Mechanism of Experimental Muscle Embolization of the Carotid Cavernous Fistula and the Fate of the Emboli

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Complications or failure in the treatment of carotid cavernous fistulas with cervical or combined cervical-intracranial carotid ligation⁴-⁶,₈,₁₀,₁₂,₁₆ have mainly been due to the presence of the collateral circulation of the internal carotid artery, namely, the cerebral communicating branches, the ophthalmic artery, or branches of the cavernous carotid segment. The intraluminal embolization method of Brooks,¹,² advocated by Lang and Bucy,³ is simple and effective but has not been used widely because of the fear that the muscle or its fragments may pass into the cerebral circulation and obstruct the distal arterial segment. The possibility of this complication led many surgeons⁴,¹₃,₁₄ to clip the internal carotid artery intracranially before embolization. This procedure itself was not always simple or without risk.⁷,⁸ Since there has been no report on definite complications in patients treated by embolization, its failure⁴,¹₁,₁₅ seems to be due to the use of improper muscle embolus. However, Wanissorn, et al.,¹⁷ using a muscle embolus slightly larger than the caliber of the common carotid artery alone, cured four consecutive cases of carotid cavernous fistula.

The purpose of this investigation was to study the mechanism of muscle embolization of the carotid-cavernous fistula and the fate of emboli, particularly the role of intracranial ligation of the internal carotid artery.

Experimental Method

The experiments were carried out on 48 autopsied human cadavers, within 18 hours after death, aged between 10 and 68 years. The brains were removed, leaving the intracranial carotid arteries as long as possible; the dura mater over the cavernous sinus together with related cranial nerves and surrounding tissues was removed in order to expose the cavernous carotid segment. The cervical carotid arteries were also dissected, and the external carotid arteries ligated. The common carotid arteries were then cut at about 5 cm below the bifurcations and connected to water pumps which applied pressure rhythmically, simulating the living circulation (Fig. 1). The following experiments were then performed:

1. Each of the various shapes and sizes of muscle emboli obtained from the sternomastoid was inserted into the common carotid artery to find out the optimal shape and size of the muscle embolus.

2. The muscle emboli of optimal shape and size were separately inserted into each carotid artery, which had previously been fistulized at its cavernous portion. The size of the fistula of each artery varied from 1 mm upwards.

3. After each successive embolization (Step 2 above) the pressure of the water injected was increased until the fistula recurved, in order to study the fate of the muscle emboli.

Results

Carotid Arteries and Muscle Emboli. The diameter of every intracranial internal carotid artery was less than half of that of its cavernous portion, which was in turn less than half of that of its own common carotid artery.

Muscle emboli smaller than the cavernous carotid artery could be propelled quite easily through the entire carotid artery.

Muscle emboli in block shape, of the same size as the common carotid artery or a little larger (about 1½ the size of the common carotid), obstructed the artery almost

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completely at its beginning. They were propelled gradually, at each pulsation, through the entire course of the artery. They stopped for a while at two sites: first, at the base of the skull where the artery entered the carotid canal; and second, at the clinoid region where the artery turned backward and its diameter became acutely reduced. In the cavernous portion, the muscle was elongated and compressed by the wall of the artery. The latter was distended, appearing sausage-like. No water was observed to leak through the intracranial carotid end. The emboli occupied the cavernous portion about 1½ to 2 cm in length.

Muscle emboli, more than twice the size of the common carotid artery and accommodated to the artery by massage, could be propelled through the internal carotid artery. They occupied more than 3 cm of the cavernous portion, which was too long. Therefore, muscle emboli about the size of the common carotid artery or a little larger was considered to be optimal, for it obstructed the main circulation early, occluding the cavernous carotid segment tightly but not too long.

**Optimal Muscle Emboli and the Fistularized Arteries.** Regardless of the size of the fistulous opening, a part of the muscle embolus bulged out and expanded immediately on reaching the opening, while the main part remained within the lumen of the cavernous carotid segment. The muscle incarcerated in the fistulous opening acquired a dumb-bell shape (Figs. 2 B and 3 B). The bulging part acted as a hook holding the embolus in place. The embolus blocked the artery as well as the fistula tightly, and there was no movement unless significantly higher pressure was applied.

**Fate of the Muscle Emboli.** These emboli may be classified into three categories:

1. The muscle emboli stopped at the fistulous opening; with higher pressures they slipped upward into the distal cavernous carotid segment and stopped there (Fig. 2). This occurred when the fistulous openings were too small (less than 2 mm). On increment of pressure, the bulged part first appeared slightly larger while the intraluminal part was gradually migrating upward into the distal cavernous carotid segment. Finally, when the intraluminal part of the embolus was pushed beyond the fistulous opening, the bulged part was drawn back into the lumen to follow its main part, and stopped just beyond the fistula.

2. The muscle emboli stopped at the fistulous opening but with higher pressures were expelled through the fistulous opening (Fig. 3). This was found when the fistulous openings were smaller than the diameter of the cavernous carotid segments. The bulging part appeared gradually bigger and bigger, while the intraluminal part migrated a little upward into the distal cavernous carotid segment. Finally the whole muscle embolus escaped through the fistulous opening.

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**Fig. 1.** Diagram of the experimental circulation. A continuous water pump ($P_1$) applied pressure adjusted to 80 mm Hg (diastolic pressure). Flow passed through a one-way valve ($V$) into a rubber ball ($P_2$) which was compressed manually at intervals between 60 to 70 times per min (heartbeat rate) and adjusted pressure to about 120 mm Hg (systolic pressure). Mercury manometer ($M$) is at the left and the artery in cadaver ($A$) at the right. The fistula ($F$) is above the bifurcation of the common carotid artery ($B$). The duration of migration of the optimal emboli from $B$ to $F$ was less than 5 min.