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The Rhesus Monkey as an Animal Model for Training in Interventional Neuroradiology

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The angiographic anatomy of the external carotid artery system in the rhesus monkey is described. Similarities and differences between human and monkey anatomy are emphasized, as well as anatomic variations and potential collateral pathways.

Superselective angiography and embolization in the external carotid artery system of the rhesus monkey proved to be technically feasible and potentially represents an excellent training model for surgical neuroangiographic techniques.

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In view of the rapid development of surgical neuroangiographic techniques, the need has become apparent for an animal training model in which intravascular procedures in the head and neck area can be performed. An ideal animal for such practice is one whose anatomy most closely approximates that of the human. Most of the previous studies were performed in the rat, rabbit, pig, cat, or dog; each of these animals has a very different carotid artery distribution at the base of the skull than that in man; therefore, none represents an ideal model for training. These animals often were chosen because of their easy maintenance and cost rather than their vascular characteristics. We chose the monkey because of its close anatomic relationship to humans.

The anatomy of the carotid arteries in rhesus monkeys has been described [1–5]; however, the in vivo angiographic appearance of the craniofacial arteries has not been presented in detail since the emergence of modern equipment, improved technical skills, and expanded anatomic knowledge [6–8]. With the exception of the work of Castelli and Huelke [2] in 1965, most previous studies are incomplete and inadequate because of the limited approach to the arterial anatomy. Superselective angiography now allows us to describe a more dynamic and variable anatomy of the branches to the head and neck area, taking into account all the possible variations that can exist in vivo [7].

The goal of the present study was to demonstrate the technical feasibility of superselective angiography of small arteries in the monkey and to illustrate the hemodynamic balances in the head and neck area in a fashion similar to that already shown in the human. With such characterization, the monkey can be an ideal model for training in embolization procedures.

Materials and Methods

Six rhesus monkeys (*Macaca mulatta*) ranging in weight from 5.8 to 11.4 kg were used for the embolization procedures. Eighteen hr before the procedures, the animals were injected intramuscularly (IM) with 4 mg of dexamethasone sodium phosphate (Hexadrol) and a fasting regimen was instituted. IM injections of ketamine hydrochloride (25 mg/kg) and atropine sulfate (0.5 mg/kg) were given immediately before embolization to facilitate intubation and placement of an IV catheter. A 500-ml bag of 3.3% dextrose/0.3% saline was connected to

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Key to Abbreviations Used in Figures

CC	common carotid artery
ECA	external carotid artery
ICA	internal carotid artery
VA	vertebral artery
1	superior thyroid artery
1a	glandular branch
1b	superior laryngeal artery
2	lingual artery
2a	dorsal lingual branch
2b	deep lingual artery
2c	sublingual artery
2d	inferior labial branch
2e	submental anastomosis
3	facial artery
3a	ascending palatine artery
3b	submandibular artery
3c	pterygoid branches
3d	inferior masseteric artery
3e	submental artery
3f	mylohyoid artery
3g	inferior labial anastomosis
3h	superior labial artery
3i	septal branch
3j	lateral nasal branch (alar)
3k	infraorbital anastomosis
4	internal maxillary artery
4a	parotid gland branches
4b	deep masseteric artery
4c	transverse facial artery
4d	parotid gland blush
4e	nasopharyngeal blush
4f	nasal blush
4g	middle meningeal artery
4h	middle deep temporal artery
4i	inferior alveolar artery
4j	artery of the foramen rotundum
4k	buccal artery
4l	anterior deep temporal arteries
4m	orbital branch
4n	posterior alveolar artery
4o	infraorbital artery
4p	sphenopalatine artery
4q	posterior nasal artery
4r	descending palatine artery
5	superficial temporal artery
6	posterior auricular artery
6a	sternocleidomastoid branch
7	occipital artery
8	ascending pharyngeal artery
8a	pharyngeal branch
8b	neuromeningeal branch

the catheter and administered at rates of 10–50 drops/min as required using an IVAC drip controller. A second 4-mg IM injection of Hexadrol was given at this time. General anesthesia was subsequently induced with an IV bolus of 12.5 mg/kg sodium pentobarbital (Somnotol).

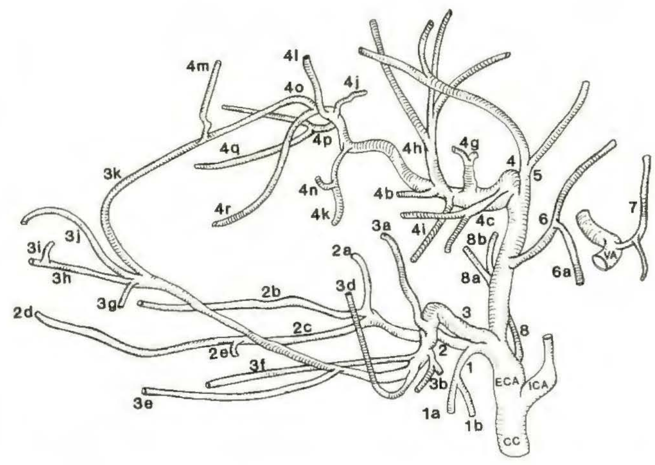


Fig. 1.—Schematic representation of external carotid artery of rhesus monkey. See key for abbreviations.

Further IV doses were administered periodically to ensure an adequate level of anesthesia. The animals were mechanically ventilated throughout the procedures. Heart rate was monitored by using ECG electrodes connected to an audio amplifier. The animals were warmed with a heating pad and their temperatures were continuously monitored with anal probes and telethermometers. Gallamine (2 mg/kg Flaxedil) was given to ensure muscle relaxation during fluoroscopy. Intraoperative anticoagulation was maintained with IV heparin sodium (300 U/kg), administered as needed. Hexadrol (4 mg) was given immediately after embolization and then in decreasing doses over the next 48 hr. Postoperative analgesia was achieved with codeine phosphate (3 mg/kg).

Superselective angiography was performed, and the external carotid artery branches were analyzed on both sides; the external carotid branches were embolized with microparticles. The femoral route was always chosen; left and right femoral punctures were alternated for each procedure. The patency of the femoral artery was maintained each time. Heparin was not used in the flushing system of the introducer sheath; only infusion under pressure with normal saline was used. A 3-French catheter through a 4-French introducer sheath* was used, as was nonionic contrast material.† The angiographic equipment used in the laboratory consisted of a portable C-arm, digital angiographic unit with ¾-in. (1.9-cm) video recorder system.‡ During the superselective injection, the flow patterns into the anastomotic channels of the external carotid branches were observed on fluoroscopy and taped to be copied later on film. Monitoring of the whole procedure was achieved on fluoroscopy; none of the procedures lasted longer than 85 min. Hard copies were taken of the arterial, capillary, and venous phases and whenever the collateral circulation patterns were apparent. Specifically, similarities and differences between the angiographic patterns of the external carotid artery branches in the monkey and human were sought.

Angiographic Analysis

The technical results were satisfactory, and it was possible to catheterize the first division of all external carotid artery branches in every monkey. The resolution of the system allowed us to evaluate vessels as small as 300 μm (Fig. 1).

* Cook, Inc., Bloomington, IN.

† Iohexol 180, Sterling Drug, Aurora, Canada.

‡ OEC-Diasonics Medical Systems, Salt Lake City, UT.

As has been described previously [9], the aortic origin of the cervical vessels in the rhesus monkey is slightly different from that in humans because in the rhesus monkey the left common carotid artery originates from the innominate artery. We did not find this to be a major obstacle in catheterization (Fig. 2). The common carotid artery is small and the external carotid trunk represents its direct continuation (Fig. 3).

The superior thyroid artery in the monkey usually arises from the lingual-facial trunk and not as a separate branch from the external carotid system, as it is usually seen in humans. The territory of the superior thyroid artery is the same as in the human.

In the monkey the lingual and facial arteries invariably arise from a common trunk (Fig. 4). The lingual artery in the monkey represents the main supply to the tongue and the floor of the mouth. The submental artery in the monkey is poorly developed and does not allow for much of a contribution from the facial artery toward the floor of the mouth, as is often seen in humans. Instead, anastomoses are more developed toward the mylohyoid artery system in the monkey. The main difference between the vascular distribution in the monkey and that in humans is the origin of the inferior labial artery. In the monkey, this vessel represents the terminal branch of the sublingual artery, as it pierces the mandible in the midline and may be fed by the left or the right sublingual artery. In humans, the inferior labial artery arises from the facial artery. The medial aspect of the mandible in humans is usually supplied by the medial mandibular artery, a branch of the lingual artery. Other branches of the lingual artery (dorsal and deep lingual) are exactly the same in monkeys and humans (Fig. 5).

The facial artery in the monkey (Figs. 5 and 6) arises from a common trunk with the lingual artery. The ascending palatine, submandibular, and buccomasseteric arteries have similar configurations in monkeys and humans. The septal branches of the superior labial artery and alar artery represent terminal branches of the facial artery in the monkey. Anastomoses from these vessels via the infraorbital and buccal arteries toward the internal maxillary artery territory can be visualized in the monkey in a manner similar to that in humans. Anastomoses from the distal facial artery via the infraorbital and palpebral arteries toward the ophthalmic system can also be demonstrated in the monkey similar to the human situation. As previously indicated, the submental branch of the facial artery in the monkey is poorly developed and does not represent a viable anastomosis toward the lingual artery territory.

The occipital artery in the monkey is in hemodynamic balance with the vertebral artery as far as the supply to the scalp is concerned; in fact, frequently the vertebral system dominates the supply to the posterior aspect of the scalp (Fig. 7). Therefore, the size of the occipital artery in the monkey is variable.

The ascending pharyngeal artery in the monkey is a very small branch of the external carotid artery. The anterior pharyngeal and posterior neuromeningeal branches could be identified after embolization of the lingual-facial and internal maxillary artery territories (Fig. 8). The pharyngeal branch may give rise to the ascending palatine artery, similar to the configuration in 30% of humans.

The internal maxillary system in the monkey (Fig. 9) reveals the main branches to be similar to those in humans. The inferior alveolar, the middle meningeal, superior masseteric, and deep temporal arteries can all be identified. The greater palatine artery was noted to shadow the hard palate, and the buccal artery to course downward to cross the oral lucency on the lateral view. This buccal artery often gives an anterior branch anteriorly to the cheek and buccinator muscle. The superior alveolar artery, which is often difficult to identify, has a curved shape, is concave superiorly, and courses anterior and parallel to the greater palatine artery. The infraorbital artery is difficult to recognize, perhaps because of the recurrent flow via the facial anastomosis. The sphenopalatine

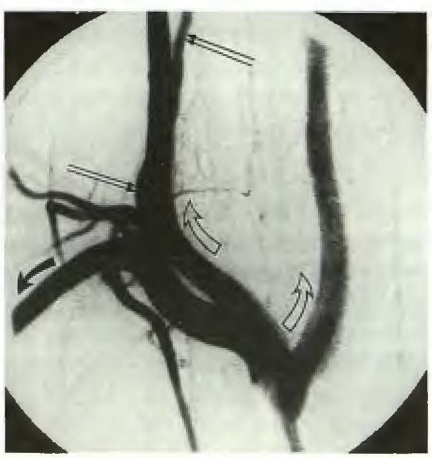


Fig. 2.—Selective injection of right innominate artery. Subclavian flow (*solid curved arrow*) is well seen. Note that both common carotid trunks (*open curved arrows*) originate from same arterial system. Vertebral artery on right side is dominant in this particular monkey (*straight arrows*).

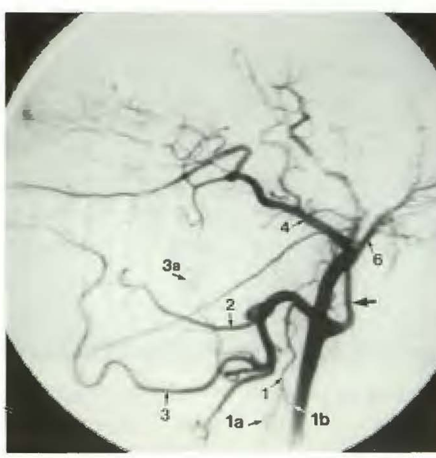


Fig. 3.—Common carotid injection on right side shows usual pattern of external carotid artery branches at craniofacial junction. Note asymmetry between external carotid trunk, which seems to prolong common carotid artery, and small size of internal carotid artery (*arrow*). See key for abbreviations.

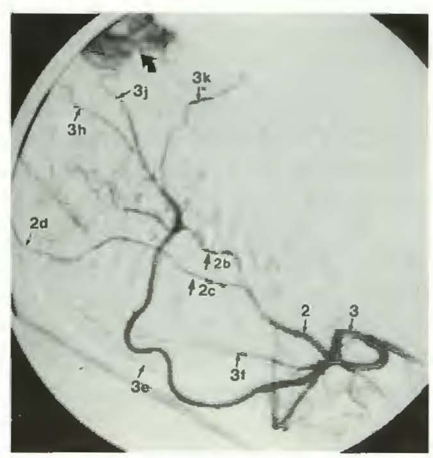
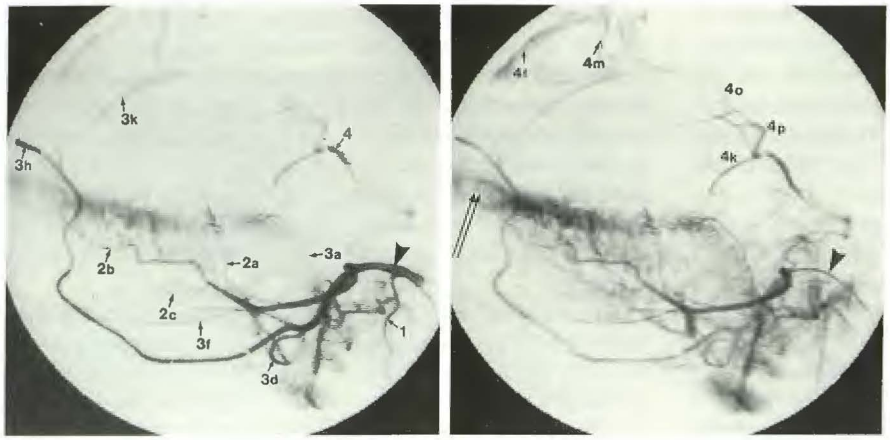
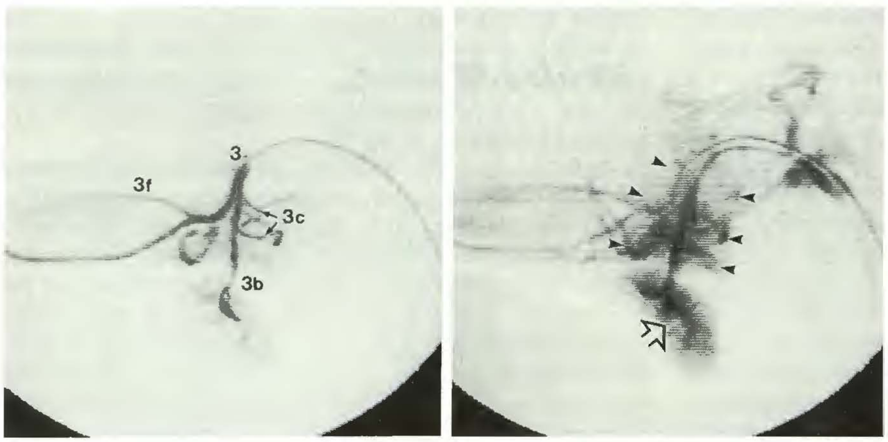


Fig. 4.—Selective injection of facial-lingual trunk. Facial artery through its infraorbital anastomosis (3k) refluxes into distal internal maxillary system showing nasal mucosal blush (*arrow*). Lingual arterial branches are well demonstrated. See key for abbreviations.



A B

Fig. 5.—*A* and *B*, Early (*A*) and late (*B*) phases of selective injection with catheter tip (*arrowhead*) in facial-lingual trunk show distal branches of facial-lingual system, particularly sublingual (2c), superior labial (3h), and infraorbital (3k) branches. Note also opacification of internal maxillary branches and tongue mucosal blush (*arrows*). See key for abbreviations.



A B

Fig. 6.—*A* and *B*, Early (*A*) and late (*B*) phases of selective injection of facial artery. Note small size of branch supplying mylohyoid muscle (3f). Submandibular gland is quite prominent and shows a significant blush related to selectivity achieved (*arrow*). Medial pterygoid muscle is also well delineated (*arrowheads*). See key for abbreviations.

7

Fig. 7.—Vertebral injection shows artery of first cervical space supplying medial musculocutaneous occipital territory (7). Posterior auricular artery was noted to supply supraauricular cutaneous area, apparently in balance with other potential sources of supply.

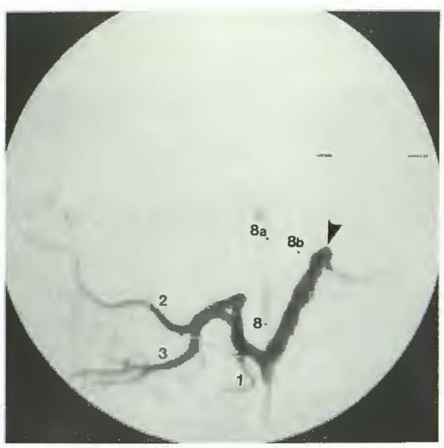


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Fig. 8.—Common external injection after embolization of distal external carotid system (*arrowhead*). Only after this procedure could ascending pharyngeal trunk (8) and its branches be demonstrated. Note small size of these vessels. See key for abbreviations.

branches toward the nasal fossa, such as the nasopalatine and posterior nasal arteries, can be recognized by elimination after identification of the other branches. Different from the human anatomy is the supply toward the temporal muscles, which in the monkey is via the middle deep temporal or anterior deep temporal arteries rather than the posterior deep temporal arteries in humans (Fig. 10).

The various scalp arteries are in hemodynamic balance. The superficial temporal artery is often small in the monkey, while the posterior auricular artery is more often the dominant

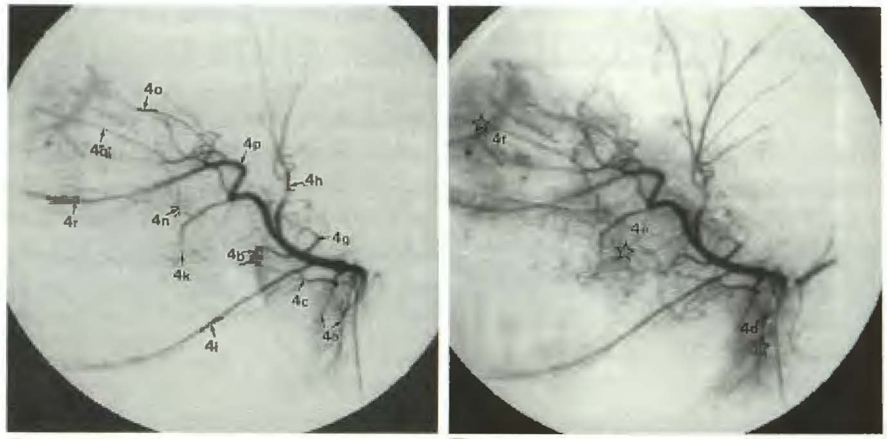

Fig. 9.—*A* and *B*, Early (*A*) and late (*B*) phases of selective injection into internal maxillary artery. Most internal maxillary branches are seen during this injection, as well as contribution of transverse facial artery to supply of masseteric muscle. In late phase, stain of parotid gland (4d), nasopharynx (4e), and nasal fossa (4f) is well seen (*stars*). See key for abbreviations.

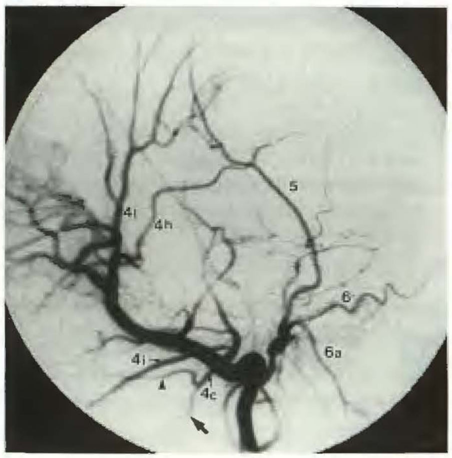

Fig. 10.—Distal external injection in monkey with dominant superficial temporal artery (5) arising in a common trunk with posterior auricular artery (6). Note anterior deep temporal dominance (4l) to supply of temporal muscle, which is different from middle deep temporal dominance to supply of same muscle on angiogram of internal maxillary artery (Fig. 9). Here, branches of transverse facial artery (4c) and zygomatic (*arrowhead*) and superior masseteric (*arrow*) arteries are well seen. See key for abbreviations.

Fig. 11.—Selective injection of transverse facial artery (4c). Note opacification of zygomatic branches (*arrowhead*) and superior masseteric artery (*solid arrow*). Venous return is well seen (*open arrow*) at posterior edge of mandible.

feeder toward the scalp. The transverse facial artery is a constant branch from the distal external carotid artery and courses anteriorly below the zygomatic arch (Fig. 11).

Anastomoses in the monkey between the intracavernous portion of the internal carotid artery and the internal maxillary artery can be demonstrated after proximal occlusion of this system; these anastomoses are similar to those in humans. Proximal occlusion of the internal maxillary artery in the monkey will reveal anastomoses to this system in a retrograde fashion from the distal facial artery similar to those in humans. Anastomoses from the ascending pharyngeal artery toward the internal maxillary artery system are much less developed in the monkey, as compared with humans.

The capillary and venous patterns of the external carotid system in the monkey are similar to those in humans. The mucosa of the pharynx, tongue, and parotid and submandibular glands can all be readily identified in the monkey. The only difference between the monkey and human is that the nasal mucosal blush and its venous drainage are best seen after internal carotid injection (ophthalmic and ethmoidal arteries) in the monkey; in humans, the superior and inferior ophthalmic veins are visualized after injection of the internal maxillary artery.

Review of the angioarchitecture of the external carotid system in the monkey reveals three major functional territories: digestive, neuromeningeal, and musculocutaneous. The digestive system of the head and neck comprises the floor of the mouth and its contents; it is supplied by the facial, lingual, and superior thyroid arteries. The supply toward part of the dura and certain cranial nerves is from the internal maxillary artery system, which evolved from the internal carotid system as a stapedial branch to become part of the external carotid system. Grafted onto this disposition are the arterial feeders needed for the muscles and cutaneous cover, which are late to differentiate. The angioarchitecture of the external carotid system of the monkey is more easily recognizable than that in humans, in particular, its embryonic differentiation into two main systems: the digestive system (lingual-facial trunk) and the neuromeningeal system (internal maxillary artery).

Conclusions

Superselective angiography of the monkey has revealed many similarities to and some differences from the human vascular anatomy of the external carotid artery system (Table 1). Knowledge of the angioarchitecture of the external carotid

TABLE 1: Differences Between the External Carotid Artery Branches and Territories in Humans and Rhesus Monkeys

Artery	Human	Rhesus Monkey	Fig. No.
Superior thyroid	Separate origin is common	Common trunk with facial and lingual arteries is usual	4
Lingual	Common trunk with facial artery is unusual	Common trunk with superior thyroid and facial arteries is usual	4, 5
	Territorial supply to floor of mouth is in balance with facial artery (submental artery)	Represents main supply to floor of mouth; no significant anastomoses from facial artery	
	Inferior labial artery is branch of facial artery	Inferior labial artery is branch of sublingual artery (lingual artery)	
Facial	Common trunk with lingual artery is unusual	Common trunk with lingual and superior thyroid arteries is common	5, 6
	In balance with lingual artery for supply toward floor of mouth	Submental branch toward floor of mouth is small	
Ascending pharyngeal	Anastomoses toward internal maxillary artery are well developed	Anastomoses toward internal maxillary territory are poorly developed	8
Occipital	Main feeder toward coverings of occiput, in balance with posterior auricular artery and to a lesser extent vertebral artery (anastomoses can be developed after embolization)	In balance with posterior auricular artery and vertebral system; the latter often represents dominant supply to posterior aspect of scalp (even prior to embolization)	7
Internal maxillary	Posterior deep temporal arteries represent main supply toward temporal muscles	Anterior and middle deep temporal branches represent main supply to temporal muscles	9

system in the monkey, its variations, and its anastomoses will be helpful if this primate is chosen as a model for training in superselective angiographic and interventional (or surgical) radiologic techniques. With this knowledge, it will be possible to redistribute the blood flow in the head and neck area of the monkey in a predictable fashion. Training in this type of sophisticated blood-flow manipulation may become even more important with the development of selective chemotherapy for head and neck malignancies in humans.

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