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The blood supply of the human temporalis muscle: a vascular corrosion cast study

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ABSTRACT

Knowledge as to the blood supply of the human temporalis muscle is limited to its extramuscular path and relations, little information existing about the intramuscular vascular architecture. To investigate the 3-dimensional vascular network in the human temporalis muscle, in 5 fresh cadavers an infusion of methylmethacrylate resin was made via the carotid vessels with subsequent removal of the organic tissues by a corrosion process. The vascular corrosion casts of the temporalis muscle were studied by stereomicroscopy and scanning electron microscopy. In 6 well perfused muscle specimens, the temporalis muscle was found to be consistently supplied by 3 arteries: the anterior and posterior deep temporal arteries, and the middle temporal artery. Each primary artery branched into the secondary arterioles and then terminal arterioles. The venous network accompanied the arteries, and double veins pairing a single artery was a common finding. Arteriovenous anastomosis was absent, whereas arterioarterial and venovenous anastomoses were common. The capillaries formed a dense interlacing network with an orientation along the muscle fibres. Understanding of the intramuscular angioarchitecture of the temporalis provides the vascular basis for surgical flap manipulation and splitting design.

Key words: Masticatory muscles; vasculature.

INTRODUCTION

The blood supply to the temporalis muscle in man is mainly derived from the anterior and posterior deep temporal arteries (ADTA, PDTA), branches of the maxillary artery in the infratemporal fossa (Bradley & Brockbank, 1981; Mathes & Nahai, 1982; Antonyshyn et al. 1986). Based on cadaver dissections, Antonyshyn et al. (1986) related the point of entry of these vessels into the muscle to skeletal landmarks. They noted that both ADTA and PDTA entered the muscle below the zygomatic arch and deep to the coronoid process. The anterior pedicle is located 1 cm anterior to the coronoid and 2.4 cm inferior to the arch, whereas the posterior pedicle is 1.7 cm posterior to the coronoid and 1.1 cm inferior to the arch. Each vessel is on average 2 cm in length and enters the muscle through its deep surface. There is an additional blood supply derived from the middle temporal artery (MTA), a branch of the superficial temporal artery. This vessel runs lateral to the surface of the muscle supplying the temporal fascia and a few of its branches were noted to enter the temporalis muscle (Abul-Hassan et al. 1986).

Studies of the intramuscular vessels in the temporalis muscle are available only for man (Mathes & Nahai, 1981), monkeys (Bradley & Brockbank, 1981) and cats (Fujimoto, 1959; Saito, 1988). Mathes & Nahai (1981) were only able to demonstrate the presence of 3 main primary arteries and a few branches of the secondary arterioles; this was a limitation of the barium latex infusion medium used. Bradley & Brockbank (1981) showed a radiograph of a barium infused temporalis muscle from a monkey illustrating the rich intramuscular vascular network but unfortunately without description of its fine details. In the cats, Fujimoto (1959) found that the temporalis muscle is supplied by 5 arteries. In addition to the 3 present in man, the posterior auricular and buccal arteries also contribute to the muscular vasculature. Multiple vascular anastomoses were identified by Saito (1988) in the cat PDTA and anastomoses were

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noted with the ADTA, the MTA and the posterior auricular arteries.

The use of corrosion casts to demonstrate skeletal muscle vasculature is a relatively new application. Potter & Groom (1983) produced the first report on corrosion casting of the microcirculation in skeletal muscles, and this was shortly followed by that of Gaudio et al. (1984). The tissues overlying the muscle to be studied should preferably be excised shortly after the setting of the infusion medium because when the specimen is corroded, all the tissues and the anatomical planes are lost leaving only the medium which fills the vascular lumen. The 3-dimensional architecture of the vessels can be well demonstrated and analysed both by stereomicroscopy and scanning electron microscopy. The difference in the nuclear marking of the endothelium on the corrosion cast may also allow differentiation of the artery/arteriole from the vein/venule (Gaudio et al. 1984; Aharinejad & Lametschwandtner, 1992).

This study aims to define the 3-dimensional network of intramuscular vessels in the human temporalis muscle using the corrosion cast technique.

MATERIAL AND METHODS

Fifteen fresh human cadavers were available for the investigation of the temporalis muscle vasculature and 5 cadavers obtained within 24 h of death were selected for the corrosion cast study. There were 3 males and 2 females aged between 6 mo and 3 y at the time of death. These children died from infectious diseases either of the respiratory or gastrointestinal systems, and their bodies were donated by their parents to the Faculty of Stomatology at the Sun-Yat-Sen University of Medical Sciences, China, specifically for medical research.

Anatomical dissections of both sides of the neck were performed to expose the external carotid arteries and the internal jugular veins. Each external carotid artery was cannulated at thyroid level and the catheter secured by multiple ligatures. The common and internal carotid arteries were ligated and the internal jugular veins were divided and left open for drainage. The catheter on each side was connected via an infusion set to a bottle of 500 ml normal saline solution mixed with 2.5 ml of heparin (12500 IU). The external carotid vascular network was flushed by the heparinised saline solution until the fluid emerging from the internal jugular veins became totally clear. This was followed by an infusion of 1 l of 40% Dextran and 400 ml of 20% mannitol to reduce extravascular oedema of the head and neck region. The vascular system was fixed by an injection of 40 ml 2% phosphate buffered glutaraldehyde.

The semipolymerised methylmethacrylate resin was prepared according to the methodology of Ran et al. (1990). The antipolymerisation agent in the methylmethacrylate monomer was removed by triple cleansing with 2% sodium hydroxide solution in a 5:1 ratio. The supernatant was then washed three times with distilled water and dehydrated by adding an excess amount of anhydrous sodium sulphate crystals. The filtered solution was mixed with methyl acrylate solution to a ratio of 9:1. A 6% equivalent in weight of benzoyl peroxide was added followed by a small amount of fluorescein red dye. The resin was filtered to remove any residual sediment and distributed into several small flasks. The resin in the flasks were individually warmed in a hot water bath of 8 °C until the viscosity of the solution reached that of glycerine. The polymerisation process was halted by placing the flasks in a cold water bath. The resin was then kept in a refrigerator to be used when the cadavers were ready.

After the external carotid arterial system of the cadaver was fixed by the glutaraldehyde solution, 10 ml of methylmethacrylate monomer fluid was infused into each side. The semipolymerised methacrylate resin was loaded into several 5 ml syringes. The polymerisation was activated in each syringe by adding 2 drops of 0.01% N,N-dimethylaniline. The resin in the syringes was quickly infused into the external carotid arteries of both sides under pulsatile manual pressure. The polymerising resin drained through the internal jugular veins which were left open for drainage. Any other points of leakage were clamped. The adequacy of infusion was checked by the appearance of a pink colour on the tip of the tongue and the conjunctiva. Both the external carotid and the internal jugular vessels were then ligated. The head specimens were submerged in a hot water bath at 80 °C for 2 h to complete the polymerisation process of the methylmethacrylate resin.

The heads were sectioned sagittally through the midline. The temporalis muscle was exposed on each side by removal of the overlying skin and the superficial temporal fascia. Plaster of Paris was poured into the cranial cavities and the set plaster formed a support for the halfhead specimens. The specimens were then submerged in 20% potassium hydroxide macerating solution and the tissues were slowly corroded. The solution was changed every few days until all organic tissues were dissolved. The plastic casts were cleaned thoroughly under running tap water and air dried. Microdissection of the corrosion

cast was performed under a stereomicroscope (Nikon SMZ-10, Japan) and the findings recorded by photography (Nikon FM2 with a 120 mm medical lens). The casts were frozen and selective areas were removed. They were freeze-dried and mounted on copper stubs with conductive colloidal carbon. The specimens were sputter-coated with gold and the casts were examined under scanning electron microscope (JEOL JXA-840 SEM).

RESULTS

Of the 10 temporalis muscle specimens, only 6 corrosion casts were judged to have adequate infusion of the intramuscular vasculature for further analysis.

The arterial network

The temporalis muscle was seen to be supplied consistently by 3 primary arteries (Fig. 1). The ADTA was located in the anterior portion, the PDTA in the midportion and the MTA in the posterior portion. The ADTA entered the medial side of the muscle at its anteroinferior aspect. This primary artery ran upwards within the anterior region, parallel with the muscle fibres, to reach the cephalic part of the muscle. There were numerous secondary arteries branching almost at right angles from the primary artery. The terminal arterioles in turn came off the secondary arteries either as lateral branches or divided in a dichotomous manner. The PDTA entered the middle portion of the muscle at its inferomedial aspect. The primary artery ran upwards to the cephalic part of the muscle at an oblique angle to the direction of the muscle fibres. The secondary arteries branched out approximately at right angles from the primary artery, and in turn the terminal arterioles from the secondary arterioles. The direction of the terminal arterioles was parallel to the muscle fibres. The MTA entered the posterior portion of the muscle at its posteroinferior aspect with the primary artery running perpendicular to the direction of the muscle fibre. The secondary arteries arose mainly at right angles from the primary artery and in turn ran parallel with the muscle fibres. The terminal arterioles branched out again at right angles from the main trunk of the secondary artery or in a dichotomous manner as terminal branches.

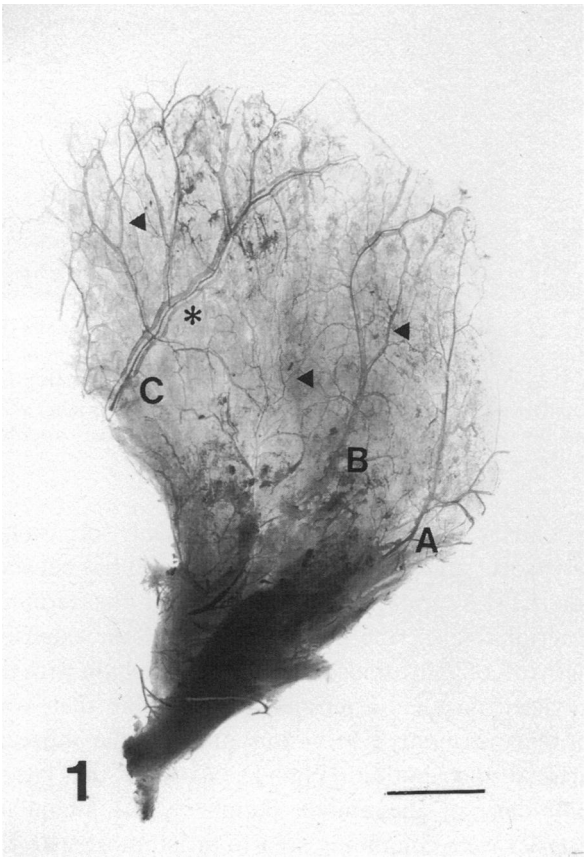

Fig. 1. Lateral view of corrosion cast illustrating the vascular supply of the human temporalis muscle deriving from 3 primary sources: the anterior deep temporal artery (A) in the anterior portion, the posterior deep temporal artery (B) in the midportion and the middle temporal artery (C) in the posterior portion. Double veins pairing with the middle temporal artery are seen (*). Extensive vascular anastomoses are present between the vessels' own branches or with adjacent vessels (arrowheads). Bar, 1 cm.

The venous network

The network of venous distribution correlated well with the arterial network. Veins were similarly classified like the intramuscular arteries into primary veins, secondary venules and terminal venules. The veins and venules generally ran alongside, and pairing with the corresponding arteries and arterioles (Fig. 2*a*, *b*). Double veins pairing with a single artery were a common observation for the primary MTA (Fig. 1) and were occasionally observed with the secondary vessels. This phenomenon was more commonly seen at the terminal venules which double-paired with the corresponding terminal arterioles (Fig. 2*c*).

Vascular anastomosis

Arterioarterial and venovenous anastomoses were commonly seen, whereas arteriovenous anastomoses were not observed. Anastomosis was normally established only with vessels of corresponding level, that is primary with primary artery and secondary with secondary arteriole, etc. The primary arteries normally had anastomotic connections only at the end of their path. Anastomoses between the secondary arteries

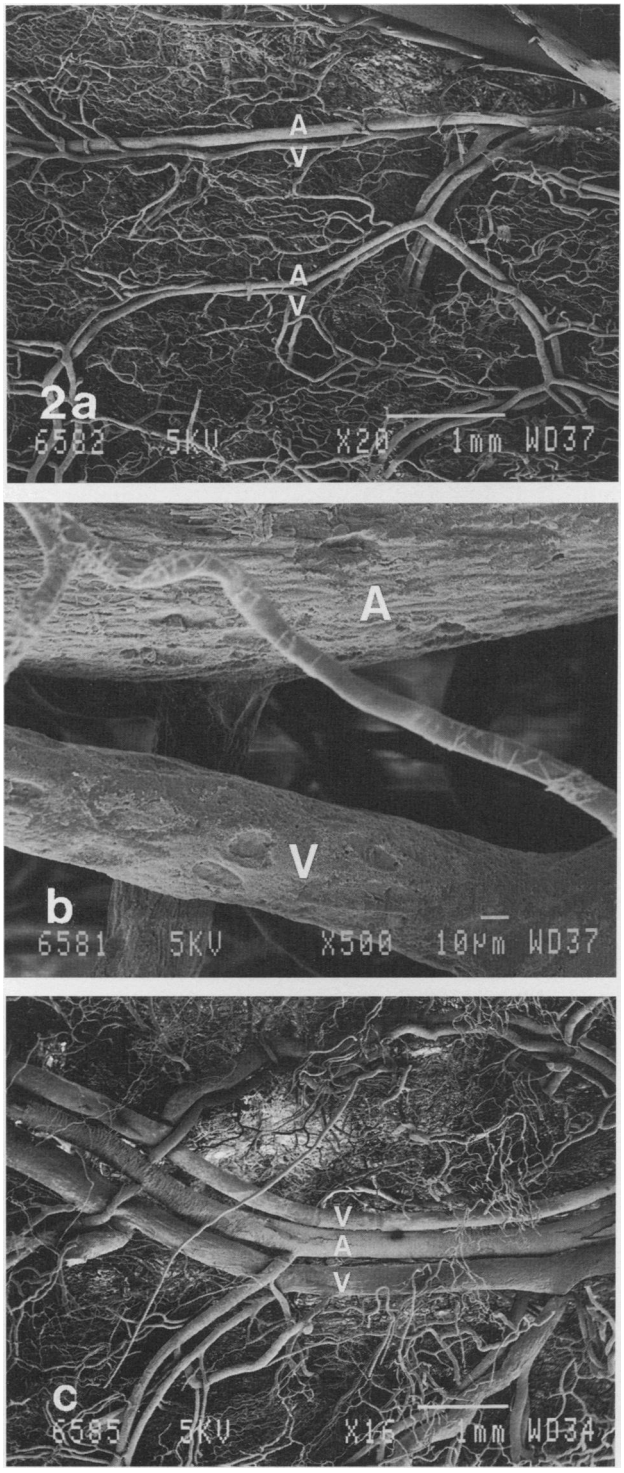

Fig. 2. (*a*) The veins and venules (V) normally run alongside the corresponding arteries and arterioles (A). (SEM, ×20). (*b*) The artery is distinguishable from the vein by the nuclear markings on the vascular cast. The upper vessel is an arteriole (A) and lower one a venule (V). (SEM, ×500). (*c*) Similar pattern of double secondary venules (V) accompanying a secondary arteriole (A). (SEM, ×16).

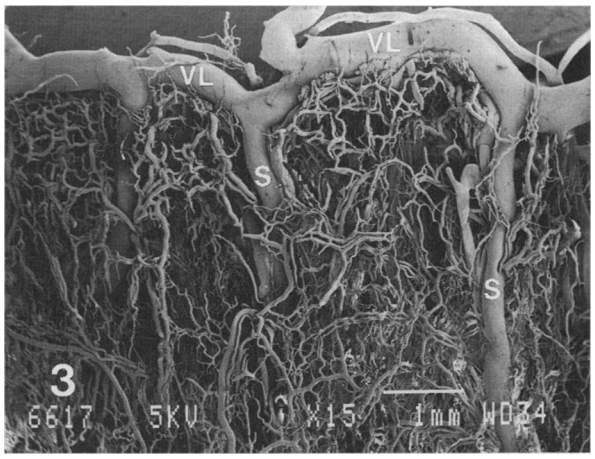

Fig. 3. At the upper semicircular periphery of the temporalis muscle, the secondary vessels (S) form multiple serial vascular loops (VL). (SEM, ×15).

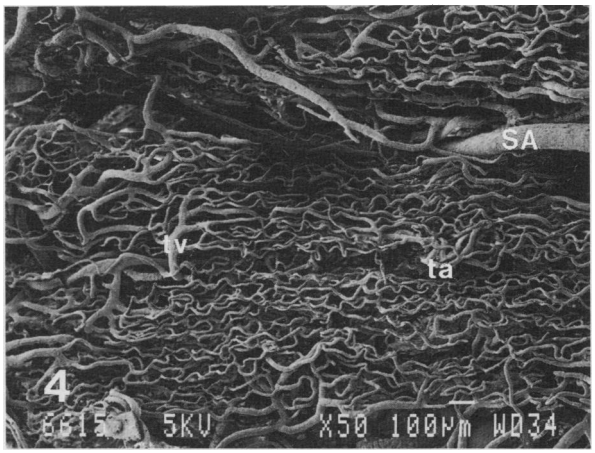

Fig. 4. The capillaries branch out from the terminal arterioles (ta) and are arranged in parallel rows in the general direction of the muscle fibres. They are collected to form terminal venules (tv). The capillaries tend to wrap around each muscle fibre forming wavy bundles with capillary-free areas between. SA, secondary arteriole. (SEM, ×50).

were most common in the intermediate section of the muscle. The secondary arteries of the ADTA normally had anastomoses with the secondary PDTA vessels, and similarly the secondary arteries of the PDTA with secondary arteries of the MTA. Only occasional cross-over anastomosis of secondary arteries between the ADTA and MTA was seen. At the terminal arteriolar level, the arterioles formed an extensive network of anastomoses in a random fashion with the adjacent terminal arterioles, either within their own primary arterial distribution or with the adjacent arterial distribution (Fig. 1). Around the lateral boundary of the muscle periphery, the secondary arteries were commonly seen to anastomose with the adjacent arteries forming multiple vascular loops (Fig. 3).

The capillary network

The capillaries were shown to be oriented along the general direction of the muscle fibres (Fig. 4). They

branched out of the terminal arterioles and grouped into terminal venules. The capillaries measured around 10–20 μm and formed a dense interconnecting network throughout the whole muscle. Some tended to wrap around the muscle fibres forming wavy bundles with capillary-free areas between.

DISCUSSION

Spalteholtz (1888) reported the first study of the vascular architecture in skeletal muscles. The vascular arrangement was mapped with the muscle made transparent, the vessels having been infused with Indian ink. Muscle specimens obtained from rabbits, dogs and man were analysed in a systematic manner and he observed a consistent pattern of intramuscular vessel arrangement. The main arteries divided into branches which ran parallel to the muscle fibres and connected with each other by interarterial loops or arterioarterial anastomoses. The terminal arterioles formed the final branches which gave rise to the capillary network. The capillaries were noted to run in the same direction as the muscle fibres. They drained into the terminal venules and by a similar sequential branching as the arteries to form the main veins. This basic vascular pattern in skeletal muscle was widely accepted and confirmed by Zweifach & Metz (1955), Grant & Wright (1968), Stingl (1969), and Eriksson & Myrhage (1972).

Controversies about the intramuscular vessels lie mainly in the terminology of the vascular branches and the presence of different forms of anastomoses. Stingl (1973) described the muscular microcirculation of the rat spinotrapezius muscle and categorised it into 6 sections: central arteriole, terminal arteriole, precapillary arteriole, capillary, terminal venule, and central venule. In this study the latest and simplest terminology for intramuscular vessels was adopted, as proposed by Myrhage & Eriksson (1984): primary artery, secondary arteriole, terminal arteriole, capillary, terminal venule, secondary venule and primary vein. The 'secondary' arteriole is considered equivalent to the former 'central' arteriole and the precapillary arteriole is not included. The skeletal muscle vascular network may alternatively be divided into a 'macromesh' and a 'micromesh'. The 'macromesh' forms the first order vascular network which consists of the primary and secondary vessels, whereas the 'micromesh' consists of the terminal vessels and the capillaries.

There are 3 possible forms of vascular anastomoses: the arterioarterial anastomosis or the choke artery, the venovenous anastomosis or the oscillating vein, and the arteriovenous anastomosis (Taylor & Palmer, 1987; Taylor et al. 1990). The anastomoses may occur between branches of the same primary vessel or with the adjacent vessels. In mammalian skeletal muscles, the choke artery/arteriole and oscillating vein/venule are commonly observed, whereas the arteriovenous anastomosis is generally considered rare (Hammersen, 1964; Eriksson & Myrhage, 1972; Stingl, 1973). This was not agreed by Saunders et al. (1957) since they were able to demonstrate arteriovenous anastomoses and these preferential vascular channels were previously called 'metarterioles' by Zweifach & Metz (1955). Recently, Hjortdal et al. (1992) studied blood flow of myocutaneous flaps in pigs using radioactive tracers and microspheres of different sizes. The large microspheres were able to bypass, and not be lodged in, the capillaries suggesting the presence of arteriovenous shunting in the muscle, as well as in the subcutis and skin. However, the true presence of the shunts in skeletal muscle was disputed by a reviewer of that paper (Bassingthwaighte, 1992).

The vascular branches that enter the muscle can be identified by anatomical dissection and traced back to their main sources. The extramuscular pathway may be highlighted in the dissection by infusion with silicone rubber such as latex. However, the large molecular size and viscosity of these polymers limit their penetration into the fine vascular branches of the intramuscular network and only the primary arteries and a few of the larger secondary arterioles may be shown (Mathes & Nahai, 1982). In this study of the human temporalis muscle, the vascular architecture was well demonstrated by the corrosion casts in a 3-dimensional manner down to capillary level. However, the infusion of polymerising methylmethacrylate solution is a very technique sensitive method and a poor cast will form if either the solution sets too quickly or excessive infusing pressure is applied. Some specimens were wasted during the pilot trial whilst gaining experience to develop the technique and 4 more vascular casts were later found inadequate following the corroding process. The quality of the cast may be improved by controlling the perfusion pressure with a pressure gauge. Furthermore, the size of the temporalis muscle is too large to be placed inside the vacuum chamber of the scanning electron microscope, and the casts have to sectioned into several smaller pieces for this investigation. A combination of stereomicroscopy and scanning electron microscopy is a good method to establish the anatomy of a sizable specimen. However, measurement of the vascular dimensions is not accurate because of significant shrinkage from the methylmethacrylate

resin. Nevertheless the vascular corrosion cast serves as an excellent tool to illustrate vascular anatomy.

To conduct this experiment, the availability of fresh human cadavers is essential for vascular infusion to be successful. The use of a coloured infusing medium and harvesting of the temporalis muscle would inevitably produce discolouration and distortion of the head. Fresh adult cadavers for this type of experiment proved impossible to obtain locally but not child cadavers. Despite this drawback in the material, the vascular data and pattern of the temporalis muscle obtained from children are thought to form a sound anatomical basis for the understanding of the temporalis muscle flap commonly used in adult patients. There is no doubt that the intramuscular vessels will grow with the muscle and the capillary density will be modified by mechanical requirement and chronic hypoxia (Appell & Hammersen, 1978; Potter et al. 1991). However, the vascular territory and differentiation in muscles would have been established after birth. Taylor & Minabe (1992) stated that this phenomenon was even recognised 2 centuries ago by John Hunter. They quoted that at some stage of fetal development, the fetus would have acquired a fixed number of arteries and that the subsequent size, shape and direction of each vessel are a result of hypertrophy and elongation or, alternatively, atrophy in order to meet the demands of growth in that area.

A consistent general pattern of vascular supply has been described in mammals (Taylor & Minabe, 1992). This is referred to as the angiosome concept of vascular architecture. Angiosomes were defined as composite blocks of tissue supplied by the same source vessels (Taylor & Palmer, 1987). This angiosome concept was considered broadly applicable to skeletal muscles in both man and animals (Watterson et al. 1988; Taylor et al. 1990; Taylor & Minabe, 1992). However, the fine arrangement of vascular network within any individual muscle varies slightly between different animals. Mathes & Nahai (1981) graded the muscular circulation in human temporalis as type II, meaning that dominant vascular pedicles enter the muscle close to its origin with small vascular pedicles entering the muscle belly. From the present study, the intravascular arterial supply is shown as deriving separately from the muscle origin and the posterior muscular territory. This would fit the same authors' classification as type III rather than II with the new information. With regard to the venous territory, the temporalis can be classified as type C according to Watterson et al. (1988) which is stated to have multiple territories connected by anastomosing oscillating veins.

The vascular supply of the human temporalis muscle is clearly shown in this study to be derived from 3 sources. The branching pattern of the vessels in the human temporalis muscle generally conforms to the arrangement of intramuscular vessels of other muscles both in man and other mammals (Spalteholtz, 1888; Myrhage & Eriksson, 1980; Taylor & Palmer, 1987; Watterson et al. 1988). The veins and venules were confirmed as running closely with the corresponding arteries and arterioles. The presence of double veins associated with a single artery was commonly observed at all levels of the vascular network of the temporalis muscle. This phenomenon is a well recognised feature in skeletal muscle microcirculation (Stingl, 1969; Myrhage, 1977). Vascular anastomoses were frequently found either among the branches of an individual vessel or between the vessels. Anastomoses arranged in loop forms were particularly common at the muscle periphery. However, only the arterioarterial and venovenous anastomoses were noted while arteriovenous anastomoses were absent. This is in general agreement with most of the literature (Hammersen, 1964; Eriksson & Myrhage, 1972; Stingl, 1973). In skeletal muscles, the primary and secondary vessels generally run along the perimysial connective tissues (Myrhage & Eriksson, 1980). The terminal vessels then insinuate between the muscle fibres enabling the capillaries to be in close contact with individual muscle fibres, thus forming a dense interlacing network. The mean number of capillaries surrounding each muscle fibre was found to be around 3–4 (Plyley & Groom, 1975). The biochemical characteristics of the muscle fibres seem to have a positive correlation with capillary density. Muscles dominated by slow contracting oxidative fibres were found to have more than twice as high a blood flow and capillary density than muscles dominated by fast contracting glycolytic fibres (Romanul, 1964; Gray & Renkin, 1978; Myrhage & Eriksson, 1984). The capillary density may be modified by factors such as local mechanical demand on the muscle (Potter et al. 1991) or systemic chronic hypoxia (Appell & Hammersen, 1978).

Understanding the vascular anatomy inside the temporalis muscle has significant surgical implications. The temporalis muscle can be used as a pedicled flap for maxillofacial and pharyngeal reconstruction. Some authors (Shagets et al. 1986) proposed flap splitting techniques on the assumption that the muscle is supplied equally by the ADTA and PDTA. The finding that the MTA has a prominent vascular territory will influence the coronal splitting design, whereby the flap should be divided into

unequal proportions. The presence of many vascular loops around the muscle periphery highlight the point that during harvesting of the temporalis flap, the incision should be made beyond the muscle border in order to minimise damage to these vascular loops. Damage to this peripheral vascular network will result in muscle oedema which subsequently may contribute to difficulty in tunnelling the flap medial to the zygomatic arch and into the oral cavity. A good understanding of the vascular pattern of the temporalis muscle therefore not only provides a sound anatomical basis for splitting the muscle flap but also improves the safety of the split pedicles.

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