Flow Replacement Bypass for Aneurysms:

Decision-Making Using Intraoperative Blood Flow Measurements

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ABSTRACT

Purpose: There is much debate regarding the optimal strategy for extracranial-intracranial (EC-IC) bypass for complex aneurysms. We introduce the concept of a flow replacement bypass which aims to compensate for loss of flow in the efferent vessels of the aneurysm. The strategy to achieve this utilizes direct intraoperative flow measurements to guide optimal revascularization by matching graft flow to demand.

Methods: We reviewed all EC-IC bypass cases performed over a 6 year period. We identified cases in which intraoperative flow measurements using an ultrasonic flow probe were utilized to determine the revascularization strategy, and analyzed the decision-making paradigm.

Results: Twenty three cases were analyzed. For terminal aneurysms, flow measurement in the affected vessel at baseline predicted the flow required for full replacement: MCA 50 ± 25cc/min (n=9); PICA 13 ± 7cc/min (n=4); PCA 33cc/min (n=1); SCA 10cc/min (n=1). For proximal ICA aneurysms (n=8), the flow deficit from baseline during carotid temporary occlusion was measured (26 ± 18cc/min, an average of 44% drop from baseline). The adequacy of flow from the superficial temporal artery (STA) or occipital artery (OA), when available, was assessed prior to bypass, and STA, OA or vein interposition grafts were used accordingly. Measurement of bypass flow following anastomosis confirmed not only patency but sufficient flow in all cases: MCA 50 ± 25cc/min, PICA 18 ± 9cc/min, PCA 64cc/min, SCA 12 cc/min, ICA 36 ± 25cc/min (STA) and >200cc/min (vein).

Conclusions: Direct intraoperative measurement of flow deficit in aneurysm surgery

requiring parent vessel sacrifice can guide the choice of flow replacement graft, and confirm the subsequent adequacy of bypass flow.

INTRODUCTION

There is much debate and variability regarding the strategy for EC-IC bypass in the setting of complex aneurysms [20, 26, 28, 30]. Fundamentally, bypass in aneurysm surgery is created for the purpose of flow replacement, whereby a conduit is established to compensate for loss of flow in the efferent vessels of the aneurysm. Options for donor grafts range from in situ pedicles, such as the superficial temporal artery (STA) or occipital artery (OA), to interposition grafts using radial artery or saphenous vein as conduits. Terms such as "high flow", "intermediate flow" and "low flow" have been variably used to imply vein, radial artery and in situ pedicles respectively. Methods for selection of such graft have been primarily based upon speculation using expected territory flows, or preoperative assessments such as balloon occlusion testing (BOT), to deduce the anticipated flow needing replacement. However, the optimal revascularization strategy should directly match graft flow to demand on a case by case basis, preventing the higher morbidity of an interposition vein or arterial graft if unnecessary, and avoiding inadequate replacement if an in situ pedicle is insufficient.

In this paper, we propose the concept of a *flow replacement bypass* implemented using intraoperative flow measurements for graft selection and verification of bypass success.

METHODS

Patient population and selection criteria

We performed a retrospective review of bypass surgeries (n=125) performed at the University of Illinois Medical Center at Chicago over a 6 year period. The cases in which

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bypass was performed for the purposes of flow replacement in the treatment of anterior or posterior circulation aneurysms were selected (n=42). Of these, we identified the cases in which detailed records of intraoperative flow measurements were available, and were utilized in the decision-making for revascularization strategy; the flow measurements and outcomes in these cases were analyzed. Cases of bypass surgery performed for flow augmentation in anterior or posterior circulation ischemia were excluded. Patients with aneurysms undergoing primary vessel sacrifice without bypass were also excluded.

Preoperative assessment

Patients were admitted for either elective surgery or emergently following hemorrhage or following onset of acute symptoms or signs related to the aneurysm. DSA was performed in all patients preoperatively to define the location and anatomy of the aneurysm, evaluate the size and adequacy of in situ donors such as the STA or OA, and assess the status of the anterior and posterior communicating arteries when relevant.

For carotid aneurysms felt not to be amenable to direct surgical or endovascular treatment, BOT was performed to assess tolerance to carotid sacrifice, unless the patient's clinical condition did not allow reliable monitoring for neurological changes, or heparinization, during the test (as with neurologically impaired patients, and/or subarachnoid hemorrhage). At our institution the BOT protocol consists of temporary balloon occlusion of the ICA for 15 minutes with continuous neurological and electroencephalographic (EEG) monitoring [11], followed by hypotensive challenge, with assessment of cerebral blood flow using ^{99m}Tc-HMPAO single photon emission

computed tomography (SPECT) [17, 31]. SPECT images are analyzed for asymmetrical distribution of the tracer and hypoperfusion ipsilateral to BOT, and compared to SPECT images obtained at baseline.

Intra-operative blood flow measurements

Intraoperatively, blood flow was measured quantitatively in cc/min using an ultrasonic flow probe (Charbel Micro-Flowprobe; Transonics Systems Inc., Ithaca, NY). The probe utilizes the principle of ultrasonic transit-time to sense flow in vessels independent of the flow velocity profile, turbulence or hematocrit [9, 21]. The flow probe is manufactured in a variety of sizes to accommodate intracranial or extracranial vessels ranging from 1 to 3mm in width. Direct vessel contact is not required as space between the probe and vessel can be filled with an ultrasonic couplant, typically saline. In vitro and in vivo studies have established the accuracy of flow measurements using this device [21].

Flows through the vessels of interest associated with the aneurysm, in situ donor vessel (when available), and the bypass conduit after completion of the anastomosis, and after proximal occlusion or trapping of the aneurysm were recorded. Blood pressure and end-tidal carbon dioxide (CO_2) are kept constant during all flow measurements. In addition, EEG burst suppression is routinely induced by inhalational agents during aneurysm surgery, and the flow measurements are performed once a steady state of EEG burst suppression has been achieved.

<u>Intraoperative management</u>

For **terminal aneurysms**, (Fig. 1), i.e. those located beyond the anastomotic connections of the Circle of Willis such as the middle cerebral artery (MCA), posterior cerebral artery (PCA), posterior inferior cerebellar artery (PICA), and internal carotid artery (ICA) terminus), the standard cranial approaches are utilized. The STA for anterior circulation aneurysms, or the OA for PICA/vertebral aneurysms, are carefully preserved. Once the aneurysm and associated vessels are exposed using standard microdissection, flow measurements are obtained in all distal vessels which could be compromised by trapping of the aneurysm. For example, the M2 branches would represent the distal vessels in the case of an M1 aneurysm, or the PICA trunk would represent the distal vessel in a PICA origin aneurysm. The cumulative flow in the distal vasculature reflects the *distal territory flow* requiring replacement by the bypass, and is used to guide the choice of appropriate bypass (in situ STA or OA vs. interposition vein or artery graft), and the subsequent adequacy of the bypass.

For **ICA aneurysms**, (Fig. 2), including cavernous segment, ophthalmic and paraclinoid aneurysms, the operation is performed with simultaneous exposure of the cervical ICA in the neck, while performing a standard ipsilateral pterional craniotomy. The STA when available is preserved, using Doppler to map the course of the anterior and posterior branches in relation to the planned craniotomy incision prior to the opening. Following craniotomy, the sylvian fissure is routinely opened with microdissection, exposing the M1 and A1 segments. Flow in the M1 is measured and recorded at baseline, and then repeated following temporary occlusion of the ICA. Temporary occlusion is performed

on the cervical ICA when the planned surgical intervention is to be proximal occlusion, or on the supraclinoid ICA distal to the aneurysm if the surgical plan is trapping of the lesion. The decrement in M1 flow during temporary vessel occlusion is designated as the *flow deficit*, and used to determine the appropriate donor vessel (in situ pedicle STA graft vs. interposition graft), and to ensure adequate bypass flow following anastomosis.

The flow capacity of in situ pedicle grafts (STA or OA) are directly measured to determine their adequacy for flow replacement. This is performed by determining the *cut flow* of the donor graft [4], which reflects the maximal potential flow capacity of the vessel. Flow measurements in the intact STA or OA generally demonstrate low values in the 5-10cc/min range due to the small caliber of the vessels and the high resistance of the surrounding scalp tissue. However the full carrying capacity of the vessel can be determined once the vessel is dissected, and the distal end is cut allowing the blood to flow freely (termed the *cut flow*) [4, 25]. Once the vessel has been dissected free from surrounding tissues, it is wrapped in papaverine-soaked cottonoids for 20-30 minutes during the time that the craniotomy is performed, to relieve any spasm induced by vessel manipulation. The flow is then measured shortly prior to planned bypass. If the cut flow approaches or exceeds the flow required for adequate flow replacement, the in situ graft is utilized for the bypass. Existing data regarding blood flow and perfusion assessment during vessel occlusion indicate that a 20-25% or greater reduction in distal flow is correlated with ischemia [11, 12, 15]. Therefore, to avoid risk of ischemia, we accept a cut flow only within 20% of the recipient territory flow as adequate. The cut flow is generally measured prior to cutting the graft to its final length in order to allow heparin

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flushing of the vessel distal to the ultimate anastomosis site (in order to prevent risk of endothelial injury from the flushing needle). For vessels of small diameter such as the STA, the reduction in graft length with final trimming will inevitably result in some increase in carrying capacity. If the in situ vessel is inadequate, an interposition graft is used.

Bypass technique

The technique for STA bypass has been previously described in detail [10]. In brief, the STA is dissected, transected and fish-mouthed following heparin irrigation, and sutured to the appropriate recipient branch using interrupted suture technique with 10-0 nylon suture. The same technique is utilized for OA bypass. Running suture technique is occasionally employed if the donor and recipient are of larger size (>2mm).

For interposition grafts, we utilize saphenous vein grafts preferentially to radial artery due to the ease of harvesting and preferred tissue handling properties. The vein is harvested in the calf or thigh following preoperative mapping to determine the suitability (size and length) of the vein. The vein is subjected to pressure distention with heparinized saline utilizing the Shiley balloon distention kit, and sutured to the appropriate recipient branch with 9-0 or 8-0 nylon using running suture technique for the distal anastomosis. The graft is tunneled pre-auricular through a 28 French chest tube to the neck. The proximal anastomosis is created to the external carotid artery in either an end-to-end fashion, or end-to-side fashion after creating an arteriotomy with an appropriately sized aortic punch device. Running suture technique using 7-0 prolene is utilized. Typically,

2000 units of intravenous heparin is administered prior to temporary occlusion for the distal anastomosis, and an additional 1000 units prior the proximal anastomosis. The proximal anastomosis is occasionally created in an end-to-end fashion to the stump of the STA if the donor vessel is suitable.

Postoperative management

Patients with both in situ and vein grafts are routinely maintained on 325mg of aspirin daily beginning immediately postoperatively (administered per rectum if oral administration is not feasible). Postoperatively the success of the bypass is judged by angiographic patency, in addition to quantitative measurements of blood flow through the graft using quantitative magnetic resonance angiography (QMRA)[6].

Analysis

Absolute values of flow measurements, or averages ± standard deviations (if multiple cases of the same aneurysm type), are provided. Individual territory flows and subsequent replacement bypass flows are presented.

RESULTS

Patient population

During the study period, we identified twenty three bypass surgeries which used intraoperative flow measurements to guide the revascularization strategy. The age of these patients at the time of bypass ranged from 22 to 77 years old, with an average age of 56 years old**.** Female patients comprised the majority, 78% (n=18) of the group.

Aneurysm characteristics and operative procedures

The aneurysms treated with bypass and flow replacement strategy consisted of 8
proximal ICA, 2 ICA terminus, 7 MCA, 2 vertebral artery (VA), 2 PICA, 1 basilar artery
(BA) BA terminus, and 1 PCA aneurysm (Table 1 and 2). Bypass using an in situ pedicle
donor vessel, either STA or OA, was performed in 16 of the 23 (70%) cases. In some
cases the option for use of STA was not present as the patient had undergone prior
craniotomy with disruption of the STA. The remainder of cases consisted of saphenous
vein interposition grafts between the cervical carotid or STA stump and MCA.

In the majority of cases the bypass was performed as a permanent conduit for
replacement of flow once the aneurysm had been excluded from the circulation. However
in a small number of cases (n=4), the bypass was performed as protection against
ischemia when prolonged temporary vessel occlusion was anticipated or required; in
these cases the aneurysm was ultimately amenable to direct clipping without parent
vessel sacrifice. The adequacy of the bypass during the temporary vessel occlusion was
assessed in the same fashion as in the patients who underwent permanent vessel sacrifice.

Flow replacement strategy

Terminal aneurysms (Table 1)

For the MCA aneurysms (n=7) and the ICA bifurcation aneurysm (n=2) the *distal
territory flow* calculated from the branches in the MCA averaged 50±25 cc/min. For the
VA/PICA aneurysms flow in the PICA distal to the aneurysm (n=4) averaged 13±7

cc/min. For a trapped BA terminus aneurysm (n=1), flow in the isolated SCA was 10

cc/min. For the PCA aneurysm (n=1) the distal PCA flow was 33 cc/min. These

aneurysms were comprised of fusiform aneurysms or complex aneurysms which

incorporated branch vessels. Four patients were treated for aneurysms which had recurred

after previous clipping or endovascular interventions performed at other institutions.

In four cases, the STA could not be assessed as an in situ donor due to prior craniotomy,

vessel injury or diminutive size. In the remaining cases, the adequacy of flow from in situ

donors was assessed prior to bypass. Cut flows in the STA and OA varied from 8cc/min

to 82cc/min, and approached or exceeded the *distal territory flow* which required

replacement in all but one case (case#2, illustrative case). Consequently, in cases where

the in situ pedicle was deemed adequate, it was utilized for revascularization without use

of interposition vein or arterial grafts.

Subsequent to the bypass and aneurysm trapping/parent vessel sacrifice, bypass flow was

measured to confirm adequate flow replacement, whether a vein graft or in situ donor had

been utilized. Measurement of bypass flow following anastomosis was able to confirm

not only graft patency but sufficient territorial flow in all cases: MCA territory, 50±25

cc/min; PICA territory, 18±9c/min; SCA territory 12 cc/min; PCA territory 63 cc/min.

Proximal ICA aneurysms (Table 2)

For proximal ICA aneurysms, the *flow deficit* from baseline in the MCA averaged 26±18

cc/min, an approximate 40% drop from baseline. The 8 cases included 4 patients who had

failed BOT due to evidence of hypoperfusion on the SPECT portion of the BOT. An additional 3 patients were not good candidates for preoperative BOT, having presented with Hunt and Hess grade 3 or 4 subarachnoid hemorrhage; in these cases angiography suggested that carotid occlusion would be poorly tolerated due to small or absent collaterals. In one additional patient, BOT was not performed as angiography demonstrated the posterior communicating artery (PcoA) to be arising from the base of the aneurysm; proximal BOT was felt not to be useful in accurately reflecting tolerance to ischemia if the aneurysm were to require trapping with occlusion of the PcoA origin.

The flow in the STA ranged from 10 to 55 cc/min in 7 cases; in one case the STA was diminutive and could not be utilized. In the patient with the low STA branch cut flow of 10 cc/min (case#18), the STA was truncated down to its stump[3], which demonstrated an excellent flow of 90cc/min. The stump was utilized with an interposition vein graft, carrying a final bypass flow of 85cc/min. Following anastomosis, the flow in the in situ STA grafts (n=6) averaged 28±12 cc/min, replacing the 19±5 cc/min flow deficit in those cases. In the remaining case, the flow in the ECA-vein graft bypass was 220 cc/min during carotid temporary occlusion, replacing the full hemispheric flow rather than merely the *flow deficit* due to the large size of the conduit. In this case the bypass allowed prolonged temporary clipping with suction decompression of the giant ophthalmic aneurysm; this ultimately permitted direct clipping of the aneurysm, without carotid sacrifice.

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Illustrative cases

ICA terminus aneurysm (Case # 2)

A 44 y.o. female presented with a one week history of severe headache. A head CT scan
showed hyperdensity over the right carotid terminus region. Cerebral angiogram showed
a dissecting pseudoaneurysm extending from the right supraclinoid ICA into the ICA
terminus and occluding the origin of the ACA (Fig.3A,B). This aneurysm represents a
terminal aneurysm with the outflow from the ICA terminus only supplying the MCA
territory. During surgery, flows were measured in the MCA branches and totaled 81
cc/min. The STA was dissected for the required length, and the cut flow was found to be
28 cc/min, which was inadequate for flow replacement. Therefore an interposition graft
was felt to be necessary. Although the STA branch carried inadequate flow, the STA was
truncated to its stump[3], which had a cut flow of 100cc/min. Therefore the interposition
saphenous vein was placed as a short jump graft between the STA stump and an M2
branch. Following the bypass, the pseudoaneurysm was surgically trapped. Final bypass
flow was measured to be 95 cc/min, and postoperative angiogram revealed filling of the
full MCA territory (Fig. 3C).

Proximal ICA aneurysm (Case # 16)

A 73 y.o. female presented with a two week history of progressive left ophthalmoplegia.
MRI demonstrated a giant partially thrombosed cavernous carotid aneurysm, confirmed
on DSA (Fig. 4). The patient underwent BOT, which she passed clinically. However the
SPECT demonstrated hypoperfusion in the left hemisphere during hypotensive challenge.
Intraoperatively a flow deficit of 21 cc/min was measured in the MCA trunk. The STA

cut flow was 55 cc/min, adequate to replace the flow deficit. The patient underwent STA-

MCA bypass using the anterior temporal artery as a recipient vessel. Patency of the

bypass was confirmed with flow measurement, and the aneurysm was trapped. The final

bypass flow following trapping was 51 cc/min.

Outcomes

None of the 23 patients developed stroke (radiological or clinical) as a consequence of

inadequate blood flow to the revascularized territory. Twelve patients remained

neurologically intact postoperatively. Seven patients with pre-existing neurological

deficits had no new deficits following surgery, and showed subsequent improvements.

Two patients with subarachnoid hemorrhage developed new neurological deficits and

strokes in the postoperative period secondary to severe vasospasm. One patient (case

#10) experienced a transient hemiparesis after STA-PCA bypass due to ischemia from

temporary clipping of a P2 segment perforator. Another patient suffered a vocal cord

paresis following VA aneurysm trapping (case #13) likely due to cranial nerve

manipulation during the approach.

DISCUSSION

Definitive management of giant or fusiform aneurysms may require sacrifice of the

parent vessel, with proximal occlusion or trapping. This paper illustrates the concept of a

flow replacement bypass, utilizing a flow-assisted technique aimed at matching supply to

demand in order to maintain adequate flow in the parent and/or distal branches. The flow

demand is measured directly intraoperatively: for proximal ICA aneurysms this consists

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of the *flow deficit* measured in the major distal outflow, the M1 trunk; for terminal

aneurysms this consists of the *distal territory flow* in the efferent branches of the

aneurysm. The supply from in situ pedicle grafts such as the STA and OA is determined

by measuring the *cut flow*, and the suitability of these vessels for matching the demand

determined directly. Lastly, once the bypass has been performed, the success in achieving

full flow replacement is verified intraoperatively by measuring the bypass graft flow.

Bypass Graft Options

Using this flow based strategy, the traditional decision between "high flow" and "low

flow" bypass becomes less relevant, as the primary goal is to determine the "appropriate

flow" bypass. Using in situ pedicle grafts such as the STA has the advantage of greater

patency rates, better longevity, and need for only one anastomosis [1, 28], but risks

inadequate revascularization if the STA cannot supply the needed flow; significant stroke

complications have been noted in patients with apparently intact STA bypasses [2, 13].

Indiscriminate use of interposition radial artery or vein grafts creates the need for an

additional anastomosis, and results in overall lower patency and higher morbidity rates

[14, 20, 24, 26, 27]. Additionally, for a small distal territory, the low flow requirement

may actually result in low demand and graft occlusion. Vein grafts placed in the arterial

circulation appear to require flow rates of 40 cc/min to maintain good patency rates [29].

Graft Selection Strategies

In the management of unclippable proximal ICA aneurysms, the information from BOT

itself may be a guide to the choice of flow replacement graft [16]: failure based upon

clinical criteria indicates a more profound lack of collaterals compared to failure on blood flow imaging or provocative testing, and would indicate the need for a higher flow bypass. Intraoperative flow measurements, however, are useful to confirm the results of the BOT and verify the choice of bypass graft. Additionally, in cases when BOT cannot be performed, such as immediately following subarachnoid hemorrhage, the intraoperative flow measurements can provide the necessary information regarding need for revascularization. Another intraoperative strategy described by Kubo et al advocates the use of intraoperative cortical blood flow measurements over the frontal and temporal lobes with a thermal diffusion flow probe [18], to determine the need for interposition vein graft. Although the authors achieved good results, the technique measures only blood flow in cortical regions beneath the probe, and may underestimate changes in perfusion to the entire territory at risk.

Fusiform or complex aneurysms of distal vessels, such as the MCA or its branches, typically require revascularization as collaterals to such terminal vessels are generally inadequate in the acute setting. Intraoperative measurements provide a reliable mechanism to measure *distal territory flow* and assess adequacy of in situ donor vessels. Although angiographic size of the STA or OA does correlate with its flow capacity, the correlation is not absolute; in situ pedicled arterial donors can occasionally carry flows > 100 cc/min [4]. The final bypass flow in some of our cases exceeded the measured distal territory flow. This may reflect a transient post-ischemic hyperperfusion, following the temporary vessel occlusion associated with performing the bypass, a phenomenon which

we have also observed during aneurysm surgery following temporary vessel occlusion [5].

Assessment of Bypass Patency

Intraoperative evaluation of bypass patency can be performed in a variety of ways beyond simple visual inspection and palpation of pulse. These include routine intraoperative angiography, microvascular Doppler assessment [7] or fluorescent dye (indocyanine green) angiography [23, 32]. However, these methods do not provide a quantitative assessment of the flow in the bypass and therefore are less definitive in confirming the adequacy of the revascularization strategy. An electromagnetic flow meter can provide the same quantitative information as the ultrasonic flow probe [22], but because of the requirement for intimate contact with the vessel, such as device can result in vessel constriction, and is less practical for routine intraoperative use.

Limitations of Flow Replacement Technique

It is important to ensure that systemic factors which can alter blood flow intraoperatively are kept constant during baseline and subsequent measurements, such as blood pressure, end tidal CO_2 and EEG burst suppression. For proximal ICA aneurysms, with additional territory at risk other than the MCA (such as the ACA territory, if absent anterior communicating artery, or the PCA territory, if fetal PCA), the flow deficit in the M1 will not reflect the true overall flow deficit to the hemisphere. In such circumstances flow in the ICA itself would optimally be measured, but the mass of the aneurysm itself often precludes this strategy. Alternatively, the deficit of flow in the A1 and/or posterior

communicating artery in addition to the M1 need to be measured, and presents a drawback of the technique as additional dissection and manipulation of the relevant vessels is required. Another potential limitation in the accuracy of the proposed technique of graft selection is that the major vessel flows may not reflect the only potential route of flow to the brain, given that leptomeningeal collaterals can also contribute to perfusion to some degree [8]. Furthermore, in situ grafts have the potential to 'mature' over time, albeit months, increasing their size and flow capacity [19]. As such, replacing the full flow measured in the major vessels with the flow replacement techniques may be unnecessary if leptomeningeals or graft maturation can compensate for a portion of the flow in the distal tissue bed.

Limitations of this study also include the retrospective nature of the data collection and review, and the potential for selection bypass given that all bypasses for aneurysms during the period were not managed with this flow based strategy. The latter is due to the evolution of the technique over time rather than specific selection of cases for this approach.

CONCLUSION

Challenges in decision making for revascularization of complex aneurysms fall into two major categories: graft selection and verification of bypass success. In regards to graft selection, the primary goal is to adequately match supply to demand, which requires both determining the flow demand and assessing the adequacy of potential in situ donors. A non selective approach carries the potential for an inadequate bypass if an in situ pedicle

graft is utilized, or subjecting patients unnecessarily to the additional morbidity of vein or arterial interposition grafts. Direct intraoperative measurement of flow can guide the choice of the flow replacement bypass graft, helping to ensure an optimal revascularization strategy. Furthermore, the adequacy and patency of the graft can be immediately and quantitatively verified intraoperatively.

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DISCLOSURE

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FIGURE LEGENDS

Fig. 1

Steps for using intraoperative flow measurements to implement a flow replacement

bypass for terminal aneurysms

A. A fusiform M1 aneurysm is demonstrated. Flow is measured in both M2 branches,

totaling 65 cc/min. The cut flow in the STA is found to closely approximate this distal

territory flow at 60 cc/min

B. Anastomosis is performed between the STA and an M3 branch. Patency of the bypass

is confirmed by measuring the flow in the bypass, although bypass flow is expected to be

low given that the parent vessel is still open

C. The final step in aneurysm obliteration is trapping of the aneurysmal M1 segment. The

patency and adequacy of the bypass is then confirmed by measuring graft flow, which at

65 cc/min provides complete flow replacement to the distal MCA territory.

Fig. 2

Steps for using intraoperative flow measurements to implement a flow replacement

bypass for proximal ICA aneurysms

A. A cavernous ICA aneurysm is demonstrated. Following exposure of the cervical ICA,

and the intracranial vessels, baseline flow in the M1 is measured

B. With a temporary clip on the cervical ICA, flow in the M1 is re-measured and falls

from 70 cc/min to 20 cc/min. The represents a flow deficit of 50 cc/min. If the STA cut

flow is inadequate, an interposition graft is placed between the ECA and MCA

C. Following the bypass, permanent proximal occlusion of the cervical ICA is performed, and graft patency is confirmed by flow measurement. Due to the large size of the conduit, the interposition graft flow can exceed even the previously measured flow deficit

Fig. 3

44 y.o female with severe headache and acute dissecting pseudoaneurysm of the ICA terminus

A. Antero-posterior view of right ICA angiogram demonstrating the dissecting aneurysm.

B. Antero-posterior view of the left ICA angiogram demonstrating occlusion of the origin of the A1, and cross-filling of the right ACA

C. Anteroposterior view of postoperative angiogram demonstrating the vein interposition graft between the STA stump and the MCA

Fig. 4

73 y.o female with a symptomatic partially thrombosed giant cavernous ICA aneurysm

A. Coronal T1 weighted post contrast MRI demonstrating the partially thrombosed aneurysm

B. Antero-posterior view of angiogram demonstrating the giant aneurysm with partial filling of the aneurysmal sac

C. Antero-posterior view of postoperative angiogram demonstrating the filling of the MCA branches via the STA (arrows)