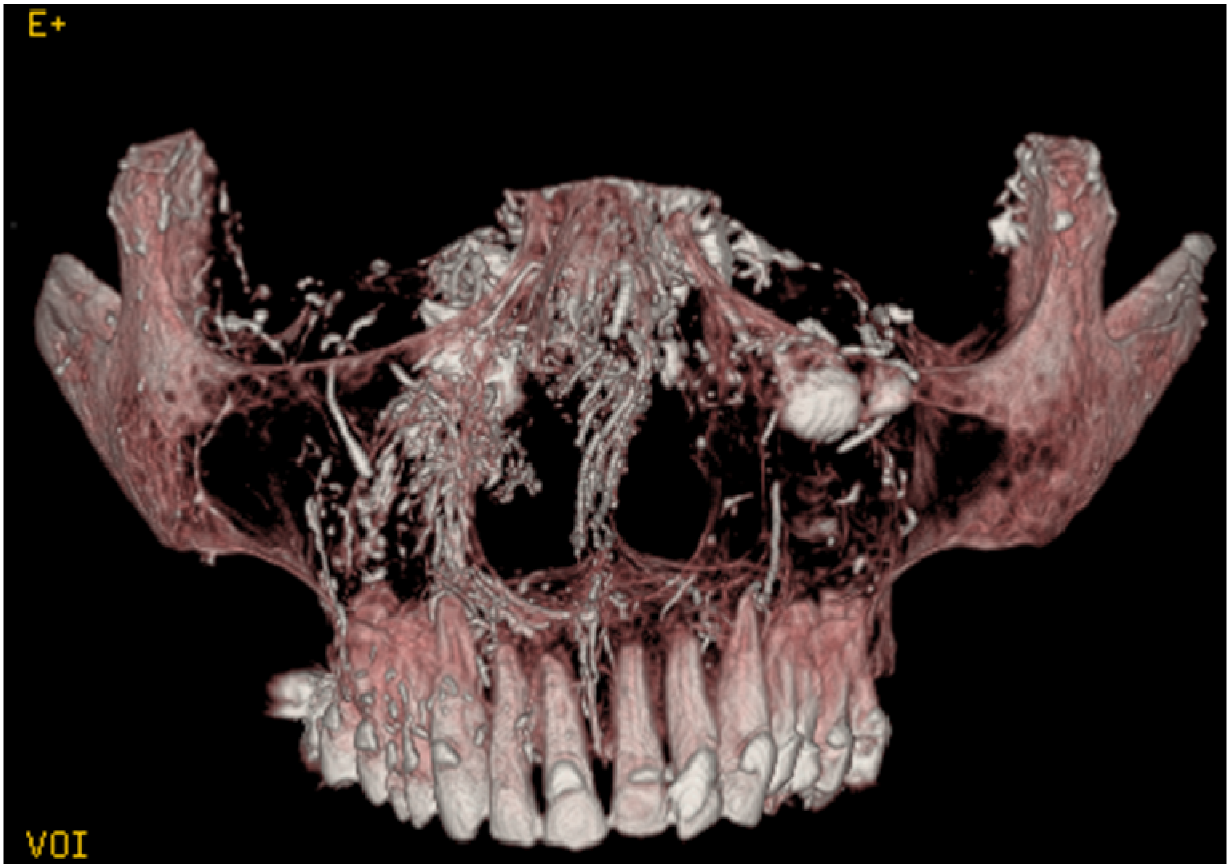


Figure 34- The descending palatine artery is seen in the pterygopalatine canal, emerging from the greater palatine foramen and coursing forward in a groove on the medial side of the alveolar border of the hard palate to the incisive canal. The contrast material is present also in the palatine mucosa.

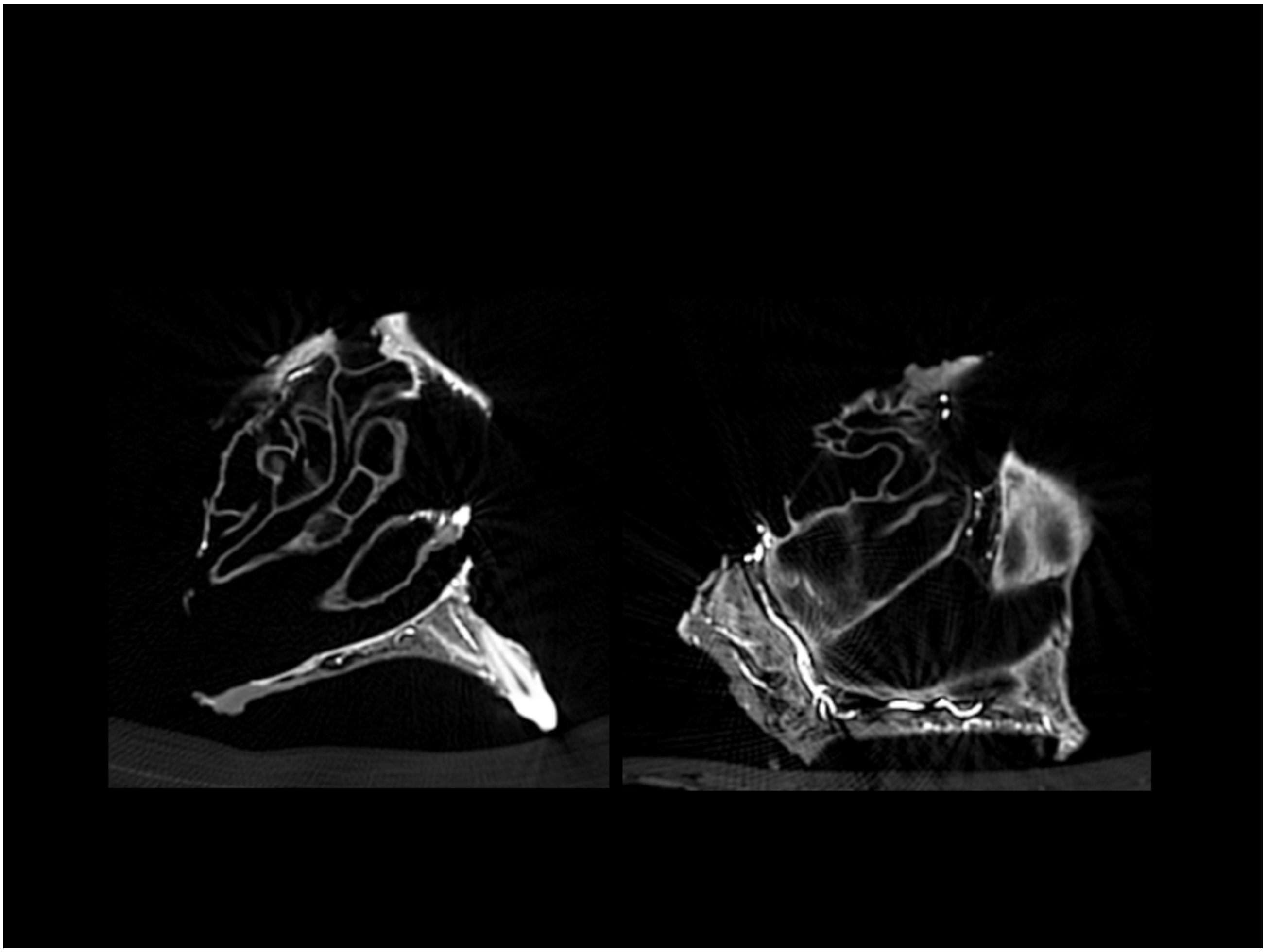


Figure 35- The contrast is shown in the mucosal lining of the turbinates, nasal septum and palatal gingiva as well as in palate and nasal bones.

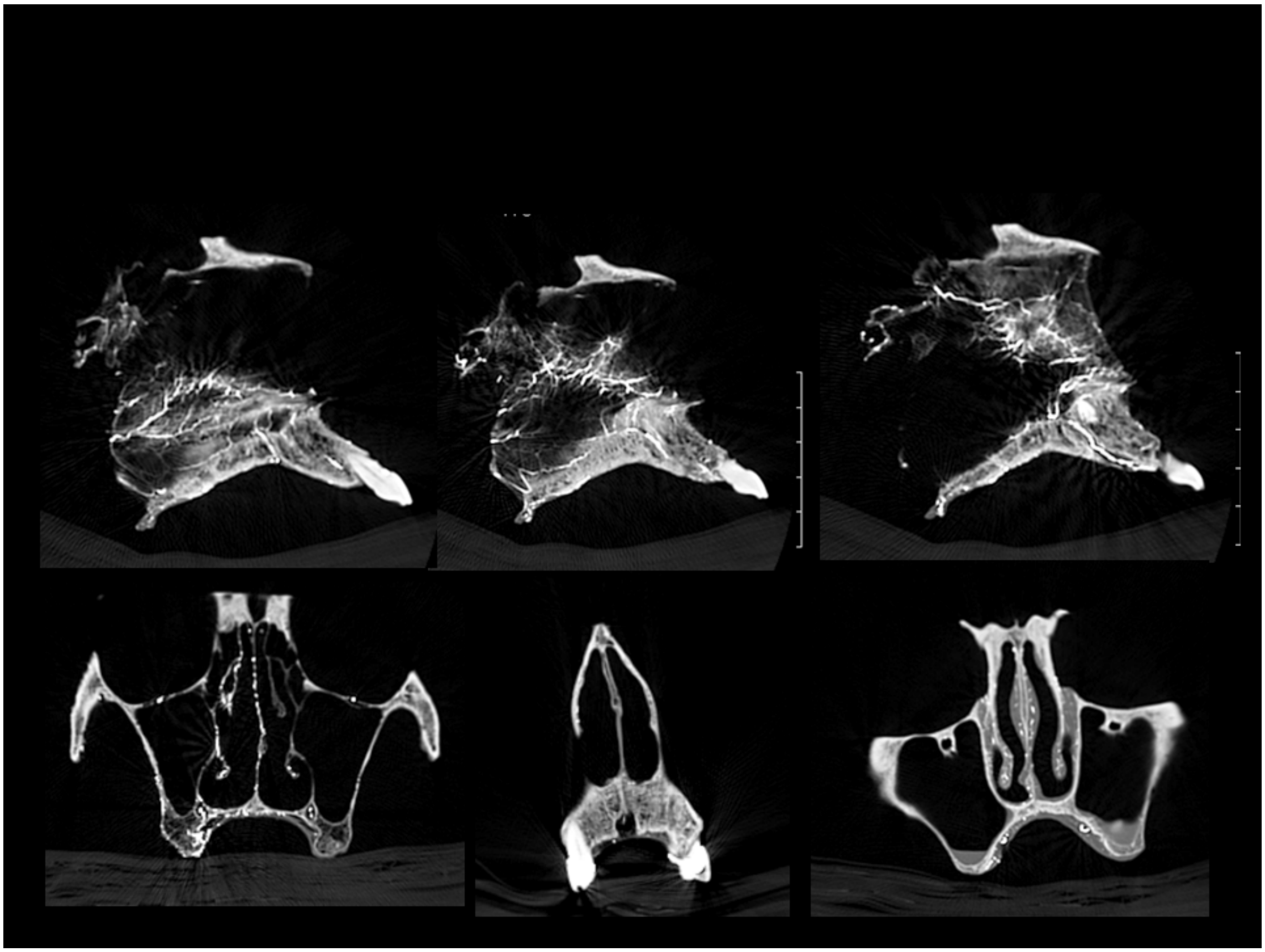


Figure 36- The contrast is present in the infraorbital artery. The lateral orbital wall, the body of zygomatic bone and the zygomatic process of the temporal bone contain the contrast in this specimen.

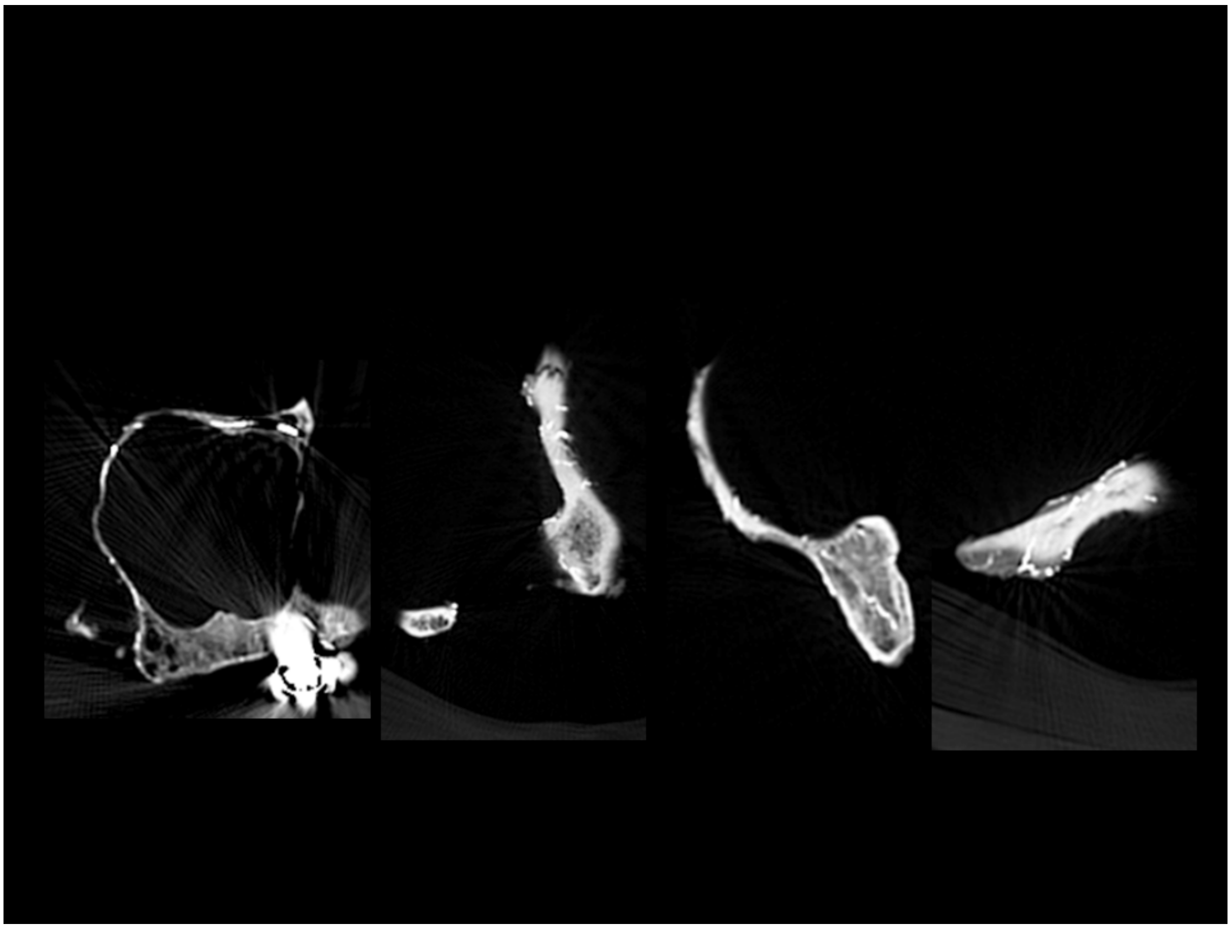


Figure 37- The contrast is present in the infraorbital artery. The lateral orbital wall, the body of zygomatic bone and the zygomatic process of the temporal bone contain the contrast in this specimen.

Injected Artery	Inferior Alveolar Artery, H	Inferior Alveolar Artery, C	Superior Alveolar Artery, H	Superior Alveolar Artery, C	Infraorbital Artery, H	Infraorbital Artery, C	Major Palatine Artery, H	Major Palatine Artery, C	Posterior Septal Branches of the Sphenopalatine Artery, H	Posterior Septal Branches of the Sphenopalatine Artery, C	Postero- lateral Nasal Branches of the Sphenopalatine Artery, H	Postero- lateral Nasal Branches of the Sphenopalatine Artery, C	Anterior Septal Branches of the Anterior Ethmoidal Artery, H	Anterior Septal Branches of the Anterior Ethmoidal Artery, C	Anterior Lateral Nasal Branches of the Anterior Ethmoidal Artery, H	Anterior Lateral Nasal Branches of the Anterior Ethmoidal Artery, H
Maxillary Artery	67.7	0.0	100.0	100.0	100.0	67.7	100.0	100.0	100.0	67.7	100.0	100.0	100.0	100.0	100.0	100.0
Superficial Temporal Artery	100.0	0.0	100.0	0.0	100.0	67.7	100.0	67.7	100.0	67.7	100.0	0.0	67.7	67.7	100.0	0.0
Facial Artery (Head)	100.0	71.4	85.7	57.1	100.0	85.7	85.7	71.4	42.9	42.9	85.7	25.7	71.4	57.1	85.7	57.1
Facial Artery (Allograft)	100.0	83.3	83.3	83.3	100.0	100.0	83.3	66.7	83.3	66.7	83.3	66.7	100.0	100.0	100.0	100.0

Table 3-The presence of the contrast in the different intraosseous arteries was expressed as the percentage of the specimens which contained the contrast over the total number of the injected specimens. P, process; H, Homolateral; C, Controlateral

Angiography of the Facial Artery

Angiography of the facial artery revealed retrograde flow of the contrast, through the infraorbito-facial anastomosis, in the infraorbital artery and the maxillary artery. Within the inferior alveolar artery the contrast became evident at the junction of mandibular body and ramus flowing retrogradely in the direction of the condyle (Figure 54-58).

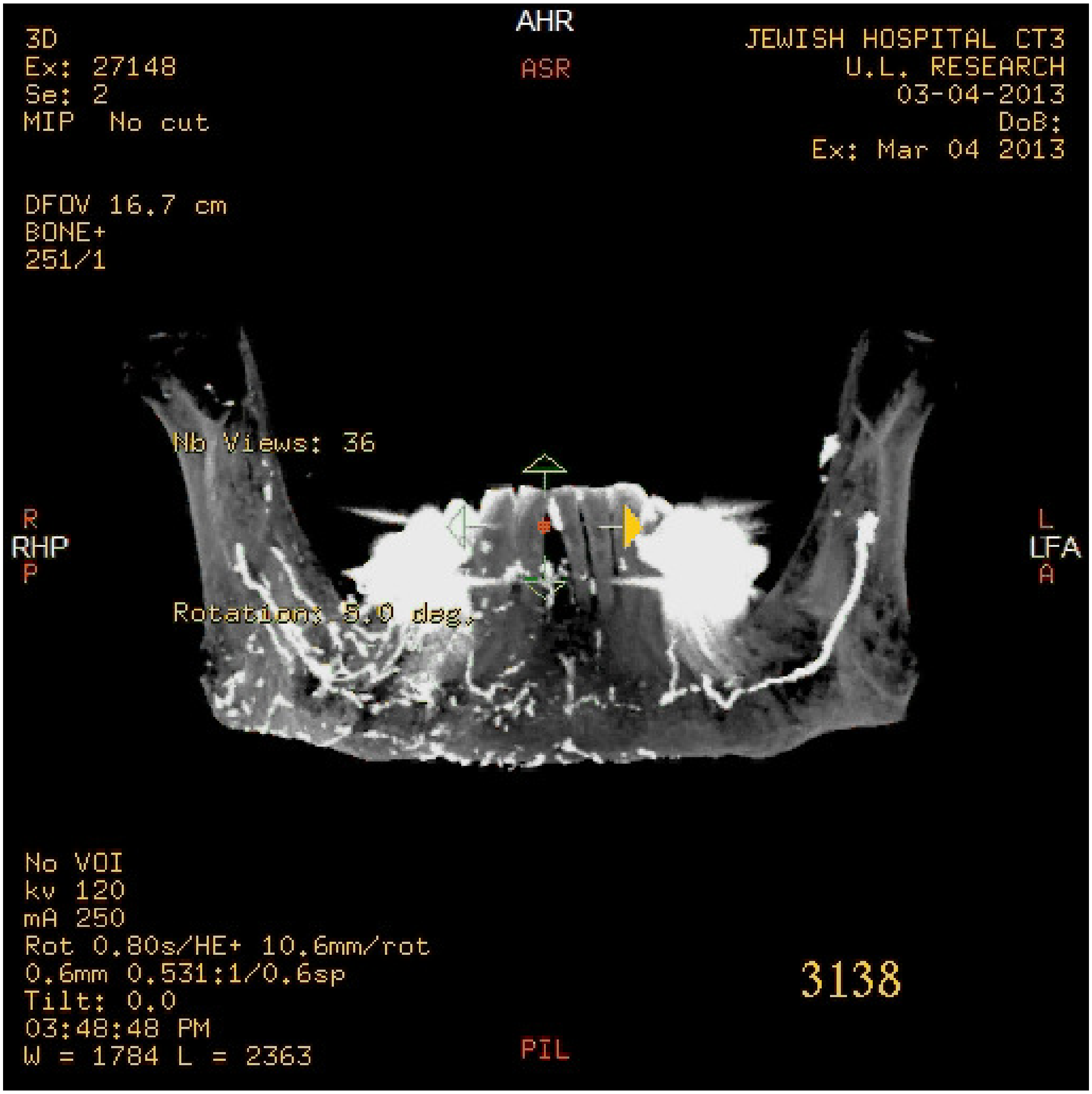


Figure 38- The contrast is present in both homolateral and controlateral inferior alveolar arteries. The right side of the mandible contains more contrast than the left side.

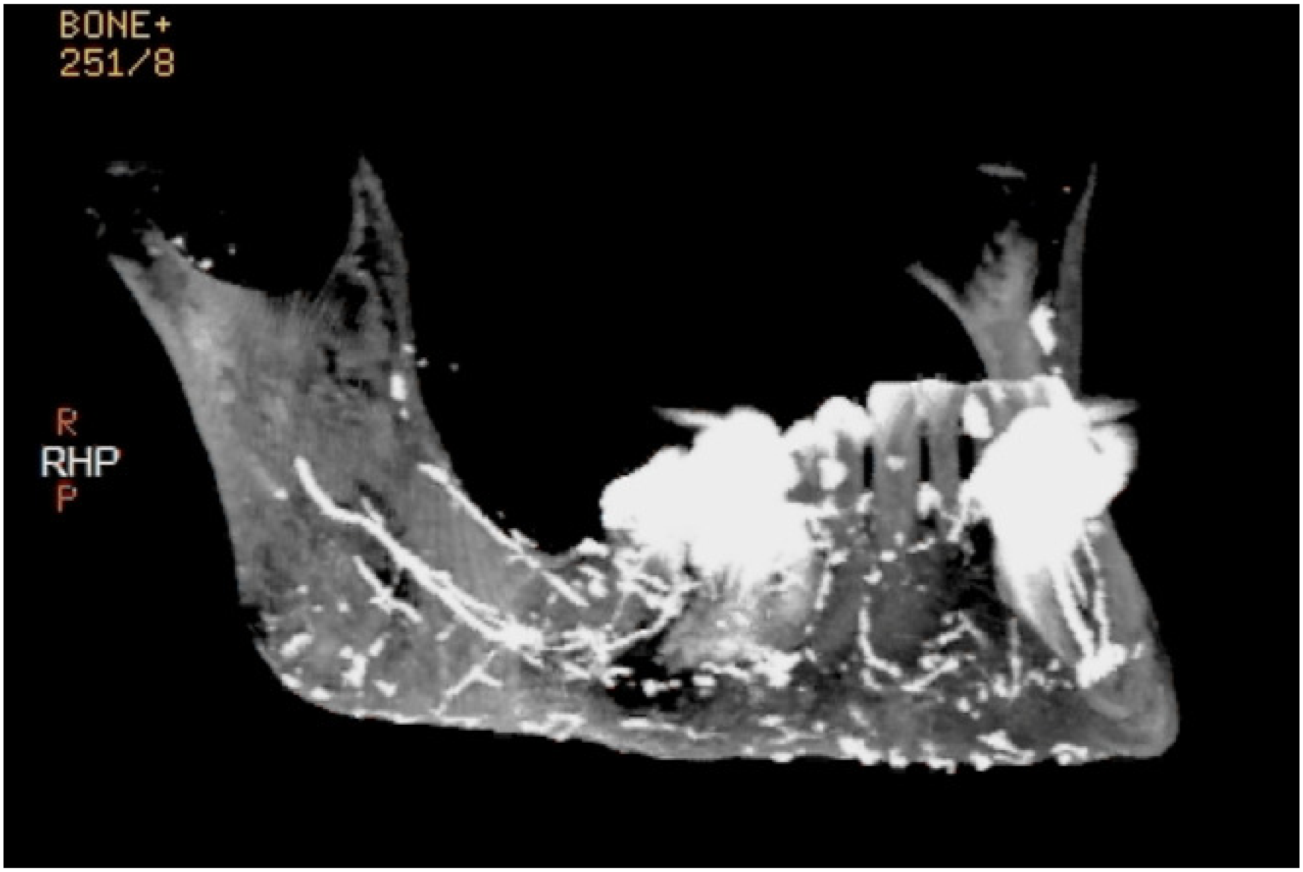


Figure 39- The contrast is present in both homolateral and controlateral inferior alveolar arteries. The right side of the mandible contains more contrast than the left side (oblique view).

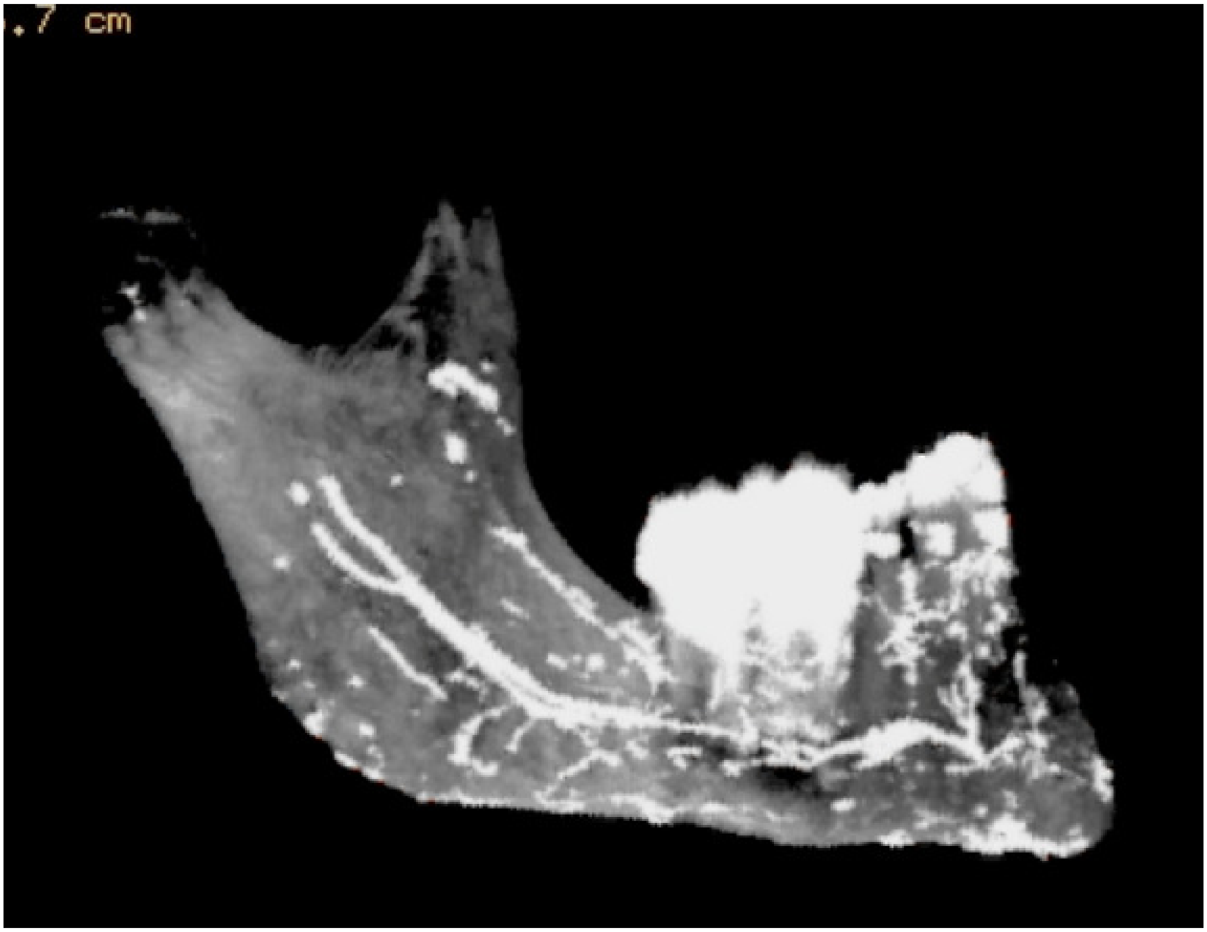


Figure 40- The contrast is present in both homolateral and controlateral inferior alveolar arteries. The right side of the mandible contains more contrast than the left side (lateral view).

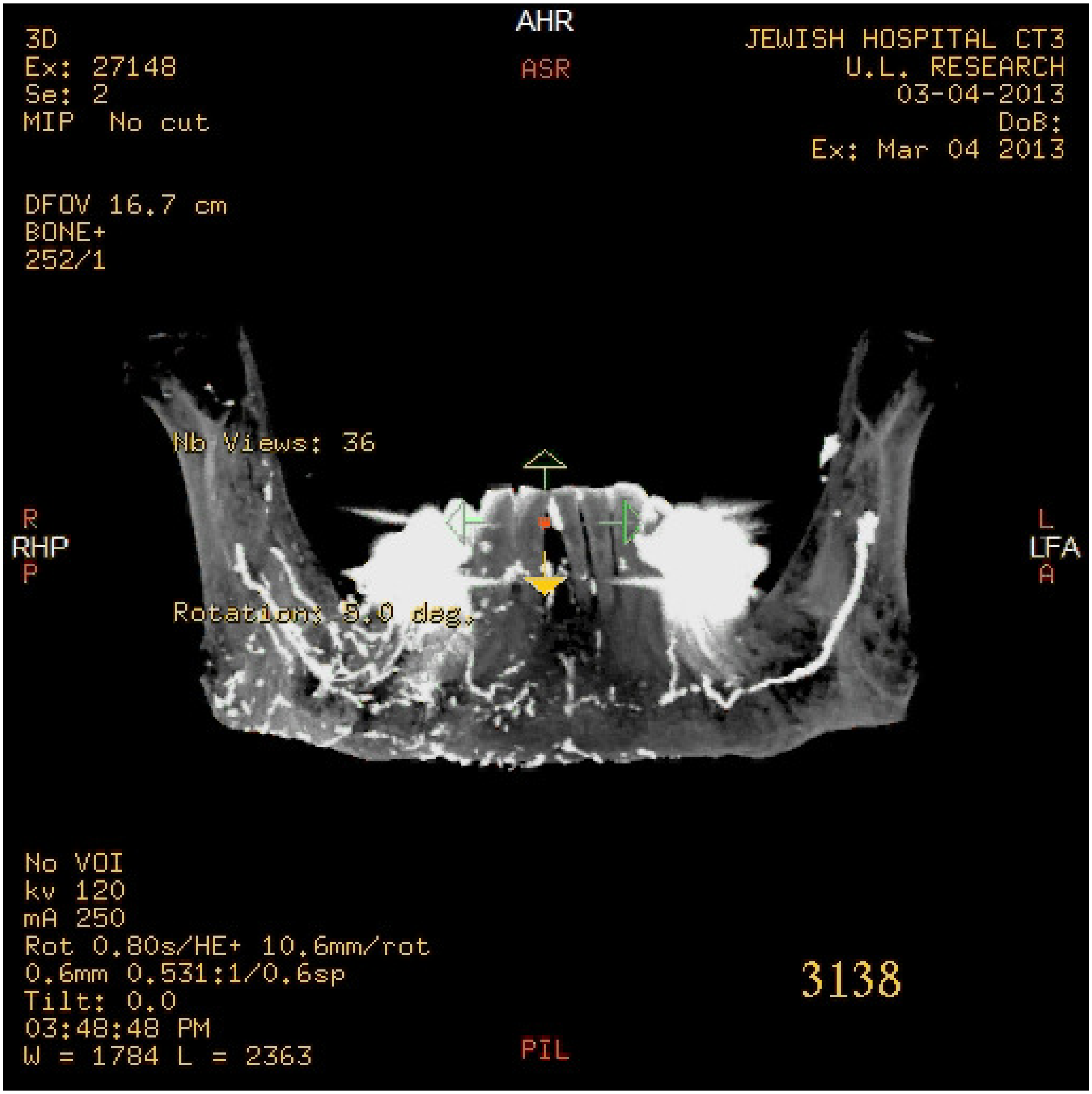


Figure 41- The contrast is present in both homolateral and controlateral inferior alveolar arteries. The right side of the mandible contains more contrast than the left side.

Figure 42- The contrast is present in both homolateral and controlateral inferior alveolar arteries. The right side of the mandible contains more contrast than the left side (antero-superior view).

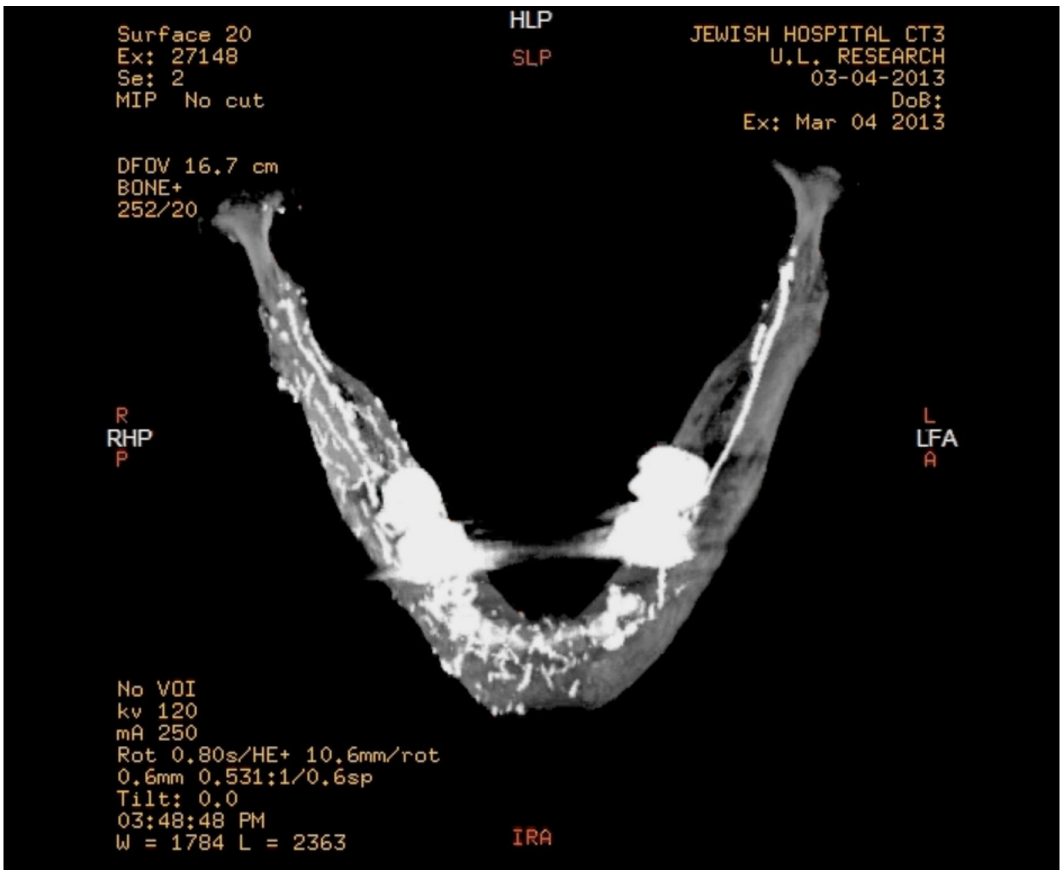


Figure 43- The contrast is present in both homolateral and controlateral inferior alveolar arteries. The right side of the mandible contains more contrast than the left side (superior view).

Figure 44- The contrast is present in both homolateral and controlateral inferior alveolar arteries. The right side of the mandible contains more contrast than the left side (posterior view).

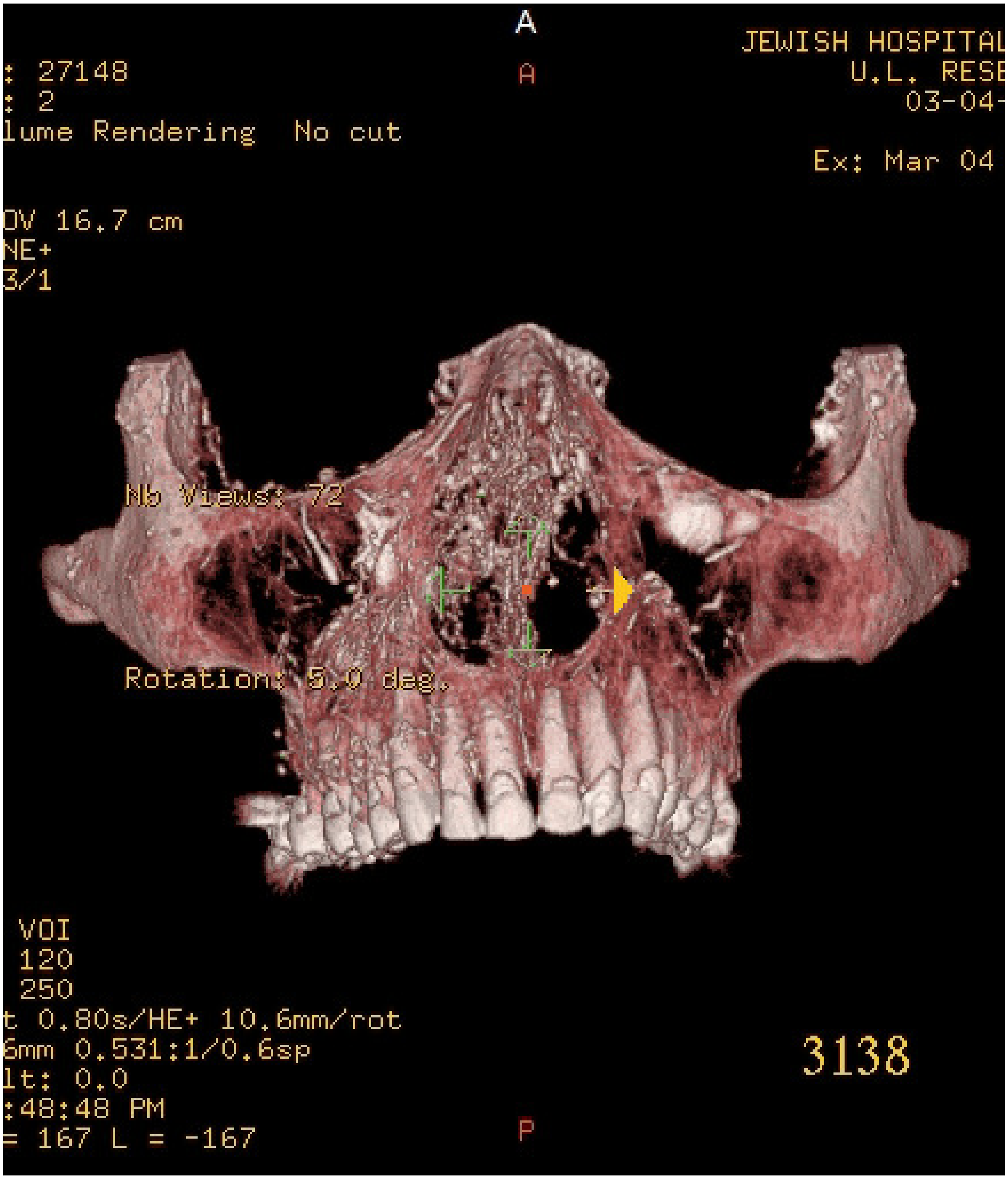


Figure 45- The contrast is present in both homolateral and controlateral infraorbital and palatine arteries, as well as in the mucosal lining of the nose and the walls of the maxillary sinus, body of the zygomatic bone and zygomatic process of the temporal bone. The right side contains more contrast than the left side.

Figure 46- The contrast is present in both homolateral and controlateral infraorbital and palatine arteries, as well as in the mucosal lining of the nose and the walls of the maxillary sinus, body of the zygomatic bone and zygomatic process of the temporal bone. The right side contains more contrast than the left side (oblique view).

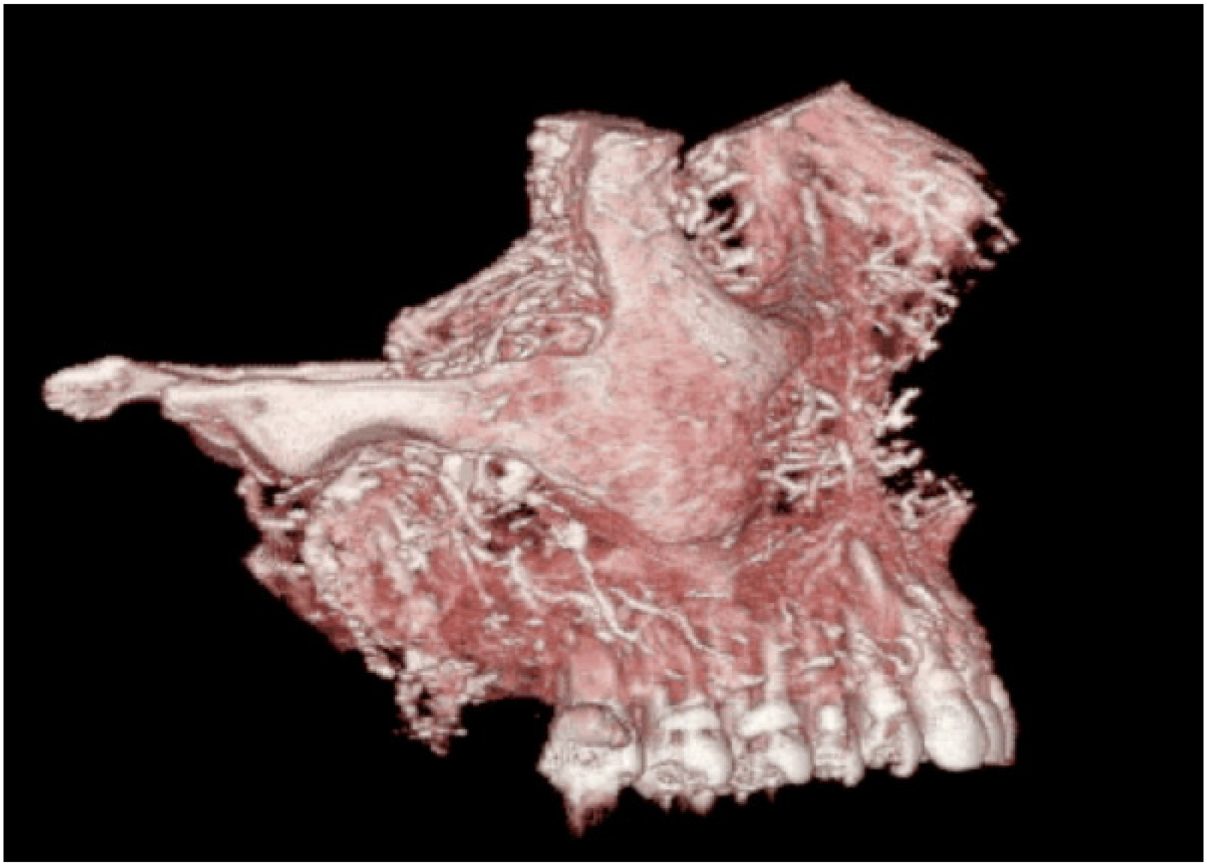


Figure 47- The contrast is present in both homolateral and controlateral infraorbital and palatine arteries, as well as in the mucosal lining of the nose and the walls of the maxillary sinus, body of the zygomatic bone and zygomatic process of the temporal bone. The right side contains more contrast than the left side (lateral view).

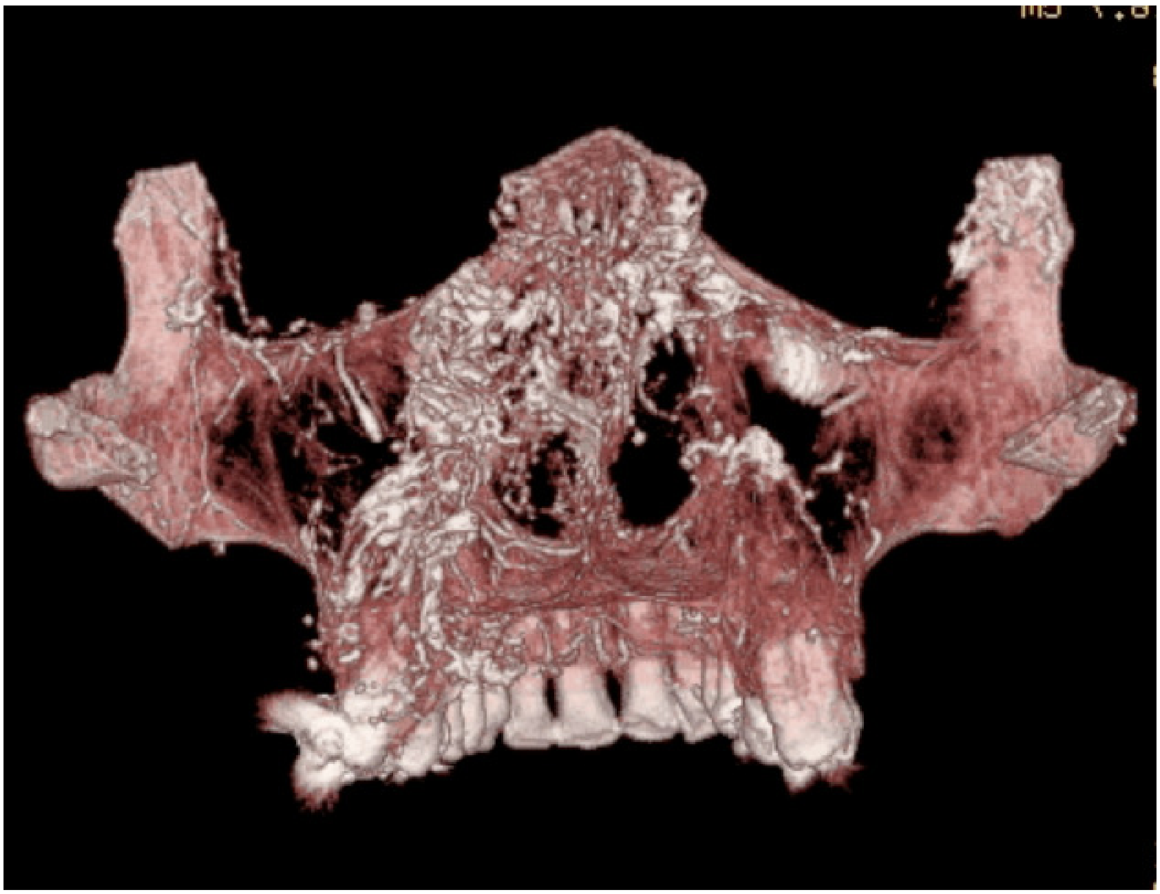


Figure 48- The contrast is present in both homolateral and controlateral infraorbital and palatine arteries, as well as in the mucosal lining of the nose and the walls of the maxillary sinus, body of the zygomatic bone and zygomatic process of the temporal bone. The right side contains more contrast than the left side (posterior view).

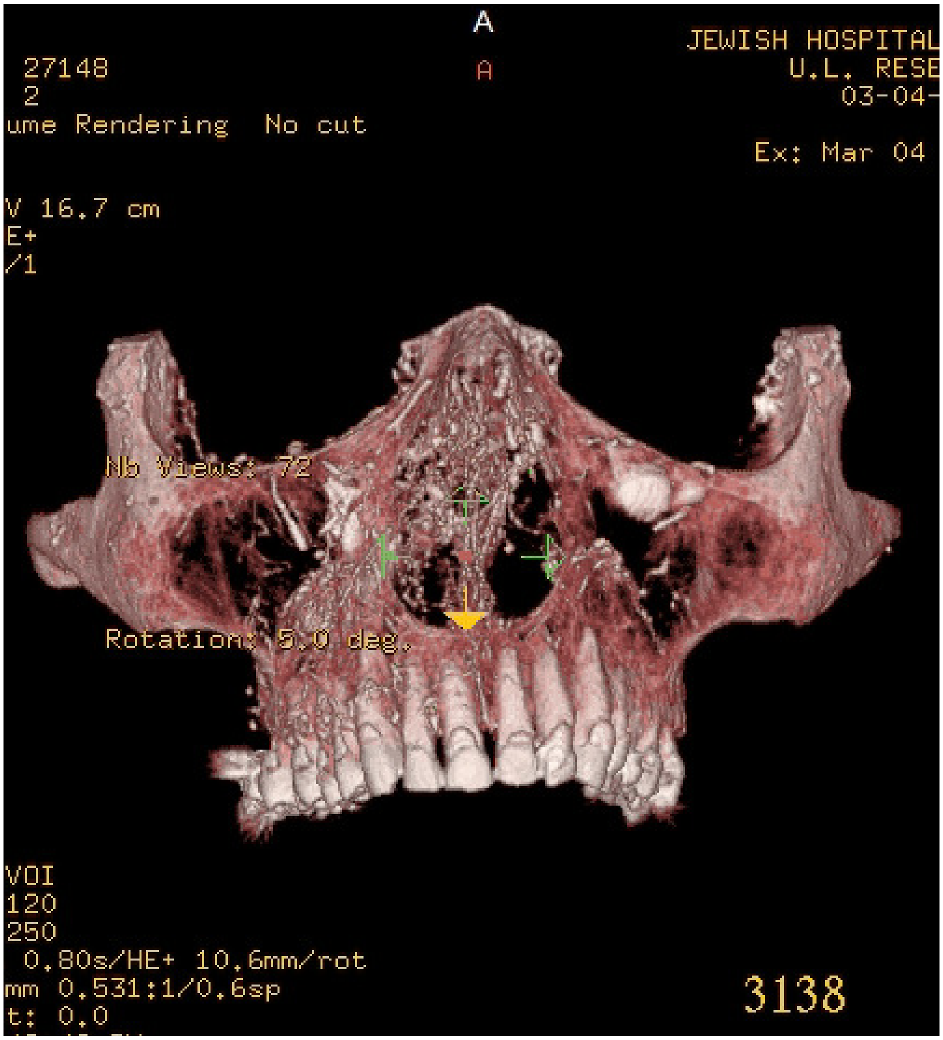


Figure 49- The contrast is present in both homolateral and controlateral infraorbital and palatine arteries, as well as in the mucosal lining of the nose and the walls of the maxillary sinus, body of the zygomatic bone and zygomatic process of the temporal bone. The right side contains more contrast than the left side. The alveolar process is well vascularized.

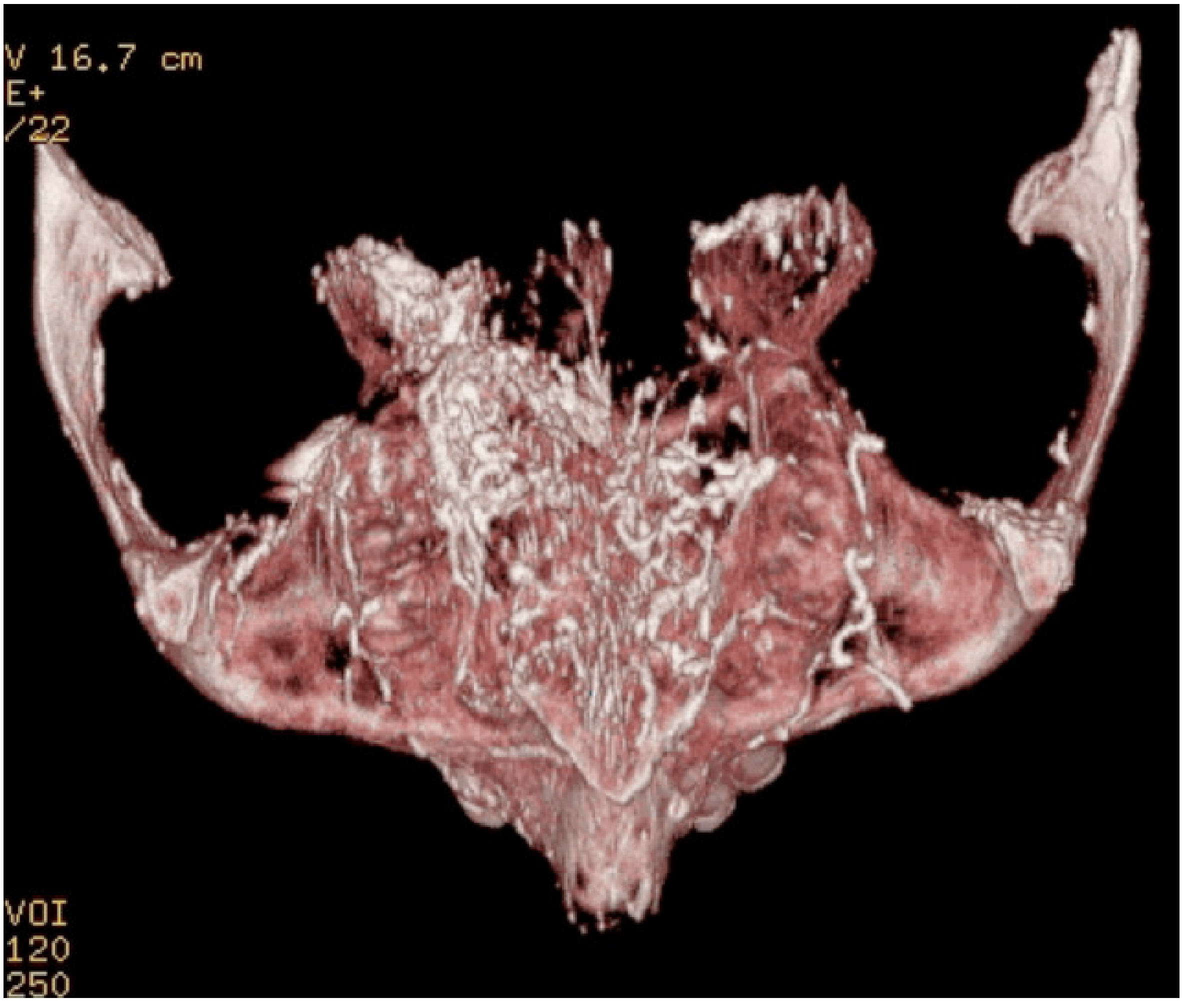


Figure 50- The contrast is present in both homolateral and controlateral infraorbital and palatine arteries, as well as in the mucosal lining of the nose and the walls of the maxillary sinus, body of the zygomatic bone and zygomatic process of the temporal bone. The right side contains more contrast than the left side (superior view).

Figure 51- The contrast is present in both homolateral and controlateral infraorbital and palatine arteries, as well as in the mucosal lining of the nose and the walls of the maxillary sinus, body of the zygomatic bone and zygomatic process of the temporal bone. The right side contains more contrast than the left side (posterior view).

Figure 52- The contrast is present in both homolateral and controlateral infraorbital and palatine arteries, as well as in the mucosal lining of the nose and the walls of the maxillary sinus, body of the zygomatic bone and zygomatic process of the temporal bone. The right side contains more contrast than the left side (inferior view).

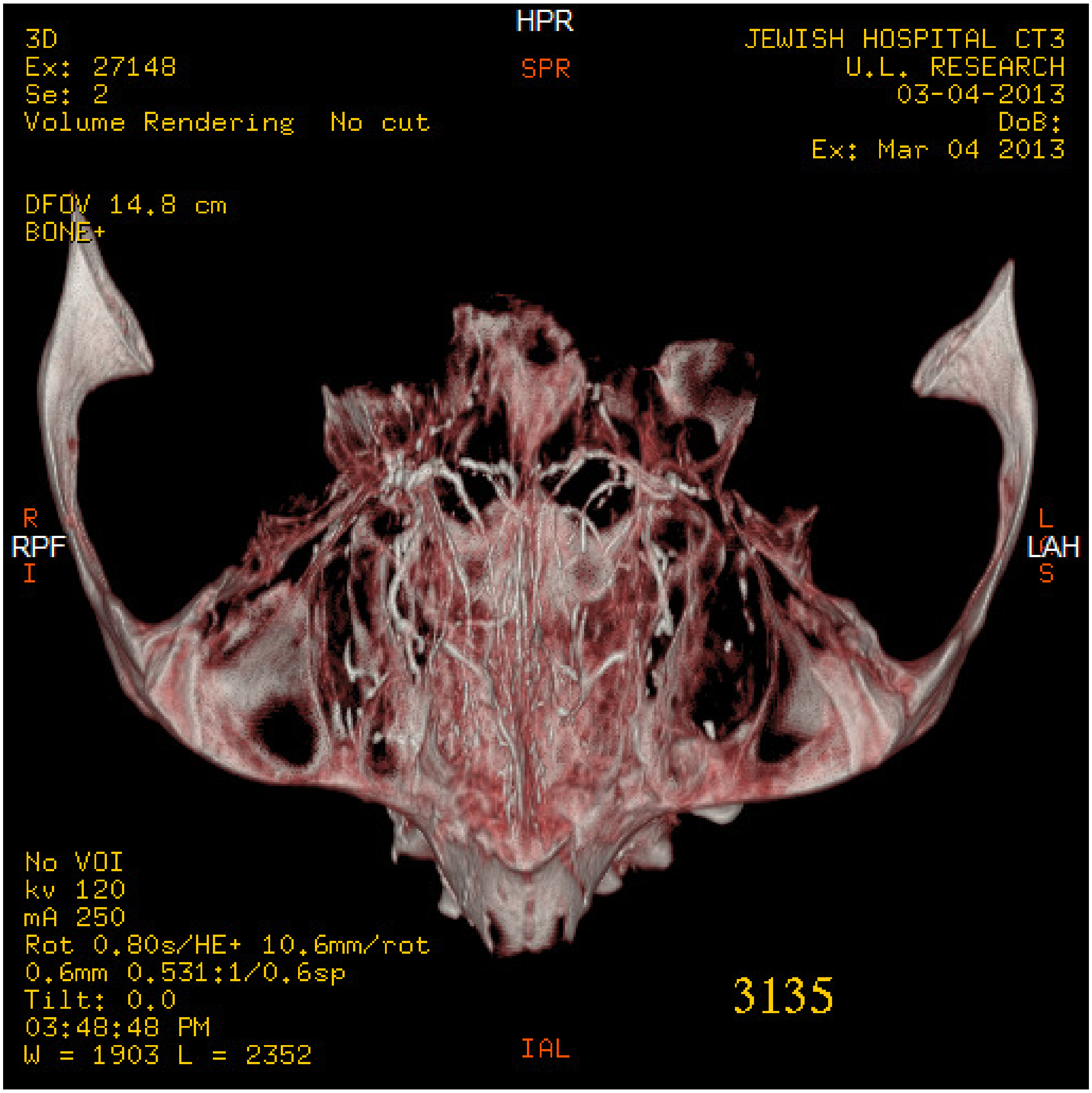


Figure 53- Both greater and smaller palatine arteries are contrasted after injection of the right facial artery.

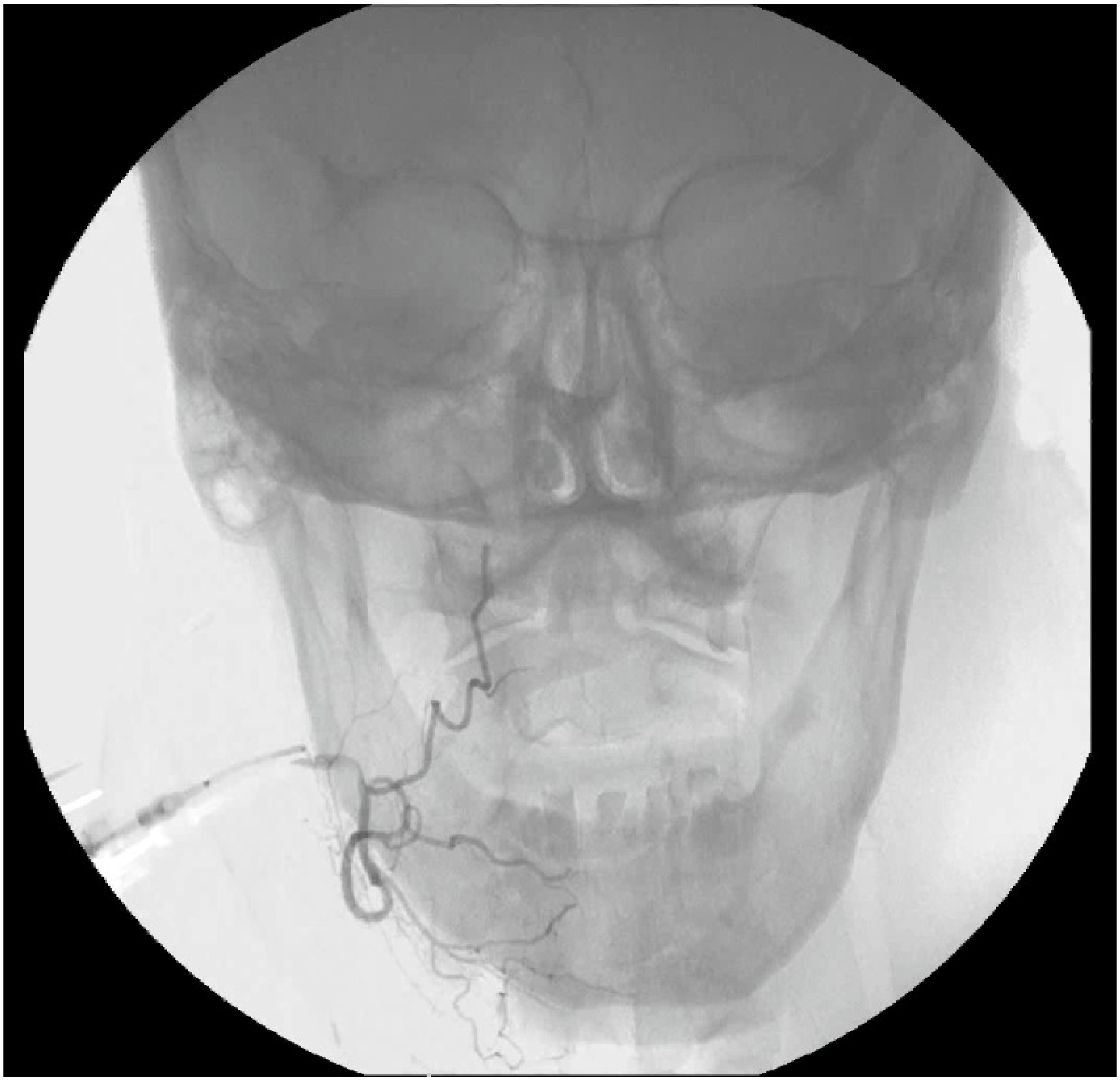


Figure 54- Angiography of the facial artery reveals retrograde flow of the contrast, through the infraorbito-facial anastomosis, in the infraorbital artery and the maxillary artery. Within the inferior alveolar artery the contrast becomes evident at the junction of mandibular body and ramus and flows retrogradely in the direction of the condyle (visualization of the right facial artery).

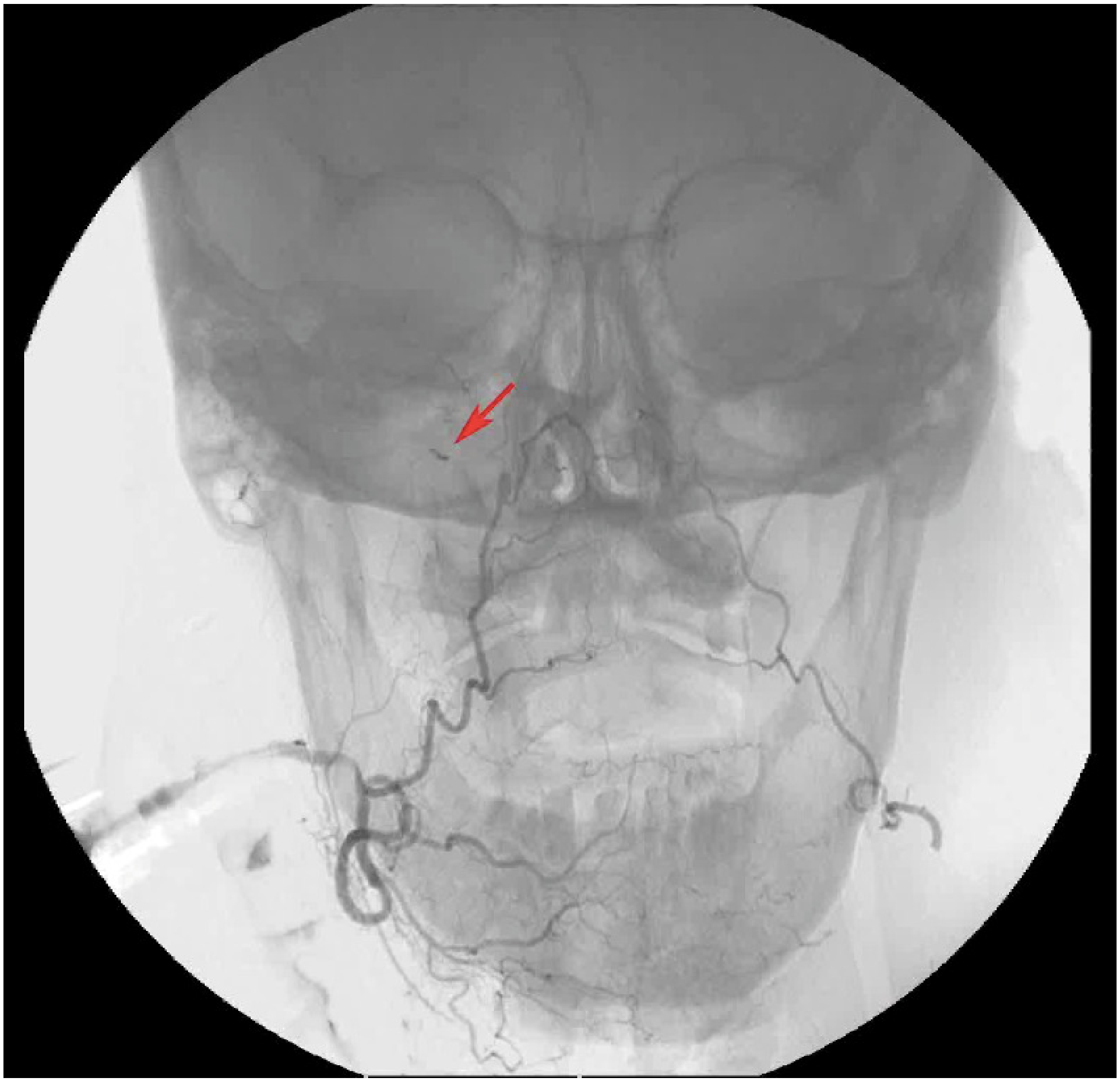


Figure 55- Angiography of the facial artery reveals retrograde flow of the contrast, through the infraorbito-facial anastomosis, in the infraorbital artery and the maxillary artery. Within the inferior alveolar artery the contrast becomes evident at the junction of mandibular body and ramus and flows retrogradely in the direction of the condyle (visualization of the right infraorbital artery).

Figure 56- Angiography of the facial artery reveals retrograde flow of the contrast, through the infraorbito-facial anastomosis, in the infraorbital artery and the maxillary artery. Within the inferior alveolar artery the contrast becomes evident at the junction of mandibular body and ramus and flows retrogradely in the direction of the condyle (visualization of the right internal maxillary artery).

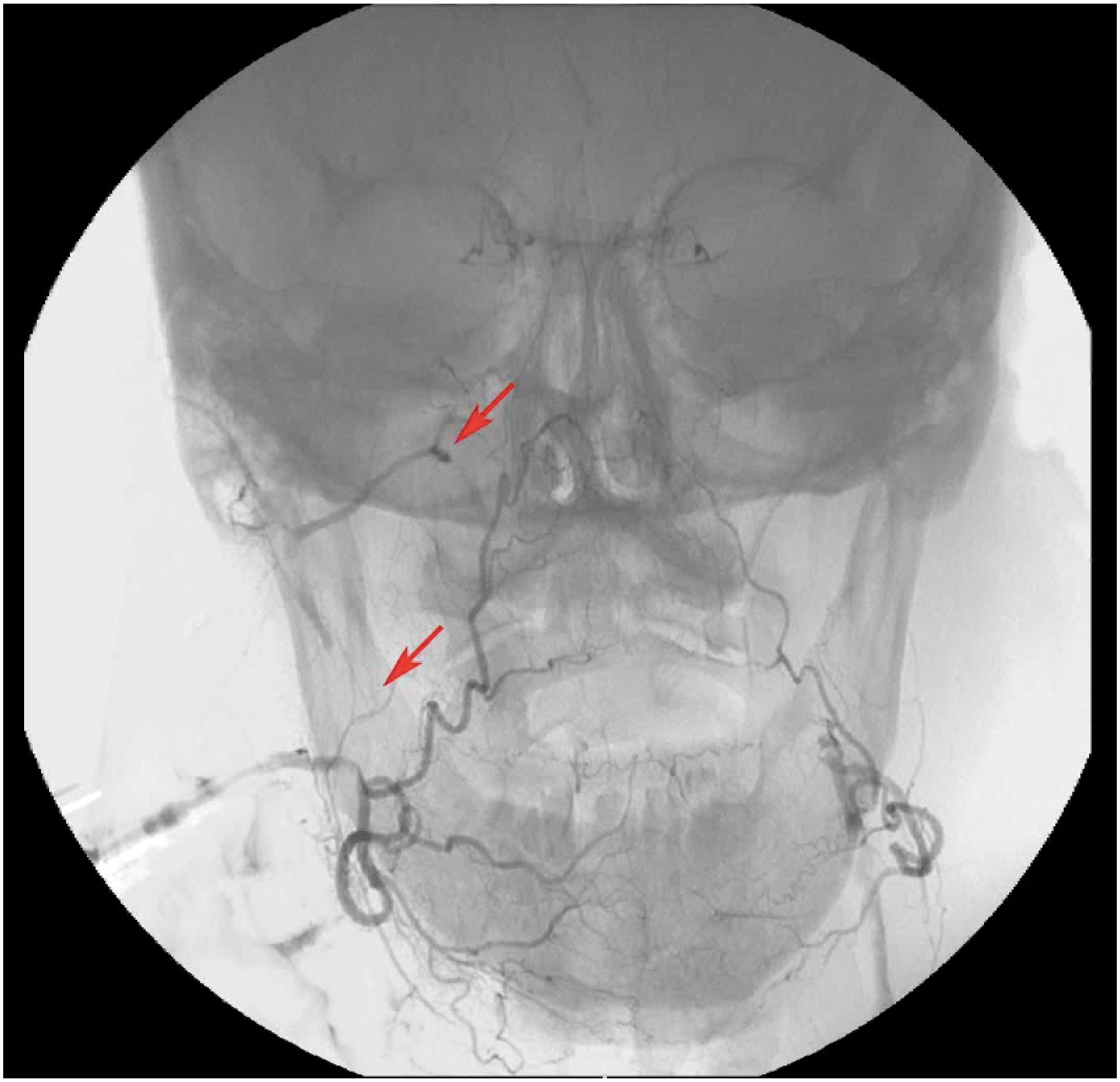


Figure 57- Angiography of the facial artery reveals retrograde flow of the contrast, through the infraorbito-facial anastomosis, in the infraorbital artery and the maxillary artery. Within the inferior alveolar artery the contrast becomes evident at the junction of mandibular body and ramus and flows retrogradely in the direction of the condyle (visualization of the right inferior alveolar artery before the maxillary artery is completely filled).

Figure 58- Angiography of the facial artery reveals retrograde flow of the contrast, through the infraorbito-facial anastomosis, in the infraorbital artery and the maxillary artery. Within the inferior alveolar artery the contrast becomes evident at the junction of mandibular body and ramus and flows retrogradely in the direction of the condyle (visualization of the temporal artery).

Discussion

Vascularized composite allotransplantation has revolutionized the field of facial reconstructive surgery, providing an unlimited supply of the missing craniofacial structures caused by devastating facial injuries. In the 8 years following the first face transplantation, the number and the complexity of the facial allografts has increased, with greater amounts of facial skeleton being included in the allograft [1].

The technical success of the composite middle and lower facial allografts demands full understanding of the perfusion of facial soft tissues and the craniofacial skeleton for reliable transfer, to ensure the viability and return of function. Specifically, optimal vascularization is necessary to guarantee the return of sensation and contractile properties in the transferred muscles [3, 13], to diminish bone resorption, prevent loss of teeth and to avoid the creation of pockets of marginal viability which can well predispose to lethal infections. Finally, ideal vascularization is of extreme importance to counteract some of the potential complications of the systemic immunosuppressive treatment such as avascular necrosis and infection.

The preclinical studies based on animal models and cadaver dissection had indicated the maxillary artery as the main blood supply of the maxilla and mandible [5, 14]. Yazici et al. [6] presented a model of vascularized maxilla based on the demonstration that the whole maxilla could be perfused by the main branches of the pterygopalatine tract of the maxillary artery. These observations were sustained by a detailed cadaveric study by the Maryland group, which showed hypovascularity of the upper maxilla and zygoma by selective injections of the superficial temporal and facial arteries. They determined that preservation of the maxillary artery was necessary for survival of the bone component of the midfacial allografts [8]. These findings were not confirmed by the progressively increasing clinical experience in facial allotransplantation, which proved that parts of the mandible, maxilla and zygoma could be safely included in the allografts based on the facial artery [4, 10, 15, 16].

The present study confirmed that the facial artery alone can sustain the perfusion of 90-95% of the lower two thirds of the facial skeleton. Contrarily to the belief that the contribution of the facial artery to the vascularization of the facial bones was mainly periosteal [4], the angiography of the facial artery showed that revascularization is principally endosseous and occurs through reversal of the flow in the inferior alveolar artery and the infraorbital artery. Hellem and Ostrup [14] showed that in presence of blocked circulation in the inferior alveolar artery the facial artery was the source of the retrograde perfusion of the mandible through symphyseal and periosteo-medullary anastomosis. We demonstrated that there is a rich anastomotic system between the facial artery and the maxillary artery through discrete sized connections. The presence of these anastomoses, especially at the mental and infraorbital foramina, mandates the preservation of these anatomical landmarks during the planning and execution of the osteotomies to allow the maximal vascularity of the bones. The periosteal contribution of the facial artery to the blood supply of the facial bones was confirmed, however this role seems minor and probably cannot independently sustain the perfusion of controlateral cortex as well as the teeth [16]. In the present study, following injection of lead oxide gel into the facial artery, the central canal branches, as well as periodontal dentogengival plexus of the teeth, were contrasted; therefore, the physiologic vascularization of the teeth could be restored. Our conclusions are also supported by the presence of viable teeth in patients undergoing segmental mandible resection or surgical interruption of the inferior alveolar artery which has been imputed as well to retrograde flow through anastomotic and periosteal sources [17].These considerations, together with evidence from the clinical experience, should address the concerns of the viability of the teeth following allograft transfer.

The only bone segments which were not consistently vascularized by the facial artery were the mandibular condyle and coronoid process, the frontal and temporal processes of the zygomatic bone and the zygomatic process of the temporal bone. Although the presence of the contrast in these segments was observed in more than 50% of the specimens, caution and clinical judgment in a case to case basis should be used when including these components in the allograft. We observed that the perfusion of the facial skeleton in the allografts was better than in the selectively injected heads in the majority of the specimens, which seems to indicate that the perfusion of the bone segments improves when the distribution territory of the facial artery is smaller. Interestingly, the contribution of the facial artery to the controlateral facial bones was greater than the maxillary artery, therefore in the event of unilateral arterial thrombosis, an allograft based on bilateral facial arteries has a greater chance of survival than an allograft based on bilateral maxillary arteries.

Conclusions

This study confirms that the facial artery can consistently support the perfusion of a composite allograft containing all the facial bones with exclusion of the mandibular condyle, coronoid process, temporal process of the zygomatic bone and zygomatic process of temporal bone. The physiologic perfusion of the teeth and deep mucosal elements of the nasal cavity and maxillary sinus is maintained. The Authors believe that bilateral vascular anastomoses should be performed, as the contribution of the facial artery seems less significant to the controlateral facial skeleton than to the homolateral components. Furthermore, bilateral anastomoses may prevent disastrous consequences of vascular thrombosis resulting from a unilateral vascular repair.

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