TESIS

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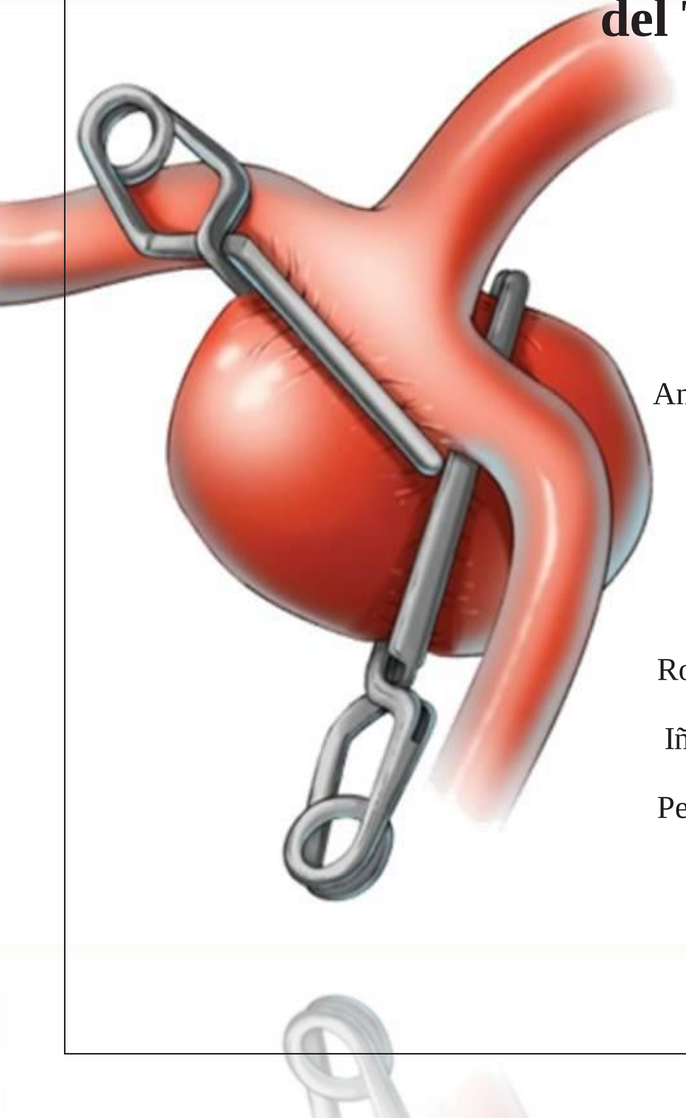
Aneurismas de Arteria Cerebral Media:

Avances en las Técnicas Microquirúrgicas y Resultados del Tratamiento



Ana Rodríguez-Hernández

Dirigida Por:

Rosario Sarabia Herrero

Iñaki Arrese Regañón

Pedro Enríquez Giraudo

Universidad de Valladolid

Facultad de Medicina

Departamento de Medicina

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Memoria presentada por **Ana Rodríguez Hernández** para optar al grado de Doctora

por la Facultad de Medicina de la Universidad de Valladolid

DIRECTORES

Rosario Sarabia Herrero

Jefa del Sª de Neurocirugía

H. Universitario Río Hortega

Profesora asociada

Facultad de Medicina

Universidad de Valladolid

Pedro Enríquez Giraudo

Sº de Medicina Intensiva

H. Universitario Río Hortega

Profesor asociado

Facultad de Medicina

Universidad de Valladolid

Iñaki Arrese Regañón

Sª de Neurocirugía

Coordinador de la U. Patología Cerebrovascular

H. Universitario Río Hortega

Universidad de Valladolid

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"What is right is not always popular

and what is popular is not always right."

Albert Einstein (1879-1955)

A Celia,

en honor a la memoria de su madre

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A mi madre por su esfuerzo titánico criando sola, o peor que sola, a 4 hijos; y por su mágica administración de un sueldo humilde con el que ha conseguido garantizar los estudios superiores de los 4, incluidos másteres, dobles carreras y estancias en el extranjero. Sencillamente impresionante. Nunca dejará de admirarme que alguien que ha sufrido tanto tenga aún tanto amor, tanta generosidad y tanta amabilidad que repartir a propios y extraños.

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I.- Resumen / Abstract

RESUMEN

El tratamiento de los aneurismas cerebrales ha cambiado radicalmente desde la publicación del ISAT (International_Subarachnoid_Aneurysm_Trial), que provocó la adopción generalizada de una política pro-embolización en la que la cirugía se reserva solo para aquellos casos en los que fallan los tratamientos endovasculares. Sin embargo, este nuevo algoritmo terapéutico es foco de importantes controversias y numerosos autores plantean serias dudas sobre su validez científica.

En el caso de los aneurismas de la arteria cerebral media (ACM), una de las localizaciones más frecuentes de aneurismas intracraneales, el nuevo paradigma terapéutico ha generado, si cabe, más dudas y confusión. Estos aneurismas se han considerado clásicamente complejos para el tratamiento endovascular y, en cambio, favorables y fácilmente accesibles para el tratamiento microquirúrgico. Además, las técnicas microquirúrgicas han avanzado notablemente en los últimos años, permitiendo un tratamiento aun más eficaz y seguro de los aneurismas de ACM complejos.

Este trabajo pretende explorar la hipótesis de que los aneurismas de ACM son un claro ejemplo de aneurismas cuyo tratamiento quirúrgico sigue ofreciendo actualmente resultados muy superiores al endovascular.

Para ello se revisa la base de datos prospectiva del Servicio de Neurocirugía Vascular de la Universidad de California (San Francisco) en la que, durante un período de 13 años, se incluyeron un total de 2455 aneurismas tratados con microcirugía, de los cuales 631 fueron aneurismas de ACM. Los resultados clínicos y radiológicos del clipaje convencional y de los nuevos avances técnicos en microcirugía, se analizaron y se compararon con los resultados de otras series de tratamiento quirúrgico y endovascular identificadas mediante una revisión sistemática de la literatura.

Los resultados obtenidos se han condesando en las cuatro publicaciones que dan origen a esta tesis y que nos han permitido concluir que: 1) la cirugía debe seguir siendo el tratamiento de elección para los aneurismas de ACM; 2) las técnicas no convencionales como el flash de fluorescencia, el clipaje contralateral y las opciones de bypass intracraneal amplían las posibilidades de tratar con éxito aneurismas complejos y; 3) los resultados quirúrgicos de esta revisión pueden servir como referente de los resultados a los que debe aspirar la terapia endovascular.

ABSTRACT

The treatment of cerebral aneurysms has radically changed since the publication of the International_Subarachnoid_Aneurysm_Trial (ISAT), which led to the widespread adoption of a pro-embolization policy in which surgery is reserved only for those cases in which endovascular treatment fails. However, this new therapeutic algorithm has raised controversy and serious concerns about its scientific validity.

The management of middle cerebral artery (MCA) aneurysms, one of the most frequent locations of intracranial aneurysms, has been questioned and confused by these changes in aneurysm practice. These aneurysms have long been considered unfavorable for endovascular treatment and, conversely, favorable and easily accessible for microsurgical options. Also, microsurgical techniques have significantly advance in recent years, granting an even safer and more effective treatment of complex MCA aneurysms.

This manuscript investigates the hypothesis that MCA aneurysms remain an example of intracranial aneurysms where surgical treatment is currently superior to the available endovascular options.

The prospective database of the Neurosurgical Vascular Service at the University of California (San Francisco) was reviewed. During a 13 years period, 2455 intracranial aneurysms were microsurgically managed at the institution and 631 of them were MCA aneurysms. Clinical and radiological results of conventional clipping and new developments in microsurgical techniques were analyzed and compared with the results of previous surgical and endovascular series that were identified through a systematic review of the literature.

The results have been published through the four manuscripts that integrate this thesis project and allowed us to conclude that: 1) Surgery should remain the treatment of choice for MCA aneurysms; 2) Non-conventional microsurgical techniques such as flash-fluorescence, contralateral clipping and intracranial bypass options expand the possibilities of successfully treating complex MCA aneurysms and; 3) Surgical Results from our experience set a benchmark that endovascular results should match before being considered an alternative.

II.- Introducción

II.- INTRODUCCION

1.- Epidemiología

Los aneurismas cerebrales consisten en una dilatación patológica de la pared arterial que puede ir aumentando progresivamente de tamaño causando síntomas neurológicos por efecto de masa o llegando a romperse provocando una hemorragia intracraneal generalmente de distribución subaracnoidea.

Se estima que la incidencia global de hemorragia subaracnoidea (HSA) de origen aneurismático es de aproximadamente unos 9 casos/100000 habitantes año, aunque varía de forma importante entre diferentes países, como en el caso de la población japonesa y finlandesa donde la incidencia ronda los 20 casos/100.000 hab/ año (37, 61, 74, 87, 122). En nuestro país, aunque no existen datos generales, se estima que la incidencia de HSA es algo menor que la media y ronda los 5-6 casos/100000 habitantes (23, 77). La HSA aneurismática es un problema de salud importante. Un 12% de los pacientes que sufren una HSA fallecen antes de poder recibir ningún tipo de atención médica (139). De los que consiguen llegar al hospital y recibir tratamiento, la mortalidad se estima entre un 27-44% (44, 60, 74, 76, 102, 133, 162). Entre aquellos que sobreviven, menos del 50% vuelven a su estado funcional previo al sangrado a pesar de los avances en el tratamiento (44, 62, 69, 78, 133). Además, los pacientes afectados por una HSA son relativamente jóvenes, con una edad media de 50 años (69).

Sin embargo, un porcentaje no desdeñable de los aneurismas intracraneales son asintomáticos (se estima que solo 1 de cada 200-400 aneurismas intracraneales llegaría a romperse a lo largo de la vida del individuo; (157)) por lo que su incidencia real en la población es difícil de concretar. En los últimos años, los avances en las técnicas de neuroimagen no invasiva y su amplia disponibilidad están contribuyendo a aportar cada vez más datos sobre la epidemiología y la historia natural de estas lesiones (4, 157). Por el momento, según los datos procedentes de series de autopsias y de estudios angiográficos, se estima que la prevalencia de aneurismas intracraneales en la población adulta podría variar entre un 1-5%, siendo menor hasta la segunda década de la vida y aumentando de forma constante a partir de la tercera (3, 60, 91, 123, 157, 160).

La arteria cerebral media es una de las localizaciones más habituales de aneurismas intracraneales tanto rotos como no rotos, representando entre un 21-40% de los casos dependiendo de las series consultadas (33, 77, 124). En nuestro medio, según la base multicéntrica de hemorragia subaracnoidea (HSA) gestionada por el grupo de trabajo de Patología Vascular de la Sociedad Española de Neurocirugía, los aneurismas de la ACM son responsables del 21% de las HSA (77).

2.- Etiología

Salvo en raras excepciones (95, 150), los aneurismas cerebrales no están presentes en el momento del nacimiento ni en la primera infancia, si no que constituyen una patología que se adquiere a lo largo de la vida. Es probable que los aneurismas cerebrales se formen a partir de un complejo conjunto multifactorial de circunstancias que incluirían una predisposición anatómica congénita potenciada por factores ambientales locales o sistémicos que debilitan aún más la pared arterial y conducen a la formación de la dilatación aneurismática.

Sekhar y Heros resumen los datos histológicos disponibles y apuntan a un número de factores congénitos implicados en la formación de aneurismas: defectos en la media, defectos en la elástica, punto de origen de vasos pequeños y fallo involutivo de ramas arteriales (140). El componente genético de estos factores puede ser hereditario en algunos casos, explicando así el 10% de aneurismas familiares (70, 131, 170). Otros factores etiológicos adquiridos como los cambios degenerativos, adelgazamiento de la íntima, inflamación, ateroesclerosis, hipertensión y stress hemodinámico jugarían también un papel importante (140). El tabaco y algunas drogas como la cocaína también se asocian a una mayor incidencia de aneurismas cerebrales y, por tanto, se les supone un papel etiológico en la formación de los mismos. El hecho de que la incidencia de aneurismas sea mayor en mujeres hace suponer también la implicación etiológica, aún no completamente definida, de los estrógenos. Algo menos de un 10% de los aneurismas intracraneales se dan en pacientes afectos de otras patologías sistémicas como la poliquistosis renal, el lupus eritematoso sistémico, el Ehlers-Danhlos tipo IV, el síndrome de Marfan y otras patologías con afectación sistémica vascular o a nivel del tejido conectivo (13, 46, 88, 157, 158, 161).

En aquellos aneurismas localizados en bifurcaciones arteriales los factores hemodinámicos parecen tener un papel fundamental en su formación (8, 93, 94, 142, 156). En el ápex de las bifurcaciones, la pared arterial está sometida al impacto directo del flujo sanguíneo y por tanto al mayor stress hemodinámico, lo que favorece la alta frecuencia de aneurismas en las mismas. Aproximadamente el 80-85% de los aneurismas de ACM se localizan en la bifurcación del segmento M1 de la arteria (33, 58, 124, 175) y habitualmente se dirigen lateralmente, en la dirección del eje longitudinal del segmento prebifurcación del tronco principal. Es decir, se originan en la dirección de máxima fuerza hemodinámica, en aquella que el chorro de sangre hubiese seguido de no existir la curva de la bifurcación arterial. Además, varios autores han demostrado la relación entre la geometría de la bifurcación de la ACM y la presencia o no de aneurismas (17, 63, 134), lo que aportaría más argumentos a favor del importante papel de los factores hemodinámicos en la formación de los aneurismas de ACM. Ocasionalmente los aneurismas también se pueden originar cerca de la salida de arterias lenticuloestriadas grandes o ramas corticales tempranas del segmento M1 o en los puntos de ramificación principal del segmento M2. Los aneurismas más distales son bastante raros y generalmente tienen una etiología inflamatoria (130).

3.- Presentación Clínica

Similar al resto de aneurismas intracraneales, los aneurismas de la ACM pueden presentarse tras una ruptura aguda en forma habitualmente de hemorragia subaracnoidea. Antes de que lleguen a romperse, pueden presentarse con síntomas neurológicos por efecto de masa, isquemia transitoria, crisis epilépticas, etc. También se diagnostican frecuentemente de forma incidental durante el estudio de alguna otra patología no relacionada.

La hemorragia subaracnoidea se presenta típicamente como una cefalea muy intensa y repentina que la mayoría de los pacientes describe de forma característica como la peor cefalea que han tenido en su vida. Se puede acompañar de naúseas, vómitos, meningismo, fotofobia, déficit neurológico, disminución del nivel de conciencia e incluso éxitus. Hasta en un 20% de los casos, y especialmente en aquellos asociados a aneurismas de la ACM, se pueden producir también crisis epilépticas en las primeras 24h tras la HSA (31). Desde un 15 hasta un 37% de los pacientes que sufren una HSA presentan cefaleas menos intensas en los días previos (11, 50, 65). Estas cefaleas se atribuyen a hemorragias centinela del aneurisma (50) y algunos estudios señalan que multiplican por 10 el riesgo de resangrado precoz (12)

Como veremos en detalle más adelante, el recorrido de los segmentos más proximales de la ACM transcurre por la cisura de Silvio, completamente rodeada de cerebro. Por este motivo, los aneurismas de ACM frecuentemente se "incrustan" en el parénquima cerebral según crecen y, consecuentemente, cuando se rompen se presentan también de forma habitual con un hematoma intraparenquimatoso asociado a la HSA. Algunos autores encuentran hematomas intraparenquimatosos asociados hasta en el 45-50% de las HSA por aneurisma de ACM (10, 33, 124). La particular propensidad de los aneurismas de ACM a presentar signos focales como hemiparesia o crisis comiciales parciales, se explica también (al menos parcialmente) por esta tendencia a sangrar en el parénquima cerebral. Los hematomas intraparenquimatosos tienden a afectar principalmente al lóbulo temporal (hasta en el 85% de los casos según Dashti et al. (33)) y al frontal, y con menos frecuencia se extienden hacia los ganglios de la base.

Los aneurismas no rotos se diagnostican frecuentemente de forma incidental durante el estudio de una HSA por otro aneurisma en distinta localización o durante el estudio de otras patologías no relacionadas con el aneurisma (161). Los aneurismas de ACM son los que más frecuentemente se encuentran de forma casual (157) y se etiquetan como asintomáticos. Algunos autores estiman que hasta un 60% de los aneurismas de ACM se diagnostican de forma incidental (14). Pero los aneurismas no rotos, especialmente los de mayor tamaño, también pueden presentarse con todo tipo de síntomas que incluyen cefaleas, afectación de pares craneales, efecto de masa, déficit motor y/o sensitivo, crisis epilépticas, episodios isquémicos, etc.

4.- Diagnóstico y Evaluación Preoperatoria

La angiografía cerebral con sustracción digital (ASD) continúa siendo a día de hoy el "gold standard" para el diagnóstico y el estudio anatómico de los aneurismas cerebrales. Aporta la mayor sensibilidad para el diagnóstico de aneurismas de menos de 3mm de diámetro y la mejor resolución de imagen para los vasos de menor calibre como son las arterias perforantes (32, 92, 179). La reconstrucción de las imágenes en 3D nos permite analizar todo el recorrido de la ACM en la cisura de Silvio, la longitud y profundidad de los distintos segmentos arteriales, el tamaño, morfología y proyección del aneurisma y su relación con las ramas arteriales adyacentes. Estas imágenes se pueden rotar para simular la visión que tendríamos en el campo quirúrgico, lo cual facilita la planificación tanto de la estrategia de disección como de clipaje del aneurisma (75, 174). A pesar de todas las ventajas enumeradas, la ASD no deja de ser una prueba invasiva que comporta cierto riesgo de complicaciones que aunque no llegan al 1% de los casos, incluyen infarto cerebral, daño arterial e incluso rotura del aneurisma entre otras (28, 157).

En los últimos años la angiografía por tomografía computerizada (ATC) va ganando terreno como alternativa a la angiografía y, en algunos casos, incluso como estudio diagnóstico de elección (166). Es especialmente útil en los casos de aneurismas rotos ya que aporta la ventaja de ser una prueba no invasiva y rápida que puede realizarse fácilmente justo a continuación del TC craneal simple que diagnostica la HSA. Como se ha señalado anteriormente y según numerosos estudios, su sensibilidad y especificidad es comparable a la de angiografía por sustracción digital, especialmente cuanto mayor es el aneurisma y cuanto más experto es el observador que evalúa las imágenes (5, 55, 73, 104, 169, 172). El ATC puede revelar también cualquier calcificación en las paredes del aneurisma o en las ramas que le dan origen y también permite la reconstrucción de imágenes 3D que se pueden rotar para simular la visión intraoperatoria y planificar la cirugía. Una de las principales desventajas del ATC en el estudio de los aneurismas de ACM es que su especificidad disminuye con la tortuosidad vascular que frecuentemente encontramos en este territorio. Otra desventaja es la imposibilidad de afinar el estudio de la vasculatura distal, de suma importancia en el caso de necesitar un bypass de forma imprevista.

La angiografía por resonancia magnética (ARM) se considera por el momento una prueba alternativa no invasiva que evita la radiación y las posibles alergias al contraste yodado. Se puede realizar utilizando las secuencias “time-of-flight” (TOF) o utilizando gadolinio como contraste. En un metanálisis recientemente publicado por Sailer y cols. (135), se señala que la calidad de la ARM ha ido aumentando en los últimos años y en la actualidad presenta una sensibilidad comparable a la del ATC para el diagnóstico de aneurismas intracraneales. La especificidad diagnóstica es por el momento menor que la del ATC (57, 85, 107, 135), pero parece mejorar con ARM de 3 Teslas y con las reconstrucciones 3D (86, 113). Se puede seleccionar como prueba diagnóstica de elección en los pacientes con historia de alergia al contraste yodado o función renal gravemente alterada. Es también de elección para el seguimiento a largo plazo de aneurismas previamente embolizados. En aneurismas gigantes o fusiformes ayuda a identificar posibles porciones trombosadas y a delimitar la verdadera luz del aneurisma y su relación con el parénquima circundante.

5.- Anatomía Quirúrgica

Anatomía arterial

La arteria cerebral media (ACM) se origina en la bifurcación terminal de la arteria carótida interna (ACI), se divide clásicamente en 4 segmentos que se definen por las curvaturas de la arteria a lo largo de su recorrido y que le hacen alternar su orientación entre horizontal y vertical. Finalmente se divide en ramas distales que se distribuyen por la convexidad cerebral. El *segmento M1* o *esfenoidal* comienza en la bifurcación de la ACI, transcurre paralelo al reborde esfenoidal y termina en la rodilla de la ACM, un ángulo recto que forma la arteria al pasar sobre el *limen insulae*. El *segmento M2 o insular* comienza en la rodilla de la ACM, discurre por la hendidura insular y termina a nivel del surco circular de la ínsula, en el siguiente ángulo marcado (90-180º) que forma la arteria al pasar de la superficie insular a la superficie del opérculo fronto-temporal. El *segmento M3 u opercular* comienza a nivel del ángulo que separa la superficie insular de la opercular, discurre en la hendidura del opérculo fronto-temporal y termina a nivel del siguiente ángulo que marca la transición de la superficie opercular a la superficie cortical de la cisura de Silvio. El *segmento M4 o cortical* está constituido por las ramas que se dividen por la convexidad lateral desde su salida de la cisura de Silvio hasta su territorio final.

La ACM se bifurca en dos troncos principales: *superior o frontal* e *inferior o temporal*. Dicha bifurcación se produce en la proximidad de la unión del segmento M1 con el M2, pero puede pertenecer al segmento M1 si se produce proximal al limen insulae, al segmento M2 si se bifurca distal al limen insulae o puede estar localizada justo en la unión M1-M2 si se produce a nivel del limen insulae. En cualquier caso, es importante recordar que es la rodilla de la ACM a nivel del limen insulae la que determina la transición de M1 a M2, y no la bifurcación, que puede producirse en cualquiera de los dos segmentos o en la unión de los mismos. Como ya se ha mencionado anteriormente, la mayoría de los aneurismas de la ACM se localizan a nivel de su bifurcación.

La bifurcación de la ACM puede presentar cierta variabilidad anatómica. En un porcentaje de casos que varía entre el 12% y el 26%, la arteria forma una trifurcación y se divide en un tronco superior, un tronco medio y un tronco inferior. En casos aún menos frecuentes puede existir incluso una cuadrifurcación que origine cuatro troncos principales. Una segunda bifurcación muy próximal a la primera bifurcación, puede confundirse a veces con una cuadrifurcación (82). En cualquier caso, el tamaño de los troncos que se originan dependerá de las ramas distales a las que da lugar cada uno. Pueden existir dos troncos simétricos, pero lo habitual es que alguno de los dos sea el dominante.

Otras variaciones anatómicas de la ACM clínicamente importantes son la *ACM duplicada*, la *ACM accesoria* y la *ACM "twig-like"*. Una *ACM duplicada* es un segmento M1 extra que se origina de la ACI supraclinoidea o de la bifurcación terminal de la ACI. Una *ACM accesoria* consiste en un segundo segmento M1 que se origina del segmento A1 de la arteria cerebral anterior, cerca de la comunicante anterior, lo que podría confundirnos con la arteria recurrente de Heubner. La diferencia estriba en que la ACM accesoria da ramas corticales mientras que la recurrente de Heubner, no. Por último, la ACM "twig-like" es una variación extremadamente curiosa y rara vez descrita que consiste en la sustitución del habitual segmento M1 por una red colateral de vasos que puede albergar aneurismas en su interior y que puede confundirse con una malformación arteriovenosa o un moyamoya (128).

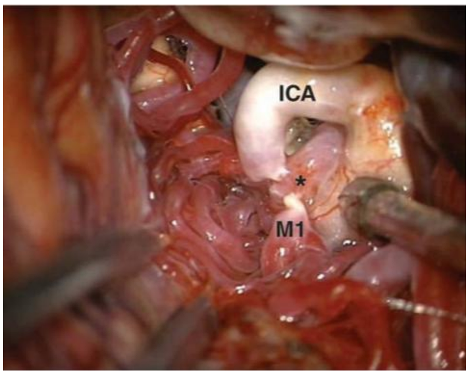

Figura 1.- Fotografía intraoperatoria que muestra el aspecto de una ACM “twig-like”.

La ACM da también origen a un grupo de aproximadamente 10 arterias perforantes denominadas arterias lenticuloestriadas laterales. Habitualmente nacen de la superficie superior o frontal del segmento M1, pero también pueden tener su origen en la bifurcación o el segmento M2. Desde allí, perforan los 2/3 laterales de la sustancia perforada anterior para ascender hacia la cabeza y cuerpo del caudado, putamen, globo pálido, la mitad superior de la cápsula interna, y la corona radiata.

Cisura de Silvio

La cisura de Silvio es la cisterna subaracnoidea que separa el lóbulo frontal del temporal y que contiene los segmentos M1-M3 de la ACM y, por tanto, la gran mayoría de sus aneurismas. Se divide en una porción proximal, esfenoidal o profunda, que contiene el segmento M1 de la ACM y sigue un plano paralelo al reborde esfenoidal y en una porción distal, lateral o cortical que queda cubierta por las venas silvianas superficiales. El complejo venoso silviano se compone de tres sistemas interrrelacionados entre sí: un sistema anterior que drena al seno esfenoparietal, seno cavernoso y seno esfenobasal o senos esfenopetrosos; un sistema posterior que drena lateralmente hacia venas temporales, vena de Labbé y seno trasnverso; y un sistema superior que drena hacia venas frontoparietales, vena de Trolard y seno longitudinal superior. La convergencia de estos tres sistemas venosos en la superficie de la cisura, crea un entramado de venas que pueden dificultar su disección inicial. Sin embargo, esta red de anastomosis nos permitirá coagular y cortar algunas venas para poder separar el lóbulo frontal del temporal sin causar un infarto venoso.

Localización Aneurismas ACM

Clásicamente, los aneurismas de la ACM se clasifican en función del segmento que les da origen en aneurismas del segmento M1 o proximales (habitualmente en relación al origen de arterias lenticuloestriadas grandes o ramas corticales tempranas), aneurismas de la bifurcación y aneurismas distales del segmento M2, M3 ó M4 (34, 43, 130). Aunque los porcentajes varían según las series consultadas, la gran mayoría de aneurismas de ACM se localizan en la bifurcación (33, 58, 124, 175). La siguiente imagen ilustra los porcentajes aproximados de todas las localizaciones:

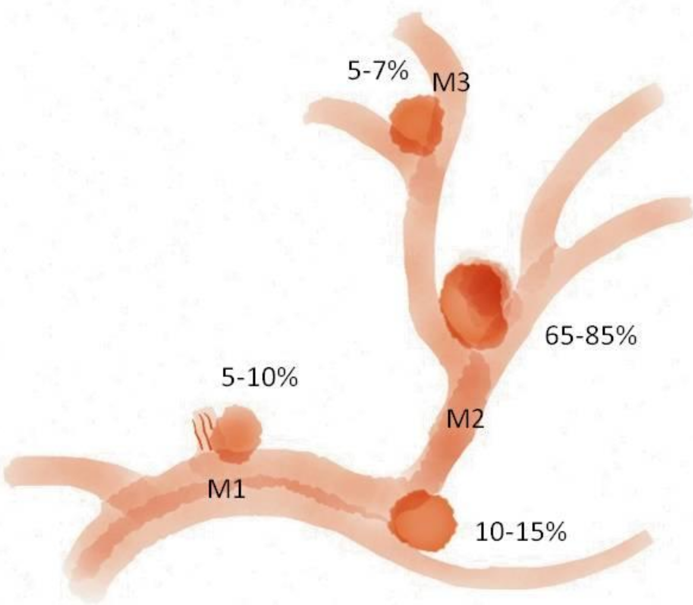

Figura 2.- Localización más frecuente de los aneurismas de ACM

6.- Descripción de las Opciones de Tratamiento

Los aneurismas que se presentan con una hemorragia subaracnoidea requieren tratamiento urgente, preferiblemente en las primeras 48-72h (12, 21, 26, 27, 31, 101, 132) o incluso, según estudios más recientes, en las primeras 24h (109, 173). El tratamiento consiste en excluirlos de la circulación mediante clipaje micorquirúrgico o embolización endovascular. En los aneurismas diagnosticados de forma incidental se puede además plantear retrasar el tratamiento o incluso, en determinados casos, realizar solamente observación. Los apartados que siguen a continuación describen de forma detallada en qué consisten y como se lleva a cabo cada una de las tres opciones de manejo terapéutico.

A.- Clipaje Microquirúrgico

Posición

El paciente se coloca en decúbito supino con un cojín debajo del hombro ipsilateral al aneurisma y con el respaldo ligeramente elevado para conseguir que la cabeza permanezca por encima del nivel del corazón. La cabeza se extiende aproximadamente 20º (dejando la eminencia malar en el punto más alto del campo quirúrgico) para permitir que la gravedad retraiga el lóbulo frontal y lo separe de la fosa craneal anterior y se rota 10-20º hacia el lado contrario al aneurisma para que la cisura de Silvio quede alineada en un plano vertical y los lóbulos frontal y temporal se separen hacia los lados de forma natural al disecar la cisura. Algunos autores defienden una rotación lateral mayor y colocan la cabeza a 30º-45º o incluso a 90º (14, 103). Sin embargo, esta posición hace que lóbulo temporal caiga sobre la cisura de Silvio y cierre el plano de disección dificultando la misma.

Craneotomía

La gran mayoría de aneurismas de la ACM se pueden resolver con una craneotomía fronto-temporal o pterional clásica iniciada con uno o varios agujeros de trépano. La localización más habitual para los agujeros de trépano es temporal y pterional (“key hole”), aunque se han descrito múltiples variaciones a esta técnica (14, 33, 52, 53, 175). La parte posterior de la craneotomía clásica sigue la línea temporal de la incisión de piel y una vez superada la línea temporal superior, se curva hacia delante siguiendo una dirección anterior para terminar medial al foramen del nervio supraorbitario. Desde ahí se curva hacia abajo siguiendo la dirección de la fosa craneal anterior hasta llegar al pterion, que impedirá el paso del craneotomo. La craneotomía se completa subiendo el craneotomo desde el trépano temporal hacia el pterion y fresando o partiendo la porción de hueso que queda sobre este.

El pterion es la estructura tridimensional que constituye la unión del hueso frontal, el hueso parietal y el ala mayor del esfenoides. Se puede localizar en la superficie gracias a la intersección de la sutura coronal con el ala mayor del esfenoides. Su estructura interna es tridimensional, lo que impide cortarlo directamente con el craneotomo requiriendo gubias y fresado para su exéresis. El objetivo es fresar el pterion y el ala menor del esfenoides medialmente a la cisura orbitaria superior para aplanar la superficie que conecta la fosa craneal anterior con la fosa media y permitir así, una vez abierta la dura, una visión completa y libre de obstáculos de la cisterna carotidea.

Una vez completada la craneotomía y el fresado del pterion, se abre la dura con una incisión semicircular desde el suelo de la fosa media hasta el suelo de la fosa craneal anterior y se retrae el colgajo sobre el pterion mediante suturas que lo mantengan fuera del ángulo de visión que queremos obtener hacia la cisterna carotidea.

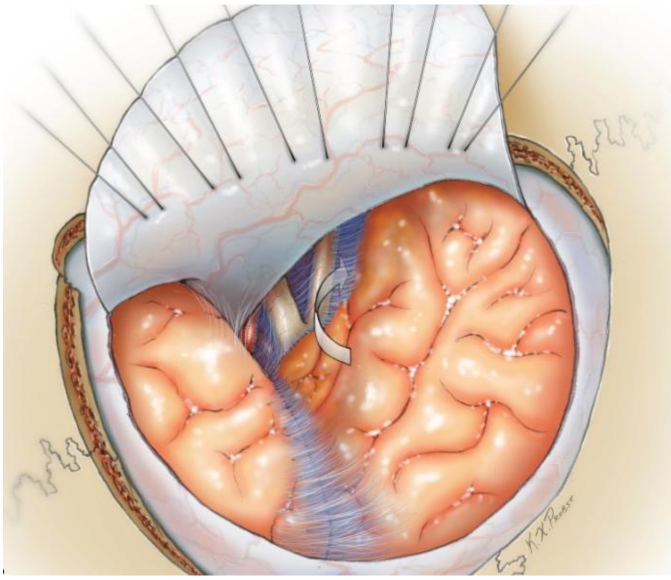

Figura 3.- Visión de la cisura de Silvio y las cisternas óptica y carotídea una vez realizada una craneotomía pterional izquierda y la apertura dural.

Disección intracraneal

La craneotomía pterional permite dos tipos de abordaje microquirúrgico a los aneurismas de ACM: transilviano o subaracnoideo (disecando la cisura de Silvio para llegar a la lesión) y transcortical o subpial (a través del girus temporal superficial).

a) Abordaje subaracnoideo o transilviano

La cisura de Silvio constituye una puerta de entrada natural hacia cualquier aneurisma localizado en el polígono de Willis. Su disección permite separar el lóbulo frontal del lóbulo temporal, abriendo así un pasillo de acceso hacia las cisternas arteriales de la base craneal.

La apertura inicial se realiza con un microbisturí de entre 20-23G o con pinzas de relojero. La disección subaracnoidea progresa cortando la aracnoides con microtijeras, separando suavemente los planos con ayuda de la punta del aspirador, inyectando suero salino en el espacio subaracnoideo y abriendo y cerrando las puntas de la pinza bipolar una vez alineadas en paralelo con las arterias y las superficies piales. Se pueden utilizar lentinas para mantener el espacio subaracnoideo abierto y para controlar algún pequeño sangrado venoso. Es importante preservar en todo momento el plano pial para evitar edema y contusiones postquirúrgicas.

La cisura de Silvio se puede disecar de *distal a proximal (o de lateral a medial)*, abriendo primero la porción más lateral de la cisura y trazando las ramas corticales de la ACM hacia la bifurcación. Este abordaje minimiza la retracción y, por tanto, las posibilidades de dañar tejido cerebral, las ramas de la ACM y sus perforantes. Sin embargo, una disección de distal a proximal aborda los aneurismas de la ACM sin tener control vascular proximal, lo cual no debería suponer mayor problema con los aneurismas no rotos pero puede resultar peligroso con aneurismas que han sangrado. En los casos de aneurismas rotos se puede iniciar la apertura distalmente para establecer los planos de disección subaracnoidea y a continuación cambiar a disección proximal para tener control vascular. En la disección *de proximal a distal (o de medial a lateral)*, se retrae el lóbulo frontal exponiendo el nervio óptico y la carótida. Se abre la cisterna carotídea y desde ahí se diseca distalmente siguiendo el segmento M1 de la ACM hacia la cisura de Silvio. Este abordaje permite la exposición y control de la ACM antes de exponer el aneurisma, pero suele requerir el uso de retractores. Además, la disección proximal produce a liberación precoz de LCR puede colapsar aún más una cisura ya de por sí difícil de disecar en los casos de HSA.

b) *Abordaje transcortical o subpial*

A través de una incisión en el girus temporal superficial y una posterior disección subpial, se expone la ACM, sus ramas y el cuello del aneurisma. Este abordaje inicialmente descrito por Heros (54), reduce la retracción cerebral y disminuye la manipulación de la ACM y sus ramas. Sin embargo, cabe la posibilidad de encontrarse la cúpula del aneurisma primero. Y, dada la incisión cortical, el riesgo de epilepsia postquirúrgica es mayor.

Clipaje

Una vez expuesto el aneurisma, podemos emplear diferentes técnicas de clipaje (un clip simple, múltiples clips, clips en tándem, etc) para su oclusión. La colocación del o los clips debe cerrar el cuello sin dejar remanentes y conseguir al mismo tiempo preservar el flujo normal en el segmento arterial que da origen al aneurisma. Un solo clip puede ocluir con facilidad un aneurisma pequeño, de morfología simple y cuello estrecho (Figura 4A). Sin embargo, un alto porcentaje de aneurismas de ACM, especialmente los localizados en la bifurcación, presentan un cuello ancho y una morfología irregular que a veces incluye una o ambas ramas de la bifuración. Los cuellos complejos se pueden descomponer en partes más sencillas que se van clipando progresivamente hasta conseguir la oclusión completa. Por ejemplo, en un aneurisma de cuello ancho podemos colocar un primer clip que cierre la porción más distal y profunda del cuello y, a continuación, ir colocando clips por encima hasta llegar a la porción más proximal y conseguir el cierre completo (Figura 4B). Las porciones del cuello que presenten ateroesclerosis o calcificaciones, se pueden evitar mediante la aplicación de un clip fenestrado que salve dicha porción más un clip menor que cierre la fenestración del anterior. Los aneurismas parcialmente trombosados se pueden abrir por completo para extraer parte del material trombótico y reconstruir posteriormente toda la cúpula con clips.

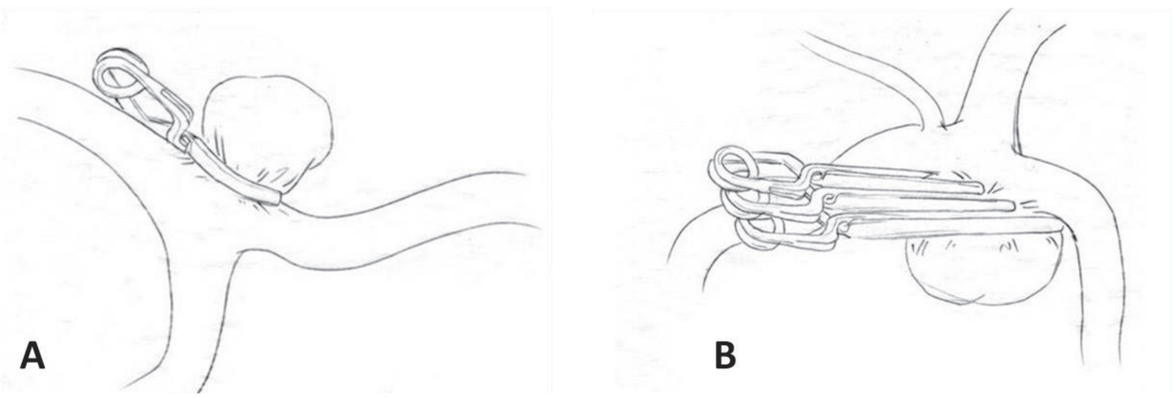

Figura 4.- Ejemplos de distintas técnicas de clipaje

Independientemente de la técnica empleada, una vez clipado el aneurisma, se debe comprobar la correcta permeabilidad de las ramas circundantes mediante inspección microscópica directa y mediante doppler, videoangiografía intraoperatoria con verde de indocianina y/o angiografía convencional (36, 82).

B.-Tratamiento Endovascular

Anestesia

El tratamiento endovascular o embolización se puede realizar bajo sedación consciente o bajo anestesia general. En un paciente con comorbilidades importantes, la sedación evita la intubación traqueal y permite la comprobación constante de la exploración neurológica durante el procedimiento. Tiene la desventaja de producir artefactos de movimiento en la imagen y, además, no es una buena opción en aquellos pacientes con algún grado de confusión o que no cooperan adecuadamente. La anestesia general permite un mejor control de la tensión arterial y la oxigenación y ayuda a reducir los artefactos por movimiento. Las desventajas incluyen la imposibilidad de realizar exámenes neurológicos y el riesgo de hipotensión sistémica (68, 83, 165).

Cateterización Vascular

La arteria femoral derecha en su segmento proximal a la bifurcación y distal a la salida de la arteria epigástrica, es habitualmente el vaso de elección para el acceso endovascular. Una vez localizada en la ingle aproximadamente sobre la cabeza del fémur, se cateteriza con un catéter guía unido a una irrigación continúa de salino y heparina para evitar complicaciones tromboémbolicas. En los aneurismas no rotos, se puede administrar un bolo inicial de 70-100 UI/kg; en los rotos, algunos autores prefieren esperar hasta que la cúpula del aneurisma esté ya protegida con coils para evitar un resangrado con la infusión del bolo de heparina (38). Habitualmente la anticoagulación con heparina se revierte al final del procedimiento salvo que se haya producido alguna complicación tromboembólica o salvo que se sospeche que los coils pudieran protruir por fuera del cuello aneurismático (35).

Una vez avanzado el catéter guía hasta la carótida interna, se debe realizar una primera imagen general de la circulación intracraneal para obtener una imagen inicial del aneurisma y detectar posibles estenosis, áreas de vasoespasmo o émbolos que requieran tratamiento antes de continuar avanzando el catéter.

Microcateterización del aneurisma

Se puede realizar de forma directa introduciendo la microguía en el aneurisma y pasando el microcatéter a través de ella, o de forma indirecta, pasando incialmente tanto la microguía como el microcatéter más allá del cuello del aneurisma, hacia la arteria distal y entrando en el cuello aneurismático con una maniobra de retirada.

Embolización del saco aneurismático

Una vez situado el microcatéter en el aneurisma, se puede comenzar a subir y liberar los coils. Habitualmente, el primer coil debe ser del tamaño del aneurisma o ligeramente inferior en el caso de aneurismas rotos (para evitar un resangrado). Después se deben ir liberando coils de forma progresiva hasta conseguir una oclusión completa del aneurisma. Entre la colocación de cada coil y al final del procedimiento, se debe realizar una imagen angiográfica para comprobar la correcta posición del coil, la porción de aneurisma que aún permanece permeable (o la oclusión completa si estamos al final del procedimiento), la ausencia de extravasación de contraste (que indicaría una ruptura) y la ausencia de complicaciones tromboembólicas.

Embolización con stent y embolización con balón

Para evitar que los coils se hernien desde el aneurisma a la arteria de origen, se pueden usar dos técnicas:

1.- Embolización asistida con stent: consiste en colocar un stent en la rama que da origen al aneurisma de tal forma que dicho stent cubra de un lado al otro del cuello. En los aneurismas de la bifurcación de ACM, esta técnica requerirá de dos stents en "Y" colocados desde la porción prebifurcación y hacia cada una de las ramas distales. La embolización asistida con stent se puede realizar accediendo con un microcatéter al saco aneurismático a través del stent. Sin embargo, puede ser complicado pasar el microcatéter a través de la red del stent. Una alternativa para evitar este problema es la técnica conocida como "jailing" o "enjaulado" que consiste en introducir primero un microcatéter en el aneurisma y liberar a continuación el stent con un segundo microcatéter, evitando así tener que acceder a través del stent.

2.- Embolización asistida con balón: una vez introducido el microcatéter en el aneurisma, se coloca e infla un balón de un lado a otro del cuello para evitar que los coils se hernien hacia la arteria. Una vez terminada la embolización, el balón se desinfla y se retira.

La embolización asistida con stent tiene la ventaja de dejar de forma permanente el stent como soporte de la masa de coils, sin embargo requiere el uso prolongado de antiagregantes (motivo por el cual no se recomienda usar en aneurismas rotos) y presenta complicaciones a largo plazo por estenosis del stent. El balón evita el uso de antiagregantes y las posibles complicaciones de estenosis a largo plazo. Sin embargo puede provocar isquemia en el territorio distal a su colocación. Por este motivo, requiere el inflado y desinflado periódico durante el proceso de embolización, con el consiguiente riesgo de rotura arterial cada vez que el balón se infla de nuevo. Algunos estudios (167, 168) señalan una mayor tasa de repermeabilización en los aneurismas embolizados con asistencia de balón.

Flow diverters

Los dispositivos de desviación de flujo o "flow diverters" consisten en stents con una doble malla metálica trenzada que ofrece una cobertura hasta tres veces mayor que la de los stents previos y cuyo mecanismo de acción consistiría, principalmente, en disminuir la entrada de flujo sanguíneo en el aneurisma redirigiendo dicho flujo a través del cuello.

Inicialmente su uso se aprobó para aneurismas gigantes o de cuello ancho (más de 4mm) de la carótida interna en los que el tratamiento quirúrgico y/o la embolización no ofrecían resultados completamente satisfactorios (38). Sin embargo, al ir aumentado la experiencia clínica con estos dipositivos, su uso se ha ido ampliando a otros aneurismas incluyendo incluso los localizados en bifurcaciones arteriales como sería el caso de los aneurismas de ACM (15, 18, 19, 20, 24, 89, 177).

Hasta la fecha, no se han completado estudios prospectivos randomizados que comparen la eficacia y los riesgos y beneficios de los stents desviadores de flujo frente a la embolización simple o el clipaje. Existe al menos un estudio multicéntrico que previsiblemente se completará en 2017 (118). Hasta entonces, la ausencia de pruebas sólidas sobre la seguridad (especialmente a largo plazo) de estos dispositivos, aboga por estudiar cada caso detenidamente y hacer un uso prudente de esta tecnología (7, 30). En particular, en los aneurismas localizados en las bifurcaciones, el uso de desviadores de flujo se ha asociado a graves complicaciones que en principio deberían contraindicar su uso (89).

Embolización con dispositivo WEB

El WEB ("*Woven Endobridge Device*"; Sequent Medical, Inc.,Aliso Viejo, CA, USA) consiste en un dispositivo auto-expandible de red metálica trenzada con forma de esfera achatada por los polos, diseñado para actuar como un derivador de flujo pero que se libera dentro del saco aneurismático (72).

Su uso requiere un estudio detallado de la morfología, diámetro, altura y tamaño del cuello del aneurisma a tratar para poder elegir el tamaño adecuado del dispositivo WEB. Se recomienda elegir un dispositivo 1 mm mayor que el diámetro medio del aneurisma y 1 mm menor que la altura media del mismo (111). Una vez posicionado el catéter guía, la cateterización del aneurisma requiere un microcateter de tamaño bastante mayor (27 French) a los utilizados para embolización con coils. Una vez colocado el dispositivo en el aneurisma, se realiza una imagen de control. Si el tamaño o la posición no son los adecuados, se recalienta el dispositivo para poder modificar su posición o para retirarlo y colocar uno nuevo de tamaño más adecuado. A pesar de la ausencia de datos clínicos al respecto, algunos autores defienden que el uso del dispositivo WEB se puede asociar al uso de stents clásicos y coils si se estima necesario (111).

La tasa de complicaciones tromboémbolicas con este tipo de dispositivo ronda el 16% de los casos, por lo que sería mayor que la descrita para otro tipo de tratamientos endovasculares (110, 111, 112). Además, no está claramente relacionada con el uso o no de antiagregantes ni con la dosis o tipo de fármaco empleado. Las series clínicas de experiencia preliminar con este dispositivo para aneurismas de ACM, describen una oclusión completa en menos del 30% de los casos tratados (111).

C.- Observación

En los últimos años parece haberse incrementado el porcentaje de aneurismas de ACM diagnosticados de forma incidental antes de que pudieran romperse. Es en estos casos diagnosticados de forma incidental en los que podría plantearse el dilema de tratar o no, ya que parece que solo una minoría de estos aneurismas acabarían rompiéndose y ya que cualquier opción de tratamiento tiene cierto riesgo de morbilidad e incluso mortalidad (13, 22, 25, 51). Si nos guiamos por los resultados del estudio internacional de aneurismas intracraneales no rotos (161), solo debería plantearse tratamiento de los aneurismas de ACM en pacientes asintomáticos cuando el saco aneurismático supere los 7mm de diámetro máximo, ya que por debajo de dicho umbral el riesgo de rotura sería prácticamente desdeñable. Por lo tanto, en pacientes con un aneurisma por debajo del citado tamaño, sería razonable ofrecerles observación clínico-radiológica como la opción de elección para el manejo de su patología. Sin embargo, algunos autores señalan que hasta en un 29% de los casos de aneurismas de ACM rotos, el saco aneurismático tenía un diámetro menor de 8mm, lo cual sugiere que los aneurismas pequeños también pueden ser peligrosos y cuestiona los resultados del estudio ISUIA y los algoritmos de manejo derivados del mismo (33, 42). Además, aunque el riesgo de rotura en determinados casos sea pequeño, las consecuencias de una posible HSA son devastadoras en un alto porcentaje de pacientes que desgraciadamente suelen ser relativamente jóvenes (16).

7.- Selección Opciones de Tratamiento: **Justificación del Estudio**

El tratamiento de los aneurismas cerebrales ha cambiado radicalmente desde la publicación en 2002 del ISAT (“International Subarachnoid Aneurysm Trial”, (96)), que provocó la adopción generalizada de una política pro-embolización en la que todos los aneurismas se consideran inicialmente para tratamiento endovascular y se reserva la cirugía solo para aquellos que presentan una anatomía desfavorable o en los que fallan los intentos de embolización (29).

Sin embargo, este algoritmo terapéutico que parece haberse implantado ampliamente gracias al ISAT, es foco de importantes controversias y numerosos autores plantean serias dudas sobre el mismo (2, 9, 117) . En primer lugar, aunque el ISAT se limitaba a analizar un pequeño grupo de pacientes con aneurismas rotos (de los 9559 pacientes posibles solo se incluyeron 2143, un 22.4%), los resultados han sido extrapolados para justificar el tratamiento endovascular tanto de aneurismas rotos como no rotos y en cualquier localización intracraneal. Por ejemplo, hay una tendencia a asumir que el tratamiento endovascular de los aneurismas de la bifurcación basilar es mejor que la cirugía y, de hecho, es la única opción terapéutica que se ofrece para estos aneurismas en muchos centros, a pesar de que el ISAT solo incluyó 26 pacientes (1.2%) de este tipo. En segundo lugar, las ventajas del tratamiento endovascular sobre el quirúrgico desaparecen a partir de los 3-5 años de seguimiento debido a las recurrencias, resangrados y morbidmortalidad asociada a los retratamientos (117). Por último, la utilización de nuevos dispositivos endovasculares como los stents intraluminares o intrasaculares para redirigir el flujo sanguíneo (“flow diverters”) se está generalizando sin que su seguridad, eficacia y durabilidad hayan sido suficientemente analizadas y, mucho menos, comparadas con el tratamiento quirúrgico en un ensayo aleatorizado.

Todos estos cambios han generado dudas y confusión acerca del tratamiento de los aneurismas de la arteria cerebral media (ACM) que, como hemos visto anteriormente, es una de las localizaciones más frecuentes de aneurismas intracraneales (119, 137, 146, 147, 164). Clásicamente, los aneurismas de ACM se han considerado desfavorables para el tratamiento endovascular dada la habitual complejidad para descifrar angiográficamente la arquitectura de las ramas que les dan origen y la alta incidencia de cuellos anchos y sacos aneurismáticos dismórficos. En cambio, son lesiones favorables para el tratamiento microquirúrgico ya que son fácilmente accesibles y manipulables con tan solo disecar la cisura de Silvio y, cuando el clipaje tradicional falla, se prestan fácilmente a técnicas quirúrgicas alternativas como la trombectomía, la reconstrucción y el bypass. Además, a pesar de no recibir la misma publicidad que los avances endovasculares, estas técnicas microquirúrgicas alternativas han evolucionado de forma notable en los últimos años permitiendo un tratamiento aún más eficaz y seguro de los aneurismas de ACM complejos.

En definitiva, los aneurismas de ACM son un claro ejemplo de aneurismas cuyo tratamiento quirúrgico sigue ofreciendo a día de hoy resultados muy superiores al tratamiento endovascular y, sin embargo, muchos centros optan por ofrecer la embolización como tratamiento de primera línea. Para contrarestar esta tendencia embolizadora de discutible base científica, el presente estudio pretende revisar los criterios de selección de pacientes, los avances técnicos y los resultados clínico-radiológicos del tratamiento microquirúrgico de los aneurismas de ACM.

III.- Objetivos

III.- OBJETIVOS

- Revisar los resultados actuales del tratamiento microquirúrgico de los aneurismas de ACM
- Describir algunas de las nuevas técnicas microquirúrgicas aplicables a estos aneurismas
- Revisar la literatura actual para comparar los resultados del tratamiento endovascular y quirúrgico para esta localización concreta

IV.- Material y Métodos

IV.- MATERIAL y MÉTODOS

Se revisa la base de datos prospectiva del Servicio de Neurocirugía Vascular de la Universidad de California (San Francisco), una institución de reconocido prestigio en este ámbito y que mantiene una política de ofertar la cirugía como tratamiento de primera línea de los aneurismas de ACM.

Durante un periodo de 13 años comprendido desde Septiembre de 1997 hasta Marzo de 2010, un total de 2455 aneurismas fueron tratados con microcirugía en 1913 pacientes. De estos pacientes, 543 (28,4% del total de pacientes) presentaron 631 aneurismas de ACM (25,7% del total de aneurismas). Había 406 mujeres (75%) y 137 hombres (25%), con una edad media de 55,3 años (rango, 1 – 87 años).

La exclusión de los aneurismas se evaluó de forma independiente por un neurorradiólogo que clasificó los resultados como oclusión completa (sin aneurisma residual), mínimo aneurisma residual (mínimo resto de cuello) u oclusión incompleta (resto de más del 5% del aneurisma inicial). Los resultados neurológicos se evaluaron mediante la escala modificada de Rankin. Una enfermera o un neurólogo no involucrados directamente en la atención del paciente y no pertenecientes al Servicio de Neurocirugía, realizaron estas evaluaciones clínicas de forma preoperatoria, postoperatoria precoz y a lo largo de todo el período de seguimiento disponible.

El análisis estadístico de las variables categóricas se realizó utilizando la Chi cuadrado, corrigiendo mediante Bonferroni para comparaciones múltiples y estableciendo una $p<0.05$ como criterio de significación estadística en el análisis univariante. Se utilizó el programa Stata 12 para dicho análisis.

Para comparar los resultados con otras series de tratamiento quirúrgico y endovascular, se realizó una revisión de la literatura en PubMed y Medline utilizando como palabras clave y como texto libre: “middle cerebral artery aneurysms” ó “MCA aneurysms” y “treatment” ó “management”. Se limitó la búsqueda a artículos en inglés y español publicados a partir de enero de 1984 y hasta enero de 2012. Inicialmente se revisó el resumen de los artículos identificados y posteriormente se obtuvo el texto completo de aquellos potencialmente relevantes. Las referencias de cada artículo incluido se revisaron también para buscar artículos adicionales.

V.- Resultados

V.- RESULTADOS

La tesis se basa en los resultados de las siguientes publicaciones originales:

1. Current management of middle cerebral artery aneurysms: surgical results with a "clip first" policy. Rodríguez-Hernández A, Sughrue ME, Akhavan S, Habdank-Kolaczkowski J, Lawton MT. *Neurosurgery* 72:415–427, 2013.
2. Flash fluorescence with indocyanine green videoangiography to identify the recipient artery for bypass with distal middle cerebral artery aneurysms: operative technique. Rodríguez-Hernández A, Lawton MT. *Neurosurgery* 70:ons209–220, 2012.
3. Contralateral Clipping of Middle Cerebral Artery Aneurysms: Rationale, Indications, and Surgical Technique. Rodríguez-Hernández A, Gabarrós A, Lawton MT. *Neurosurgery*, 71:ons116-123, 2012.
4. End-to-End Reanastomosis Technique for Fusiform Aneurysms: 3D Operative Video. Rodríguez-Hernández A, Lawton MT. *Neurosurgery* 10:157-158, 2014.

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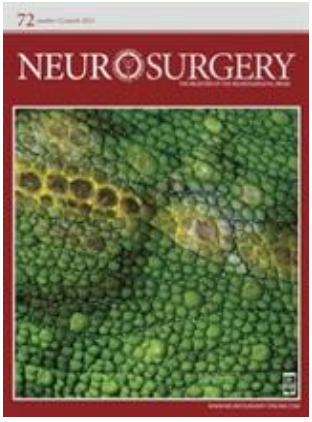

1er Artículo

RESEARCH—HUMAN—CLINICAL STUDIES

Current Management of Middle Cerebral Artery Aneurysms: Surgical Results With a "Clip First" Policy

Ana Rodríguez-Hernández, MD
Michael E. Sughrue, MD
Sina Akhavan, BS
Julian Habdank-Kolaczkowski, BS
Michael T. Lawton, MD

Department of Neurological Surgery, University of California at San Francisco, San Francisco, California

Correspondence:
Michael T. Lawton, MD,
Department of Neurological Surgery,
University of California,
San Francisco, 505 Parnassus Ave,
San Francisco, CA 94143.
E-mail: lawtonm@neurosurg.ucsf.edu

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BACKGROUND: One response to randomized trials like the International Subarachnoid Aneurysm Trial has been to adopt a "coil first" policy, whereby all aneurysms be considered for coiling, reserving surgery for unfavorable aneurysms or failed attempts. Surgical results with middle cerebral artery (MCA) aneurysms have been excellent, raising debate about the respective roles of surgical and endovascular therapy.

OBJECTIVE: To review our experience with MCA aneurysms managed with microsurgery as the treatment of first choice.

METHODS: Five hundred forty-three patients with 631 MCA aneurysms were managed with a "clip first" policy, with 115 patients (21.2%) referred from the Neurointerventional Radiology service and none referred from the Neurosurgical service for endovascular management.

RESULTS: Two hundred eighty-two patients (51.9%) had ruptured aneurysms and 261 (48.1%) had unruptured aneurysms. MCA aneurysms were treated with clipping (88.6%), thrombectomy/clip reconstruction (6.2%), and bypass/aneurysm occlusion (3.3%). Complete aneurysm obliteration was achieved with 620 MCA aneurysms (98.3%); 89.7% of patients were improved or unchanged after therapy, with a mortality rate of 5.3% and a permanent morbidity rate of 4.6%. Good outcomes were observed in 92.0% of patients with unruptured and 70.2% with ruptured aneurysms. Worse outcomes were associated with rupture ($P = .04$), poor grade ($P = .001$), giant size ($P = .03$), and hemicraniectomy ($P < .001$).

CONCLUSION: At present, surgery should remain the treatment of choice for MCA aneurysms. Surgical morbidity was low, and poor outcomes were due to an inclusive policy that aggressively managed poor-grade patients and complex aneurysms. This experience sets a benchmark that endovascular results should match before considering endovascular therapy an alternative for MCA aneurysms.

KEY WORDS: Bypass, Clip first policy, Clipping, Microsurgery, Middle cerebral artery aneurysms

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The International Subarachnoid Aneurysm Trial (ISAT) changed the management of brain aneurysms in developed countries,[1,2] legitimizing endovascular coiling as a safe alternative to surgical clipping and supplanting clipping as the aneurysm treatment of choice for many aneurysms at many centers. The Barrow Ruptured Aneurysm Trial reinforced many of the results from the ISAT and eliminated the criticism that American surgeons with more aneurysm experience would have better microsurgical results.[3] One response to these randomized trials has been the adoption of a "coil first" policy, whereby all aneurysms be considered for coiling, reserving surgery for those with unfavorable anatomy or failed coiling attempts.[4]

This management policy raises serious concerns. First, although the ISAT examined a small subset of eligible patients with ruptured aneurysms (2143/9559, 22.4%), the results have been

ABBREVIATIONS: ICG, indocyanine green; **ISAT,** International Subarachnoid Aneurysm Trial; **MCA,** middle cerebral artery; **mRS,** modified Rankin score; **SAH,** with subarachnoid hemorrhage extrapolated to justify endovascular treatment of all aneurysms, ruptured and unruptured. For example, endovascular coiling of basilar bifurcation aneurysms is perceived as superior to clipping and is the only treatment offered at many centers, but only 26 patients (1.2%) were included in the ISAT.[1] Second, the ISAT's advantages in outcome with coiling have vanished in 5-year follow-up studies owing to aneurysm recurrences, rehemorrhages, and morbidity associated with re-treatments.[5,6] Third, new devices like intraluminal and intrasaccular flow diverters are quickly expanding the feasibility of endovascular therapy, but their safety, efficacy, and durability have not been analyzed sufficiently, and there are no randomized trials comparing them with surgery.[7]

The management of middle cerebral artery (MCA) aneurysms has been questioned and confused by these changes in aneurysm practice. These aneurysms have long been considered unfavorable for coiling based on their trifurcated anatomy, broad necks, dysmorphic shapes, and branches that can be angiographically undecipherable. Conversely, MCA aneurysms have long been considered favorable for clipping because they are accessible, can be easily manipulated after splitting the sylvian fissure, and avail themselves to other treatment techniques like thrombectomy, clip reconstruction, and bypass when conventional clipping techniques fail.[8-12] The MCA aneurysm is the best example of an aneurysm whose microsurgical results are superior to endovascular results. Nonetheless, there seems to be increasing interest in treating MCA aneurysms endovascularly. They were underrepresented in the ISAT trial (303 aneurysms, 14.1%, whereas in most other aneurysm series they account for one quarter of all aneurysms), which reflects the lack of therapeutic equipoise between clipping and coiling necessary for ISAT inclusion. We favor a "clip first" policy for MCA aneurysms. In this study, we reviewed our experience with MCA aneurysms managed with microsurgical clipping as the treatment of choice.

PATIENTS AND METHODS

Patients

This study was approved by the University of California, San Francisco Committee on Human Research and conducted in compliance with Health Insurance Portability and Accountability Act (HIPAA) regulations. Patients with MCA aneurysms who were treated microsurgically were identified from the prospectively maintained Vascular Neurosurgery database. Operative reports, inpatient charts, angiographic studies, magnetic resonance imaging, computed tomographic imaging, and outpatient clinic data were analyzed retrospectively.

During a 13-year period from September 1997 to March 2010, 2455 aneurysms were treated microsurgically in 1913 patients by the senior author (M.T.L.). Of these patients, 543 patients (28.4% of all patients) had 631 MCA aneurysms (25.7% of all aneurysms). There were 406 women (75%) and 137 men (25%), with a mean age of 55.3 years (range, 1-87 years).

Surgical Management

MCA aneurysms were managed with a "clip first" policy, within the context of a multidisciplinary team that included neurointerventional radiologists and neurovascular neurologists. Patients with MCA aneurysms were discussed by the team after diagnostic angiography. When definitive endovascular treatments were available, patients were informed of all options: surgical, endovascular, and observation. With patients on the Vascular Neurosurgery service, recommendations were made for surgery as part of a clip first policy. Ultimately, patients and families had the freedom to choose therapy, and written informed consent was obtained on all patients. One hundred fifteen patients (21.2%) were referred from the Neurointerventional Radiology group, reflecting this surgical preference. This policy was not absolute, because 32 of these patients (27.8%) had attempts at coiling and 12 (10.4%) had been previously coiled. In addition, 64 patients with MCAs were treated with coiling during the study period. No patients crossed over from the Neurosurgical service for endovascular management.

MCA aneurysms were exposed by using pterional craniotomies in the vast majority of cases. Direct aneurysm occlusion with conventional clipping of the neck was the primary treatment strategy, with temporary clipping, thrombectomy, and/or clip reconstruction used as needed. Indirect aneurysm occlusion with trapping, proximal parent artery occlusion, or distal occlusion, usually with a bypass, was used as the alternative treatment strategy when direct neck clipping was not possible.

Adequacy of treatment and patency of parent vessels was analyzed intraoperatively by using intraoperative angiography, indocyanine green (ICG) fluorescence videoangiography, and/or Doppler flow measurements. Over the past 6 years, ICG videoangiography supplanted intraoperative angiography.

Outcomes

Aneurysm occlusion was evaluated independently by neuroradiologists using postoperative angiography and classified as complete (no residual aneurysm), minimal residual aneurysm (small neck remnant or dog-ear), or incomplete ($>$5% of the original aneurysm lumen remaining). Bypass patency was also assessed angiographically. Aneurysm treatment failure was defined as posttreatment growth of residual aneurysm documented by angiography, or posttreatment aneurysm rupture.

Neurological outcomes were assessed by using the modified Rankin score (mRS). A clinical research nurse or clinician not directly involved in the care of these patients and not funded by the Department of Neurosurgery performed all outcome assessments preoperatively, early postoperatively (6 weeks), and at last available follow-up.

Statistical Analysis

Univariate analysis of categorical variables was performed by using χ^2 analysis to determine covariates that had a significant relationship with patient outcome. We corrected for multiple comparisons using the Bonferroni method, and $P < .05$ was considered significant on univariate analysis. Statistics were performed with the use of Stata 12.

RESULTS

Patient Presentation

Rupture status was evenly divided, with 282 patients with ruptured aneurysms (51.9%) and 261 (48.1%) with unruptured aneurysms. Hunt-Hess grade I was the most common grade (92 patients, 32.6%) among patients with subarachnoid hemorrhage. There were 82 (29.1%) grade II and 47 (16.7%) grade III patients. Sixty-one were poor-grade patients (Hunt-Hess grades IV [50, 17.7%] and V [11, 3.9%]). Unruptured MCA aneurysms were found incidentally in 110 patients (42.1%). Other common presentations included mass effect (42 patients, 16.1%), association with other aneurysms (32 patients, 12.3%), or other lesions (32 patients, 12.3%), headache (15 patients, 5.7%), seizure (10 patients, 3.8%), ischemia (8 patients, 3.1%), and residual/recurrence after coiling (12, 4.6%).

Fisher grades were evenly divided between grade II (138 patients, 48.9%) and grade III (140 patients, 49.6%). Computed tomographic angiography and/or catheter angiography demonstrated 631 MCA aneurysms in 543 patients; 462 patients had 1 MCA aneurysm, and 81patients had multiple MCA aneurysms (Table 1). Thirty-two of the patients with multiple MCA aneurysms had mirror aneurysms, 50 in total. Most MCA aneurysms were located at the MCA bi- or trifurcation (568 aneurysms, 90.0%), with other aneurysms at the anterior temporal artery (27, 4.3%), lenticulostriate artery (19, 3.0%), and distal aneurysms on the insular, opercular, or cortical segments (17, 2.7%). Morphologically, there were 50 thrombotic aneurysms (7.9%), 30 giant aneurysms (4.8%), and 29 fusiform or dolichoectatic aneurysms (4.6%). Two hundred eighty-four other aneurysms were diagnosed and treated in 192 patients.

Surgical Management

Most patients (511, 94.1%) were managed with an ipsilateral craniotomy and occlusion of unilateral MCA aneurysms (Table 2). Of the 32 patients with mirror MCA aneurysms, 27 (5.0%) were managed with bilateral craniotomies, and 5 (0.9%) were managed with unilateral craniotomy and clipping of bilateral aneurysms. Contralateral clipping of MCA aneurysms required subfrontal dissection, medial splitting of the sylvian fissure, and favorable anatomy (small aneurysm size, inferior dome projection, unruptured, and some brain atrophy). Therefore, 570 craniotomies were performed in total, most of them pterional craniotomies (478, 83.9%). Orbitozygomatic-pterional (44 patients, 7.7%) and orbital-pterional craniotomy (14 patients, 2.5%) were used for more complex aneurysms. Thirty-four patients (6.0%) required hemicraniectomy to address cerebral edema and increased intracranial pressure.

Most MCA aneurysms (559 aneurysms, 88.6%) were treated with direct clipping (Table 2). Thrombectomy and clip reconstruction was performed with 39 of 50 thrombotic aneurysms (6.2%). Bypass with aneurysm occlusion was performed in 21 cases (3.3%), including 11 patients with giant aneurysms and 2

TABLE 1. Summary of MCA and Other Aneurysms Treated in and During the Study[a]

	Aneurysms		Patients	
	n	%	n	%
Total aneurysms during study	2455		1913	
MCA aneurysms	631	25.7	543	28.4
1 MCA aneurysm	462	73.2	462	85.1
2 MCA aneurysms	148	23.5	74	13.6
3 MCA aneurysms	21	3.3	7	1.3
Mirror MCA aneurysms	50	7.9	32	5.9
MCA aneurysm locations				
MCA	568	90.0		
Anterior temporal artery	27	4.3		
Lenticulostriate artery	19	3.0		
Distal (M2–M4)	17	2.7		
Morphology				
Thrombotic	50	7.9		
Giant	30	4.8		
Fusiform/dolichoectatic	29	4.6		
Previously coiled	12	1.9		
Other treated aneurysms	284		192	
Total treated aneurysms	915		543	

[a]MCA, middle cerebral artery.

TABLE 2. Summary of Surgical Management of MCA Aneurysms[a]

	n	%
Craniotomy		
Unilateral craniotomy for unilateral MCA aneurysm(s)	511	94.1
Bilateral craniotomy for mirror MCA aneurysms	27	5.0
Unilateral craniotomy for mirror MCA aneurysms	5	0.9
Pterional	478	83.9
Orbital-pterional	14	2.5
Orbitozygomatic-pterional	44	7.7
Hemicraniectomy	34	6.0
Total craniotomies	570	
Aneurysm treatment		
Clipping	559	88.6
Thrombectomy/clip reconstruction	39	6.2
Bypass/occlusion	21	3.3
Trapping	5	0.8
Wrapping	7	1.1
Total aneurysms	631	
Bypass		
STA-MCA	6	28.6
Reanastomosis	6	28.6
MCA-MCA in situ	1	4.8
ECA-MCA	3	14.3
CCA-MCA	1	4.8
Double bypass		
Reanastomosis + STA-MCA	1	4.8
MCA-MCA in situ + STA-MCA	1	4.8
ACA-MCA, double reimplantation	1	4.8
ECA-MCA, double reimplantation	1	4.8
Total bypasses	21	
Other		
Intraoperative rupture	31	4.9
Temporary clipping	343	54.4
Temporary occlusion duration (clipping), min	8	
Temporary occlusion duration (bypass), min	47	
Hematoma evacuation	163	30.0

[a]ACA, anterior cerebral artery; CCA, common carotid artery; ECA, external carotid artery; STA, superficial temporal artery; MCA, middle cerebral artery.

patients with previously coiled aneurysms. Five aneurysms (0.8%) were trapped without bypass. Seven aneurysms (1.1%) were wrapped because calcification, previous encasement with methylmethacrylate, dolichoectasia, or lenticulostriates originating from the dome prevented clipping.

Seventeen single bypasses and 4 double bypasses were performed (Table 2). The most common single bypasses were the superficial temporal artery-to-MCA bypass and reanastomosis of the parent MCA after aneurysm excision. Double bypasses included external carotid artery-MCA bypass with reimplantation of both superior and inferior trunks on the graft, and an intracranial variation with an A1 anterior cerebral artery-to-MCA bypass with double reimplantation of both trunks.

Intraoperative MCA aneurysm rupture occurred with 31 aneurysms (4.9%), 22 of these reruptures in patients with subarachnoid hemorrhage (SAH) and 9 in patients with previously unruptured aneurysms. Temporary clipping was a frequent adjunct to facilitate final dissection maneuvers and clip application, used with 343 aneurysms (54.3%). The mean cumulative duration of temporary clipping was 8 minutes. Hematoma evacuation was performed with 163 patients (30.0%).

Surgical complications occurred in 31 patients, including 7 arterial infarctions, 4 perforator infarctions, 2 venous infarctions, 7 epidural hematomas requiring evacuation, 5 wound infections requiring debridement/revision, and 5 frontalis nerve palsies. One patient treated with bypass and proximal aneurysm occlusion rehemorrhaged postoperatively and required reoperation for aneurysm trapping. Surgical complications resulted in permanent neurological deterioration in 7 patients.

Aneurysm Outcomes

Complete aneurysm obliteration, as measured by postoperative digital subtraction angiography, was achieved with 620 MCA aneurysms (98.3%). Two aneurysms had neck remnants (0.3%), and 2 aneurysms were incompletely occluded (0.3%). The 7 wrapped aneurysms were also incompletely occluded (1.1%).

Long-term follow-up with catheter angiography, recommended to all patients 3 to 5 years postoperatively, was performed in 106 of 480 eligible patients (22%). One hundred two patients had no recurrence of their completely obliterated aneurysms (recurrence rate, 0%). Four patients with incompletely occluded aneurysms had stable remnants that did not grow or change in their morphology. There have been no late posttreatment aneurysm ruptures, and no patient has required re-treatment. The mean length of long-term angiographic follow-up was 3.9 years.

Clinical Outcomes

Twenty-nine patients died in the perioperative period (surgical mortality rate, 5.3%) (Table 3). Twenty-five of these patients presented with ruptured aneurysms, 21 (72.4%) as poor-grade

TABLE 3. Patient Outcomes After MCA Aneurysm Surgery, for All Patients and for Subgroups of Patients With Unruptured and Ruptured Aneurysms

mRS	Preoperative		Postoperative				Preoperative		Postoperative		Preoperative		Postoperative	
			Early		Late				Late				Late	
	n	%	n	%	n	%	n	%	n	%	n	%	n	%
	All Patients						Unruptured				Ruptured			
0	20	3.7	209	38.5	217	40.0	13	5.0	136	52.1	7	2.5	81	28.7
1	174	32.0	145	26.7	148	27.3	121	46.4	73	28.0	53	18.8	75	26.6
2	137	25.2	81	14.9	73	13.4	78	29.9	31	11.9	59	20.9	42	14.9
3	115	21.2	40	7.4	39	7.2	37	14.2	7	2.7	78	27.7	32	11.3
4	48	8.8	25	4.6	23	4.2	6	2.3	8	3.1	42	14.9	15	5.3
5	49	9.0	14	2.6	12	2.2	6	2.3	1	0.4	43	15.2	11	3.9
6	0	0.0	29	5.3	31	5.7	0	0.0	5	1.9	0	0.0	26	9.2
Improved	NA	NA	367	67.6	373	68.7	NA	NA	194	74.3	NA	NA	179	63.5
Unchanged	NA	NA	122	22.5	114	21.0	NA	NA	48	18.4	NA	NA	66	23.4
Worse	NA	NA	25	4.6	25	4.6	NA	NA	14	5.4	NA	NA	11	3.9
Dead	NA	NA	29	5.3	31	5.7	NA	NA	5	1.9	NA	NA	26	9.2
Total	NA	NA	543		543		NA	NA	261		NA	NA	282	

mRS, modified Rankin score; NA, not applicable; MCA, middle cerebral artery.

SAH patients in coma (Hunt-Hess grades IV or V). Of the 4 patients with unruptured aneurysms who died, 3 had giant aneurysms, and 1 patient had an arterial infarction resulting from injury to the inferior MCA trunk during a brain tumor biopsy, during which an incidental MCA aneurysm was found and clipped. Two additional patients died at late follow-up (cumulative mortality rate, 5.7%). One late death was a Hunt-Hess grade V patient who died 8 months after surgery after awakening from coma, and the other never recovered from arterial trunk occlusion with subsequent infarction after a ruptured aneurysm with an atherosclerotic neck had been clipped.

Twenty-five patients were neurologically worse after surgery and at late follow-up (permanent neurological morbidity, 4.6%). Overall, good outcomes (mRS scores 0-2) were observed in 438 patients (80.7%) and poor outcomes (mRS scores 3-5) in 74 patients (13.6%). Relative to preoperative neurological baseline, 487 patients (89.7%) were improved or unchanged after therapy. The mean length of postoperative follow-up for all patients was 30 ± 1.9 months.

With unruptured MCA aneurysms, good outcomes were observed in 240 patients (92.0%) and poor outcomes in 16 patients (6.1%); 242 patients (92.7%) were improved or unchanged after surgery. With ruptured MCA aneurysms, good outcomes were observed in 198 patients (70.2%) and poor outcomes in 58 patients (20.6%); 245 patients (86.9%) were improved or unchanged after surgery.

According to subgroup analysis, patients who were elderly (≥65 years), presented with poor Hunt-Hess grades, had giant aneurysms, were treated with techniques other than direct clipping, experienced intraoperative rupture, or had hemicraniectomy all had worse outcomes, as measured by clinical deterioration or death (Table 4). Differences were statistically significant with ruptured aneurysms (P = .04), poor-grade (P = .001), giant size (P = .03), and hemicraniectomy ($P < .001$). The number of aneurysms treated, mirror aneurysms, bilateral craniotomies, or contralateral clipping did not impact clinical outcomes.

DISCUSSION

For decades, surgical series with MCA aneurysms have consistently demonstrated excellent results with rates of complete aneurysm occlusion above 90%, good neurological outcomes that range from 88% to 100% with unruptured aneurysms, and more

TABLE 4. Factors Influencing Patient Outcomes

	Total	Improved/Unchanged		Worse/Dead		*P*
		n	%	n	%	
Age						
<65 y	410	372	90.7	38	9.3	.37
≥65 y	133	115	86.5	18	13.5	
Presentation						
Ruptured	282	245	86.9	37	13.1	.04
Unruptured	261	242	92.7	19	7.3	
Grade						
Hunt-Hess grade I–III	221	204	92.3	17	7.7	.001
Hunt-Hess grade IV–V	61	41	67.2	20	32.8	
Size						
Nongiant	513	464	90.4	49	9.6	.03
Giant	30	23	76.7	7	23.3	
Number of aneurysms						
One	305	277	90.8	28	9.2	.86
Mirror	31	28	90.3	3	9.7	
Multiple	207	182	87.9	25	12.1	
Aneurysm treatment						
Direct clipping	480	434	90.4	46	9.6	.2
Other (thrombectomy, bypass, etc)	63	53	84.1	10	15.9	
Bypass						
No	522	470	90.0	52	10.0	.24
Yes	21	17	81.0	4	19.0	
Hemicraniectomy						
No	511	467	91.4	44	8.6	<.001
Yes	32	20	62.5	12	37.5	
Intraoperative rupture						
No	513	464	90.4	49	9.6	.06
Yes	30	23	76.7	7	23.3	

TABLE 5. Review of Endovascular and Surgical Literature for MCA Aneurysm Treatment[a]

Author	Year	Patients	Aneurysm Occlusion								Outcome - Ruptured						Outcome - Unruptured					
			Complete		Remnant		Incomplete		Failed		Good		Poor		Dead		Good		Poor		Dead	
Endovascular			n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%
Iijima	2005	154	115	77	29	20	5	3	5	3	61	85	2	2	9	13	62	95	1	2	2	3
Horowitz	2005	30	24	80	6	20	0	0	0	0	14	48	15	52	0	0	NA	NA	NA	NA	NA	NA
Doerfler	2006	38	25	66	8	21	0	0	5	13	16	89	0	0	1	6	17	95	0	0	0	0
Lubicz	2006	25	15	60	8	32	2	8	0	0	25	100	0	0	0	0	NA	NA	NA	NA	NA	NA
Quadros	2007	59	23	39	24	41	8	13	4	7	36	71	8	15	7	14	NA	NA	NA	NA	NA	NA
Guglielmi	2008	113	50	44	54	48	3	3	6	5	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Vendrell	2009	50	34	71	6	12	8	17	2	4	NA	NA	NA	NA	NA	NA	NA	96	NA	4	NA	0
Suzuki	2009	115	53	46	51	44	3	3	8	7	NA	69	NA	27	NA	4	NA	93	NA	5	NA	2
Bracard	2009	132	43	38	46	41	23	21	20	11	NA	80	NA	19	NA	1	NA	99	NA	1	NA	0
Oishi	2009	113	64	62	21	20	18	18	10	9	NA	67	NA	28	NA	5	NA	97	NA	3	NA	0
Brinjikji	2011	30	8	29	8	29	12	43	2	5	NA	97	NA	3	NA	0	NA	NA	NA	NA	NA	NA
Surgical																						
Yasargil	1984	280	NA	NA	NA	NA	NA	NA	NA	NA	NA	84	NA	6	NA	5	NA	NA	NA	NA	NA	NA
Suzuki	1984	265	NA	NA	NA	NA	NA	NA	NA	NA	205	77	49	19	11	4	NA	NA	NA	NA	NA	NA
Ogilvy	1995	65	NA	NA	NA	NA	NA	NA	NA	NA	NA	82	NA	13	NA	5	NA	NA	NA	NA	NA	NA
Rinne	1996	690	NA	NA	NA	NA	NA	NA	NA	NA	NA	60	NA	27	NA	13	NA	88	NA	12	NA	0
Chyatte	1998	61	NA	NA	NA	NA	NA	NA	NA	NA	NA	95	NA	5	NA	0	NA	NA	NA	NA	NA	NA
Morgan	2010	263	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	249	95	13	5	1	0.4
Guresir	2011	217	264	97	7	3	0	0	0	0	NA	55	NA	45	0	0	NA	96	NA	4	NA	0
Van Dijk	2011	107	95	89	NA	NA	NA	NA	NA	NA	NA	80	NA	NA	NA	NA	NA	100	NA	NA	NA	NA
Current series	2012	543	620	99	2	0	9	1	0	0	198	70	58	21	26	9	240	92	16	6	5	2

variable outcomes with ruptured aneurysms (Table 5).[7,13-29] Our experience with 631 MCA aneurysms in 543 patients demonstrated that microsurgery continues to yield excellent results with a wide spectrum of lesions and patients that included giant and thrombotic aneurysms, ruptured aneurysms in poor-grade patients, and unruptured aneurysms in elderly patients. With microsurgery as the treatment of first intention, MCA aneurysms were the most common surgical aneurysm (25% of all surgical aneurysms), and current surgical techniques successfully addressed the variety of pathological anatomy without needing endovascular adjuncts or treatment. Subgroup analysis demonstrated that poor outcomes were due to this inclusive surgical policy that aggressively managed Hunt-Hess grade IV and V patients with hemicraniectomy and hematoma evacuation, and also managed complex aneurysms with thrombectomy and bypass. The results from this experience support a "clip first" policy for MCA aneurysms.

The Case For Surgery

MCA aneurysms are adequately exposed with a simple pterional craniotomy. More invasive craniotomies were used sparingly, with orbitozygomatic and orbital-pterional craniotomies accounting for 10% of all craniotomies. The lateral and superficial location of MCA aneurysms allows for miniaturization of the pterional craniotomy, which we used increasingly in later years of this study period. Minipterional craniotomy is particularly valuable in older patients, because smaller craniotomies lower the risks of dural tears and secondary complications, whereas sylvian atrophy and easy aneurysm exposure obviate the need for larger craniotomies.

Splitting the sylvian fissure and separating the frontal and temporal lobes is a basic technique that brings the relevant anatomy of an MCA aneurysm into full view. The risks associated with sylvian dissection include venous sacrifice, venous infarction, branch artery occlusion, pial transgression, and contusions, and although some of these risks were not specifically measured in this study, they were minimal. Veins were mobilized temporally and preserved; branch arteries were mobilized frontally or temporally to clear the pathway to arterial trunks; pial layers were meticulously protected to avoid contusion injury; and retractors were rarely needed during this dissection. When the frontal and temporal lobes separate, the surgical field was both wide and shallow, allowing easy maneuverability for the aneurysm repair. Clip configurations (straight, curved, fenestrated, bayoneted, etc) and conventional clipping techniques (simple, stacked, overlapping, intersecting, tandem, etc) were adapted to repair most MCA aneurysms (89% in our experience). A hospitable sylvian exposure facilitated more challenging techniques like thrombectomy/clip reconstruction and bypass/aneurysm occlusion (Figure 1).

A major advantage of surgery is the ability to survey the complex anatomy of the aneurysm neck, its superior, inferior, and sometimes middle trunks, and surrounding lenticulostriates. Insights gained from handling this anatomy are more informative than any angiographic images. The aneurysm manipulation that is part of surgery resulted in intraoperative rupture risk that is greater than that associated with endovascular therapy (5.7% vs 3.1%, Table 6).[23] However, intraoperative MCA aneurysm ruptures are much easier to manage that those elsewhere, because proximal control requires a single clip, distal control is accessible, and again, the surgical field is wide open. None of the intraoperative ruptures in our experience resulted in morbidity or mortality.

Another major advantage of surgery is the flexibility to use these unconventional techniques when necessary, whether preplanned based on specific aneurysm anatomy or in response to unexpected findings intraoperatively. The sylvian fissure is also a gateway to other aneurysms around the circle of Willis, allowing the clipping of 284 other aneurysms in 192 patients, including contralateral clipping of mirror MCA aneurysms that spared the patient a second craniotomy.[30] The effective and durable aneurysm repair offered by mechanical closure of the neck gives surgery its most important advantage.[31] Aneurysm outcomes after surgical therapy were excellent, with complete aneurysm occlusion in 98.3% and only 1 posttreatment rupture (0.2%). Long-term angiographic follow-up in 106 patients confirmed the durability of clip repair with no aneurysm recurrences. Surgery offers important advantages for the poor-grade patient with elevated intracranial pressure. Hematoma evacuation, hemicraniectomy, and release of cerebrospinal fluid by fenestrating the lamina terminalis and membrane of Liliequist help restore normal intracranial pressure and optimize outcomes.

The Case Against Endovascular Therapy

MCA aneurysm anatomy is uniquely complex. Broad necks encompass large portions of the bi- or trifurcation (Figure 2). Anatomy of trunks or branches may be difficult to decipher angiographically, even with 3-D rotational angiography (Figure 3). Branches frequently originate from the base or side wall of the aneurysm, increasing the risk of branch occlusion with coiling. Large or giant size, intraluminal thrombus, fusiform or dolichoectatic morphology, or distal location may limit the efficacy of endovascular therapy. In our review of endovascular results in 859 patients with MCA aneurysms (Table 5), only 454 patients (53%) had complete aneurysm occlusion, with rates that ranged from 29% to 88%. Overall, 261 patients (30%) had neck remnants, 82 (10%) were incompletely treated, and 62 (7%) had failed attempts. These endovascular results are inferior to surgical results, which report rates of complete occlusion above 90%.

In a similar systematic review of endovascular treatment of 1076 MCA aneurysms in 1033 patients, Brinjikji et al[23] demonstrated that 20.4% needed balloon assistance or stents. Heavy reliance on adjunctive devices and complex techniques raises associated complication rates, and, in this same review, rates of thromboembolism, dissection, stroke, early postoperative hemorrhage, minor recurrence, and major recurrence requiring retreatment were higher than with surgical clipping (Table 6). Total morbidity and mortality associated with these complications was higher with endovascular than with surgical therapy (5.1% vs 0.9%). Intraoperative rupture was the only complication that occurred

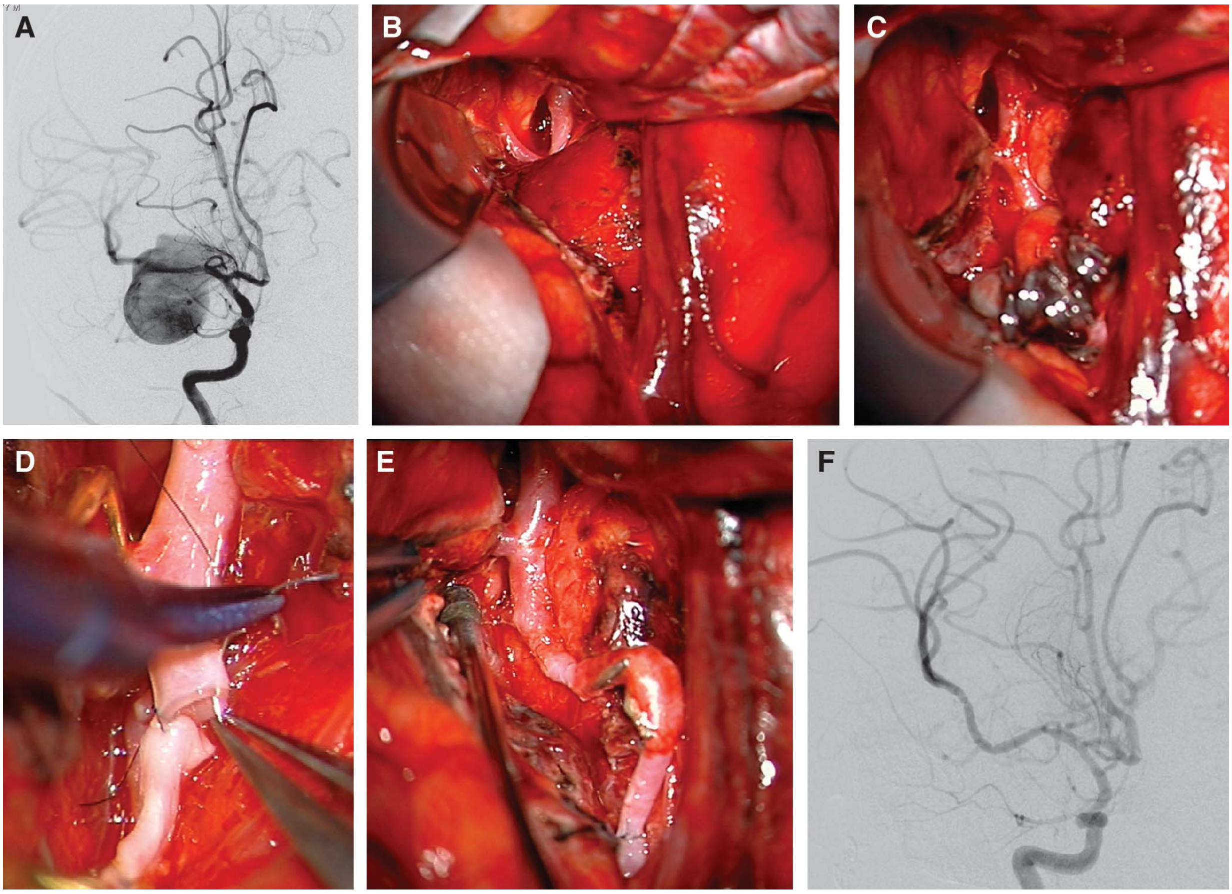

FIGURE 1. *A, a 7-year-old boy presented in coma with a subarachnoid hemorrhage from this giant, dolichoectatic M1 MCA aneurysm (digital subtraction angiography, right internal carotid artery injection, anteroposterior view). A right orbitozygomatic-pterional craniotomy and sylvian fissure split exposed the aneurysm (B), but an attempt at clip reconstruction failed to preserve flow in the efferent M1 segment (C). D, the aneurysm was excised, and the proximal and distal M1 segments were reconnected with an interposition radial artery graft sutured end-to-end. Although 2 lenticulostriate arteries were sacrificed, flow to the distal MCA territory was reconstituted (E), as seen on the postoperative angiogram (right internal carotid artery injection, anteroposterior view) (F). Hemicraniectomy helped control intracranial pressure postoperatively, and he recovered with only mild arm weakness. This case demonstrates 1 bypass option that is available when conventional clipping fails with complex aneurysms. MCA, middle cerebral artery.*

less frequently in patients undergoing endovascular therapy than in patients undergoing surgery (3.1% vs 5.7%), but the associated morbidity and mortality was higher (1.1% vs 0%), because there are fewer endovascular options for dealing with this complication. Importantly, Brinjikji et al[23] found an 18.9% rate of aneurysm recurrence, of which 9.6% was deemed major and required retreatment.

Many of these factors influenced eligibility in ISAT, which required therapeutic equipoise between clipping and coiling for inclusion. The relatively few patients with MCA aneurysms in the ISAT is an acknowledgment of these difficulties with endovascular therapy. The absolute (6.9%) and relative (22.6%) risk reductions in dependency and death after endovascular coiling were responsible for significant increases in endovascular therapy worldwide. However, subsequent analysis of ISAT data revealed the following: the advantages of coiling over clipping in terms of death and severe disability at 1 year vanished at 5 years (proportion of independent survivors, 83% and 82%, respectively)[5]; coiled aneurysms had an increased risk of rebleeding[1]; late retreatment rates are 6.9 times more likely with coiling than with clipping[32]; coiling incurred higher costs for the initial procedure, subsequent procedures, follow-up angiography, additional late procedures, and associated complications or adverse events[33]; clipping protected young patients (<40 years) from SAH better than coiling, with only

TABLE 6. Comparison of Endovascular and Surgical Complications

	Endovascular						Surgery					
	Total		Ruptured Aneurysms		Unruptured Aneurysms		Total		Ruptured Aneurysms		Unruptured Aneurysms	
Complications	n	%	n	%	n	%	n	%	n	%	n	%
Intraprocedural rupture	32/1030	3.1	19/395	4.8	6/364	1.7	31/543	5.7	21/282	7.4	9/261	3.4
Morbidity from rupture	5/1030	0.5	5/395	1.2	0/364	0.0	0/543	0.0	0/282	0.0	0/261	0.0
Mortality from rupture	6/1030	0.6	4/395	1.0	1/364	0.3	0/543	0.0	0/282	0.0	0/261	0.0
Thromboembolism	NA	NA	NA	NA	NA	NA	7/543	1.3	3/282	1.1	4/261	1.5
Morbidity from thromboembolism	33/1030	3.2	11/455	2.4	19/448	4.2	0/543	0.0	0/282	0.0	0/261	0.0
Mortality from thromboembolism	6/1030	0.6	4/455	0.9	1/448	0.2	4/543	0.7	2/282	0.7	2/261	0.8
Early postoperative hemorrhage	6/1030	0.6	6/530	1.1	0/500	0.0	1/543	0.2	1/282	0.4	0/261	0.0
Morbidity from rehemorrhage	2/1030	0.2	2/530	0.4	0/500	0.0	0/543	0.0	0/282	0.0	0/261	0.0
Mortality from rehemorrhage	0/1030	0.0	0/530	0.0	0/500	0.0	1/543	0.2	1/282	0.4	0/261	0.0
Total morbidity/mortality		5.1		5.9		4.7		0.9		1.1		0.8
Complete aneurysm occlusion	887/1076	82.4	244/310	78.7	273/320	82.7	622/631	98.6	282/282	100.0	340/349	97.4
Incomplete aneurysm occlusion	137/1076	12.7	52/310	16.8	43/320	13.0	9/631	1.4	0/282	0.0	9/349	2.6
Failed attempt	52/1076	4.8	14/310	4.5	14/320	4.2	0/631	0.0	0/282	0.0	0/349	0.0
Minor recurrence	70/758	9.3					0/106	0.0				
Major recurrence with retreatment	73/758	9.6					0/106	0.0				

Endovascular complications were based on the systematic review of Brinjikji et al, and surgical complications were based on the current series of 631 aneurysms in 543 patients.

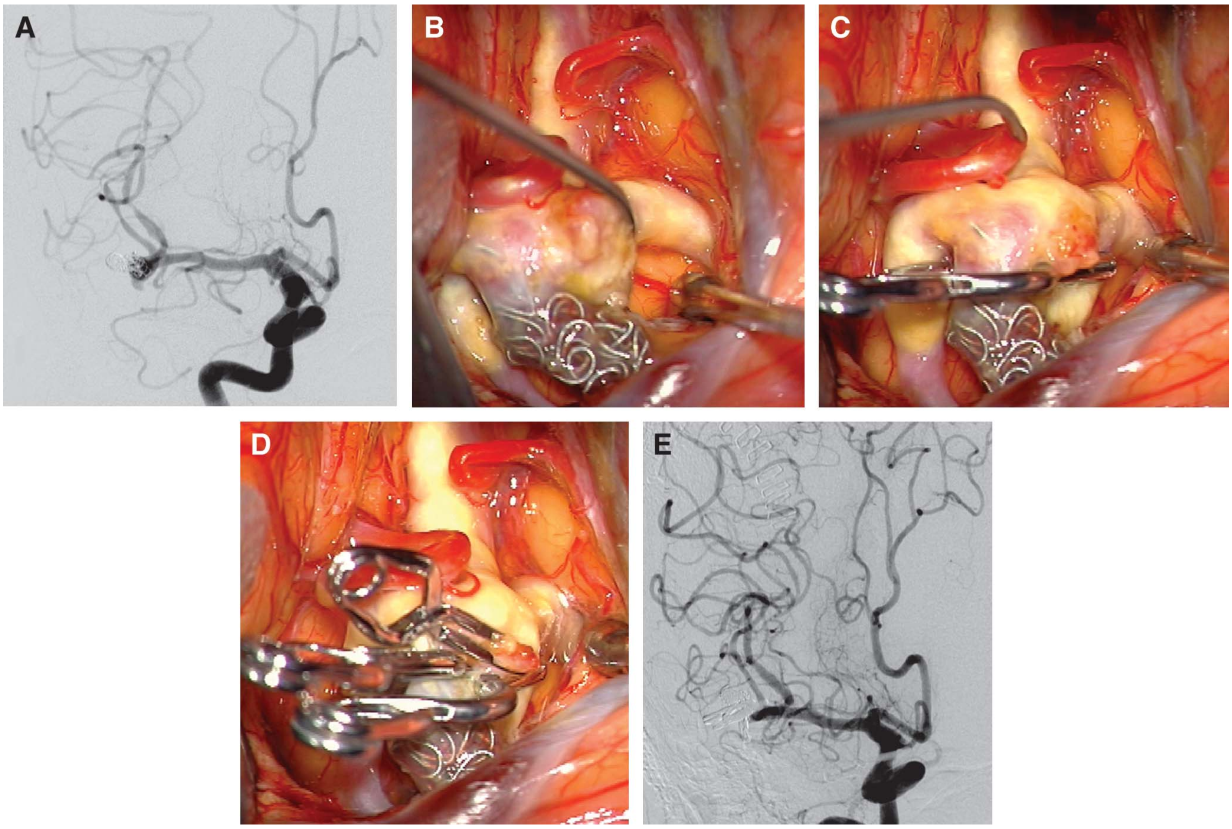

FIGURE 2. A, *a 69-year-old woman with a left MCA aneurysm was initially treated with coiling and her aneurysm recurred 6 months later, as seen on surveillance angiography (digital subtraction angiography, right internal carotid artery injection, anteroposterior view).* B, *intraoperatively, the aneurysm had a broad neck, diffuse atherosclerosis, neck calcifications, and coil extrusion through the dome. Tandem clipping repaired the neck, with a fenestrated clip around the proximal coils (*C*), and additional clips to close the proximal neck beneath the coils (*D*).* E, *postoperative angiography demonstrated complete aneurysm occlusion with preservation of the M2 branches (right internal carotid artery injection, anteroposterior view). This case demonstrates the difficulty in achieving a complete and durable coil occlusion of a broad neck MCA aneurysm, and the ease of the surgical solution. MCA, middle cerebral artery.*

small differences in safety[34]; and clipping resulted in better outcomes in elderly patients with MCA aneurysms (rate of functional independence, 86.7% and 45.5% with clipping and coiling, respectively).[35] These late findings from the ISAT attracted less attention than its initial publication, but are important reminders that the early advantages of endovascular therapy cannot be assumed to last or generalize to all aneurysms. The ISAT was a study of ruptured aneurysms, and class I data favoring coiling over clipping for unruptured aneurysms does not exist. Even with ruptured aneurysms, data favoring coiling over clipping does not exist with certain aneurysms like MCA aneurysms.

Limitations and Trends

This was not a randomized, controlled trial comparing clipping and coiling of MCA aneurysms, but rather a single-center, single-surgeon, retrospective review of surgical results only. Even though there was a "clip first" policy on the Vascular Neurosurgical service, patients were treated endovascularly during the study period when referred directly to the Neurointerventional Radiology service, preferred coiling over clipping, and had anatomy favorable for coiling. There were 64 such patients, and these patients were not included in this review because they were outside of the "clip first" policy on the Neurosurgical service. Our study was not designed to determine therapeutic superiority like the ISAT or Barrow Ruptured Aneurysm Trial. Instead, our study was designed to capture the complete picture of MCA aneurysm management from a neurosurgical perspective, including the full spectrum of patients from intact to moribund, with simple and complex aneurysms, both unruptured and ruptured. Inhomogeneity makes our study results more difficult to interpret than a randomized, controlled trial or

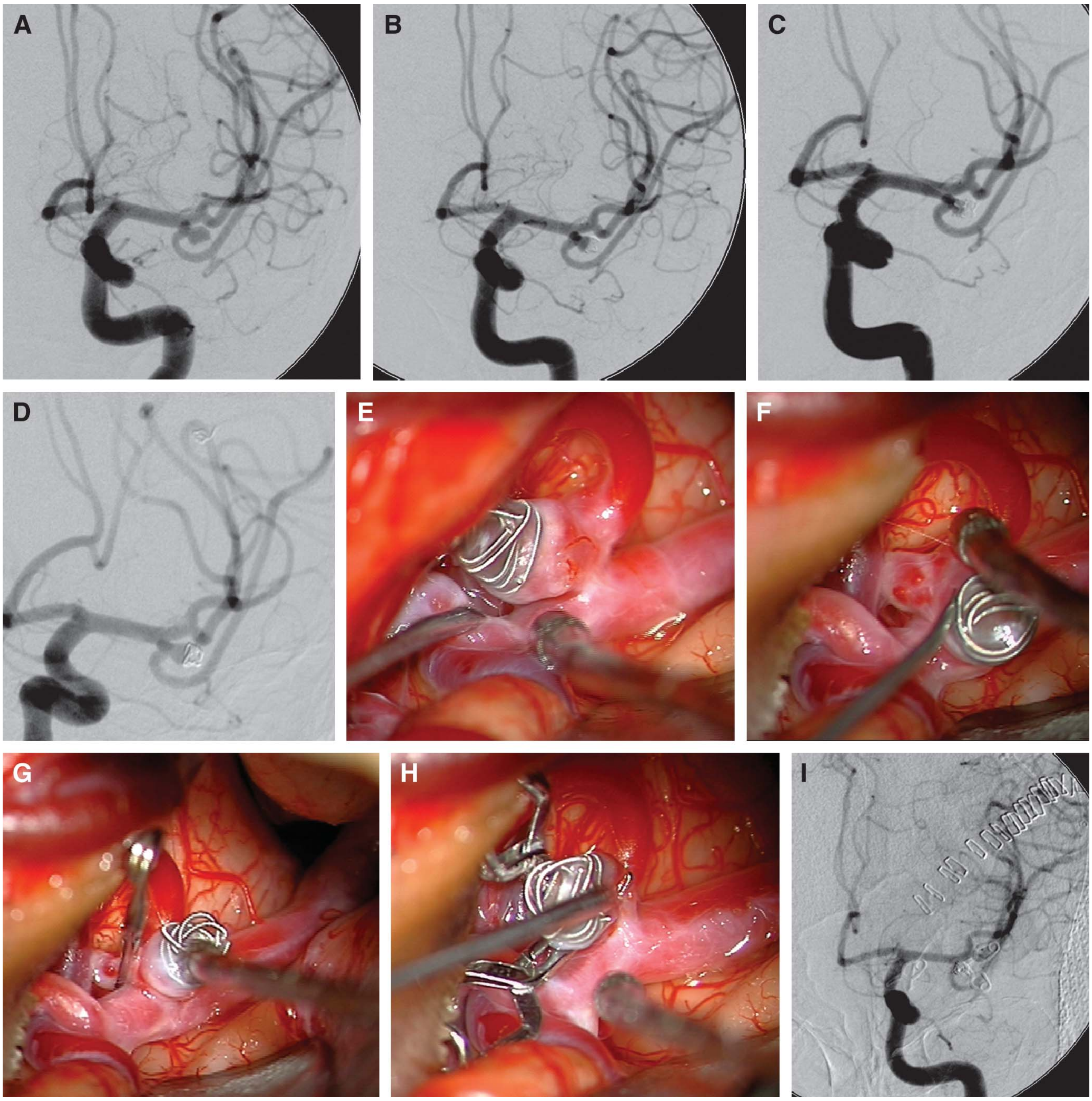

FIGURE 3. A, *a 53-year-old woman presented with SAH from a left MCA aneurysm (digital subtraction angiography, left internal carotid artery injection, anteroposterior view).* B, *the aneurysm was successfully coiled, but compacted 6 months later (left internal carotid artery injection, anteroposterior view). The aneurysm was re-treated with an additional coil (*C*), but this coil migrated out of the aneurysm and lodged in a distal M2 branch, as seen on 12-month surveillance angiography (left internal carotid artery injection, anteroposterior view) (*D*). Intraoperatively, the inferior trunk arose from the base of the aneurysm (*E*), and a daughter aneurysm was identified posteriorly (*F*). This daughter aneurysm can be appreciated as a double density on the initial angiogram (*A*). The daughter aneurysm (*G*) and the primary aneurysm (*H*) were clipped with separate clips.* I, *postoperative angiography confirmed complete aneurysm occlusion (left internal carotid artery injection, anteroposterior view). This case demonstrates the difficulties in deciphering complex MCA anatomy angiographically, the problem of aneurysm recurrence, and embolic complications associated with endovascular coiling. MCA, middle cerebral artery; SAH, subarachnoid hemorrhage.*

a retrospective review of results with 1 subgroup like unruptured MCA aneurysms.[36] However, 1 clear interpretation is that surgery offered as part of a clip first policy has the versatility to deal with this wide spectrum of patients. Multicenter, multisurgeon randomized controlled trials may not be the best methodology to establish best practices for MCA aneurysms because various patient exclusions and variability between surgeons and institutions blur the results. Although controlled studies facilitate outcome comparisons according to treatment modality, all-inclusive, single-surgeon experiences minimize these variables, reflect a realistic practice, and examine critical management factors.

Another clear interpretation of our study is that surgical management can achieve results that can be a benchmark for endovascular therapies as they evolve beyond simple coiling techniques to include stent-assisted coiling, intra-arterial flow diverters, intra-aneurysmal flow diverters, and other novel techniques. We attribute our good results to our application of neurosurgical advancements like retractorless sylvian fissure dissection,[37] bypass techniques,[11,38] ICG angiography,[10] and aggressive management of patients who have subarachnoid hemorrhage in the operating room, intensive care unit, and angiography suite.[39] However, just as multicenter trials introduce confounding variabilities, single-surgeon experiences introduce that individual's unique skills, judgments, and experience. These qualities vary greatly among surgeons and benchmark results from 1 experience may not generalize to other neurosurgeons or centers. Therefore, neurosurgeons should examine their own results, and local competencies and expertise must be considered when determining management policies at individual institutions.

Our results as well as published data on surgical clipping and simple coiling support the clip first policy at our institution and microsurgery generally as the treatment of choice for MCA aneurysms. Advances in endovascular technology will continue to spur attempts to treat MCA aneurysms. Stents or flow diverters may improve results, but the requirement of antiplatelet agents limits their application in patients with ruptured aneurysms. Furthermore, the deployment of flow diverters is technically challenging and their efficacy is unclear. Current results with the Pipeline embolization device are best in the cavernous and paraclinoid internal carotid artery where the parent artery is large and branch arteries are few, and worst in the posterior circulation were there are numerous perforators. MCA aneurysms are similarly associated with multiple branches and lenticulostriate perforators, and results in this region are unknown. Technological and technical advancements in endovascular therapy will inevitably challenge the clip first policy with MCA aneurysms, but must demonstrate results that are equivalent or superior to surgical clipping. For now, the MCA aneurysm stands out as an example of how therapeutic management decisions can be made based on aneurysm location alone. Patients are managed best when they are in specialized centers, receive care from dedicated experts, have all treatment options available to them, and are free to make their own choices. Still, they need clear recommendations from their neurosurgeons and other clinicians. Although recommendations or management policies cannot be mandated, consensus supporting surgical clipping of MCA aneurysms is particularly strong and clinicians should feel comfortable speaking with a clear and consistent voice that favors clipping for MCA aneurysms.

CONCLUSION

Surgery should remain the treatment of choice for MCA aneurysms, except when there are extenuating comorbidities or overriding patient preferences. Surgical morbidity is low, and the patient outcomes are determined largely by neurological presentation. Poor Hunt-Hess grade is often an indication for endovascular therapy, but patients with MCA aneurysms often benefit from hemicraniectomy and clot evacuation. Conventional clipping will repair most MCA aneurysms, but unconventional techniques like thrombectomy/clip reconstruction and bypass/aneurysm occlusion are possible with open surgery. Surgical results from our experience set a benchmark that endovascular results should match before considering endovascular therapy as an alternative for these lesions.

Disclosure

The authors have no personal financial or institutional interest in any of the drugs, materials, or devices described in this article.

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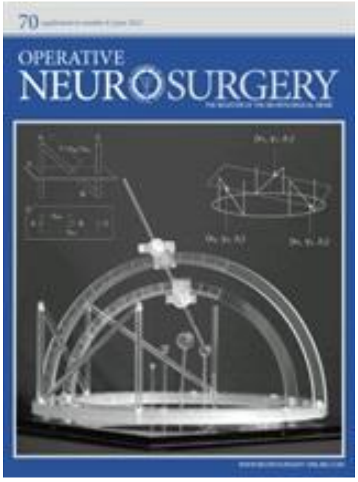

2º Artículo

Flash Fluorescence With Indocyanine Green Videoangiography to Identify the Recipient Artery for Bypass With Distal Middle Cerebral Artery Aneurysms: Operative Technique

Ana Rodríguez-Hernández, MD
Michael T. Lawton, MD

Department of Neurological Surgery, University of California, San Francisco, California

Correspondence:
Michael T. Lawton, MD,
Department of Neurological Surgery,
University of California at San Francisco,
505 Parnassus Avenue, M780,
San Francisco, CA 94143-0112.
E-mail: lawtonm@neurosurg.ucsf.edu

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BACKGROUND: Distal middle cerebral artery (MCA) aneurysms frequently have nonsaccular morphology that necessitates trapping and bypass. Bypasses can be difficult because efferent arteries lie deep in the opercular cleft and may not be easily identifiable.

OBJECTIVE: We introduce the "flash fluorescence" technique, which uses videoangiography with indocyanine green (ICG) dye to identify an appropriate recipient artery on the cortical surface for the bypass, enabling a more superficial and easier anastomosis.

METHODS: Flash fluorescence requires 3 steps: (1) temporary clip occlusion of the involved afferent artery; (2) videoangiography demonstrating fluorescence in uninvolved arteries on the cortical surface; and (3) removal of the temporary clip with flash fluorescence in the involved efferent arteries on the cortical surface, thereby identifying a recipient. Alternatively, temporary clips can occlude uninvolved arteries, and videoangiography will demonstrate initial fluorescence in efferent arteries during temporary occlusion and flash fluorescence in uninvolved arteries during reperfusion.

RESULTS: From a consecutive series of 604 MCA aneurysms treated microsurgically, 22 (3.6%) were distal aneurysms and 11 required a bypass. The flash fluorescence technique was used in 3 patients to select the recipient artery for 2 superficial temporal artery-to-MCA bypasses and 1 MCA-MCA bypass. The correct recipient was selected in all cases.

CONCLUSION: The flash fluorescence technique provides quick, reliable localization of an appropriate recipient artery for bypass when revascularization is needed for a distal MCA aneurysm. This technique eliminates the need for extensive dissection of the efferent artery and enables a superficial recipient site that makes the anastomosis safer, faster, and less demanding.

KEY WORDS: Distal middle cerebral artery aneurysms, Indocyanine green videoangiography, Intracranial bypass, Recipient artery, Superficial temporal artery-middle cerebral artery bypass

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WHAT IS THIS BOX?
A QR Code is a matrix barcode readable by QR scanners, mobile phones with cameras, and smartphones. **The QR Code above links to Supplemental Digital Content from this article.**

Most middle cerebral artery (MCA) aneurysms are located at the bi- or trifurcation of the MCA in the proximal sylvian fissure,[1] but 2% to 6% of MCA aneurysms are located in the distal sylvian fissure,[2-5] typically along insular segments that run between the limen insulae and the circular sulcus. Microsurgical treatment of distal MCA aneurysms is more demanding than proximal MCA aneurysms because the distal sylvian fissure is more difficult to split, there are fewer anatomic landmarks to guide the dissection, and distal aneurysms frequently have nonsaccular morphology that necessitates trapping and bypass.[2,4,6] Bypasses to efferent arteries can be technically difficult because they lie deep within the opercular

ABBREVIATIONS: ICG, indocyanine green; **MCA,** middle cerebral artery; **STA,** superficial temporal artery

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cleft, and the operative corridor can be narrow. In addition, the recipient artery may not be easily identifiable when the efferent anatomy lies on the deep side of the aneurysm or the aneurysm is large.

Videoangiography with intra-arterial indocyanine green (ICG) dye and microscope-integrated intraoperative near-infrared light has become a useful tool for visually inspecting the blood flow in parent and branch arteries after aneurysm clipping, in bypasses after microsurgical anastomosis, and in arteriovenous fistulae after surgical interruption.[7-10] This technology is particularly useful with distal MCA aneurysms that require bypass. We introduce a "flash fluorescence" technique that helps to select an appropriate recipient artery on the cortical surface for the bypass, enabling a more superficial and technically easier anastomosis. We present our experience with this technique in 3 cases.

METHODS

This study was approved by the Institutional Review Board and conducted in compliance with Health Insurance Portability and Accountability Act regulations.

Flash Fluorescence Technique

The technique is indicated for distal MCA aneurysms that cannot be clipped with conventional techniques because of aneurysm morphology (nonsaccular, fusiform, or dolichoectatic), size (large or giant), intraluminal contents (thrombus or previously deployed coils), or etiology (infection or dissection). Instead, these distal aneurysms require occlusion with proximal clipping, distal clipping, or trapping, together with a bypass to restore blood flow to distal MCA territories. The need for bypass is judged by the caliber of the efferent artery or arteries, the territories supplied, and the eloquence of involved brain. In general, these arteries are too distal to examine preoperatively with superselective balloon test occlusion.

Flash fluorescence is designed to select an appropriate recipient artery for bypass. It requires 3 steps: (1) temporary clip occlusion of the aneurysm's afferent artery, proximal to the aneurysm; (2) ICG videoangiography demonstrating initial fluorescence in uninvolved arteries on the cortical surface; and (3) removal of the temporary clip to reperfuse the afferent artery, with flash fluorescence in efferent arteries on the cortical surface. The combination of no fluorescence in efferent arteries during temporary clip occlusion and flash fluorescence during reperfusion enables an appropriate recipient artery on the cortical surface to be selected for the bypass.

Temporary clip occlusion of the involved afferent artery results in flash fluorescence in the efferent artery to directly select the recipient artery distally. With this direct technique, the recipient artery is initially dark during the ICG run and flash fluoresces with temporary clip removal during the same ICG run. Alternatively, temporary clip occlusion of the uninvolved arteries adjacent to the aneurysm's afferent artery indirectly selects the recipient artery distally. The indirect technique is performed as described above, but initial fluorescence illuminates the efferent arteries and subsequent flash fluorescence illuminates the uninvolved arteries that would NOT be appropriate recipients for the bypass. With the indirect technique, the recipient artery fluoresces first, and temporary clip removal flash fluoresces the uninvolved arteries. The advantage of the direct technique is that it requires only one temporary clip, which can be removed quickly with minimal ischemia time. The indirect technique requires more temporary clip application and removal, slightly longer ischemia times, and exposure of several MCA trunks. However, it definitively illuminates the recipient artery early in the ICG run with no ambiguity.

Patients

A consecutive surgical series of MCA aneurysms was reviewed to demonstrate our experience with this technique. The prospectively maintained database for the Vascular Neurosurgery Service was queried for distal MCA aneurysms, located on the M2 segment or beyond, as defined by Gibo et al.[1] Medical records, radiographic studies, operative reports, intraoperative photographs, neurological course, and clinical follow-up evaluations were reviewed.

RESULTS

Distal MCA Aneurysms

During a 13-year period, 604 MCA aneurysms were treated microsurgically by the senior author, and 22 of these (3.6%) were distal MCA aneurysms. Of these 22 patients, 11 patients (50%) had distal MCA aneurysms that were treated with conventional clipping, and 11 patients (50%) had a distal MCA aneurysm requiring a bypass as part of the microsurgical treatment. Bypass patients included 6 men and 5 women with a mean age of 34.3 years (range, 12-66 years). The aneurysm was unruptured in 9 patients. Distal MCA aneurysms had multiple, unusual anatomic features that included fusiform morphology (7 aneurysms), giant size (4 aneurysms), infectious etiology (3 aneurysms), and a thrombotic lumen (3 aneurysms).

A pterional craniotomy was used in 10 patients, and an orbital-pterional craniotomy was used in 1 patient. Aneurysm trapping was performed in 8 patients, and proximal occlusion was performed in 3 patients. Bypasses included primary reanastomosis of the parent artery (4 patients), superficial temporal artery (STA) to middle cerebral artery (STA-MCA) bypass (4 patients), combined reanastomosis and STA-MCA with 2 separate efferent arteries (1 patient); efferent artery reimplantation on an adjacent angular artery (1 patient); and a radial artery graft from the proximal M2 segment to the efferent MCA branch (1 patient).

The flash fluorescence technique was used in 3 cases. Before developing the flash fluorescence technique, 6 of 8 patients had deep bypasses in the insular recess (5 reanastomoses of the parent MCA and 1 reimplantation), whereas, after development of the technique, no patients had deep bypasses in the insular recess. Deep bypasses required more extensive dissection and more brain retraction to widely expose the aneurysm. These deep bypasses were more technically challenging and had a lower postoperative angiographic patency rate than STA-MCA bypasses; 2 of 6 deep bypasses occluded, whereas none of 6 superficial bypasses occluded.

Case 1

A previously healthy 32-year-old man was referred with persistent headaches that began with sudden and severe onset 6

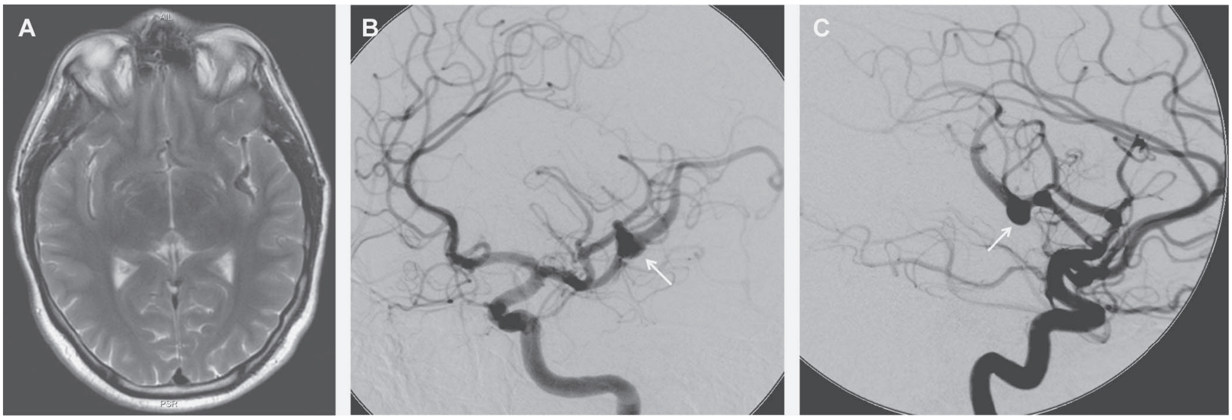

FIGURE 1. *Case 1, diagnostic studies.* **A**, *axial T2-weighted brain MRI showed a fusiform distal MCA aneurysm in the posterior left sylvian fissure. Catheter angiography (left internal carotid artery injection, anterior oblique [***B***] and lateral views [***C***]) revealed a fusiform aneurysm (arrow) on the M2 segment of the inferior trunk of the MCA with a dilated, dysplastic efferent artery. MCA, middle cerebral artery.*

weeks earlier. The results of his neurological examination were normal. A computed tomography (CT) scan revealed a hyperdense abnormality in the left sylvian fissure, and subsequent magnetic resonance (MR) imaging suggested a fusiform distal MCA aneurysm (Figure 1). Cerebral angiography revealed a dysplastic insular (M2) segment of the inferior trunk of the left MCA, with a fusiform aneurysm that measured 14 mm at its widest diameter. The superior trunk was normal.

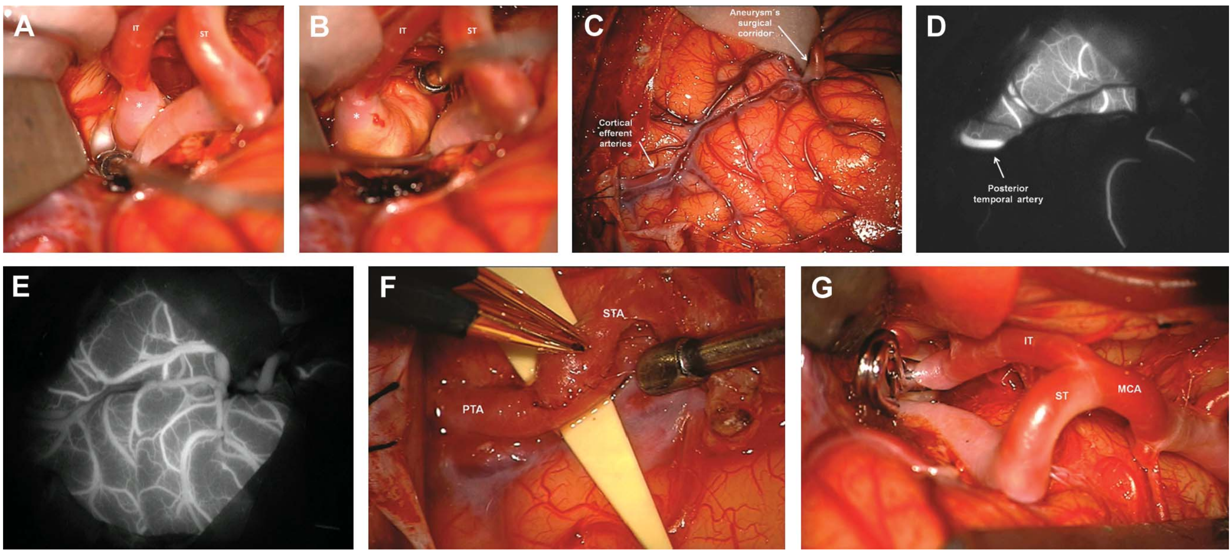

FIGURE 2. *Case 1, intraoperative photographs. A wide splitting of the sylvian fissure showed the superior and inferior MCA trunks (ST, IT) coursing deep into the insular recess (***A***) and the fusiform aneurysm (*) arising from the inferior trunk (***B***).* **C**, *the efferent arteries came to the cortical surface 4 to 5 cm away from the surgical corridor to the aneurysm. Note the posterior temporal artery exiting the distal sylvian fissure.* **D**, *ICG videoangiography with a temporary clip placed on the uninvolved superior trunk illuminated this posterior temporal artery.* **E**, *after removing the temporary clip during the same ICG run, flash fluorescence of the other arteries exiting the sylvian fissure confirmed that the posterior temporal artery was a suitable bypass recipient (indirect technique).* **F**, *an end-to-side anastomosis performed between the STA (donor) and the PTA (recipient).* **G**, *a permanent clip was placed proximally to occlude the aneurysm. MCA, middle cerebral artery; ST, superior trunk; IT, inferior trunk; ICG, indocyanine green; STA, superficial temporal artery; PTA, posterior temporal artery.*

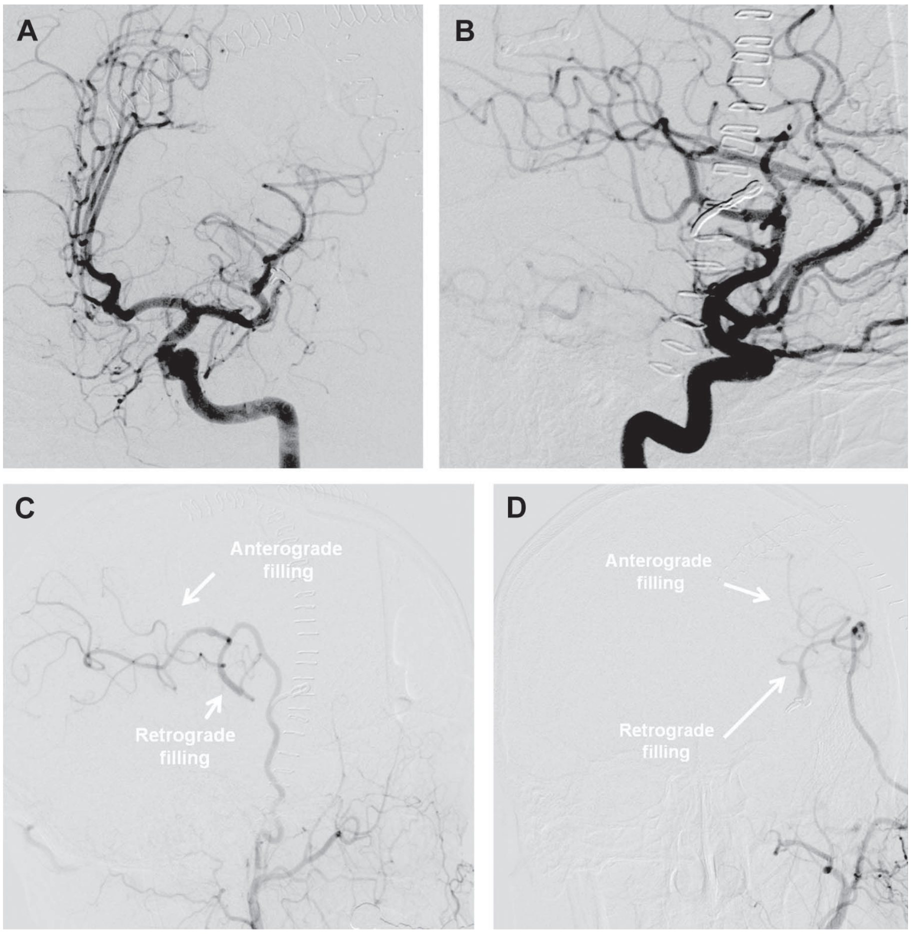

FIGURE 3. *Case 1, postoperative angiogram. Angiography confirmed complete occlusion of the distal MCA aneurysm by the proximal clip (left internal carotid artery injection, anteroposterior [A] and lateral views [B]). The STA-MCA bypass filled the efferent arteries both anterograde and retrograde, back to the aneurysm but without aneurysm filling (left external carotid artery injection, lateral [C] and anteroposterior views [D]). MCA, middle cerebral artery; STA, superficial temporal artery.*

The surgical plan was to trap the aneurysm and bypass distally with an STA-MCA bypass. The anterior limb of the STA was harvested, and a left pterional craniotomy was performed. A wide splitting of the sylvian fissure exposed the MCA from its origin to its bifurcation and deep into the insular recess. The superior trunk was unaffected, but the inferior trunk was dilated, with a yellowish color and thickened walls. The aneurysm extended deep into the insular recess, and the efferent artery could not be visualized without more posterior dissection deep to language cortex. This dissection was spared by using the flash fluorescence technique.

Opening the dura to the edge of the craniotomy gave a panoramic view of the possible recipient arteries exiting the sylvian fissure (Figure 2). The indirect flash fluorescence technique was used, placing a temporary clip on the uninvolved superior trunk. ICG videoangiography illuminated the arteries coursing out of the sylvian fissure to the temporal lobe, including the posterior temporal artery. The temporary clip was removed and flash fluorescence was observed in the arteries coursing out of the sylvian fissure to the frontal and parietal lobes. The posterior temporal artery was selected as the recipient artery, and an STA-MCA bypass was completed. The dissection returned to the proximal sylvian fissure, where the aneurysm was occluded proximally with a curved clip placed across the inferior trunk as it entered the aneurysm. A second ICG videoangiogram confirmed patency of the bypass and no antegrade filling of the aneurysm.

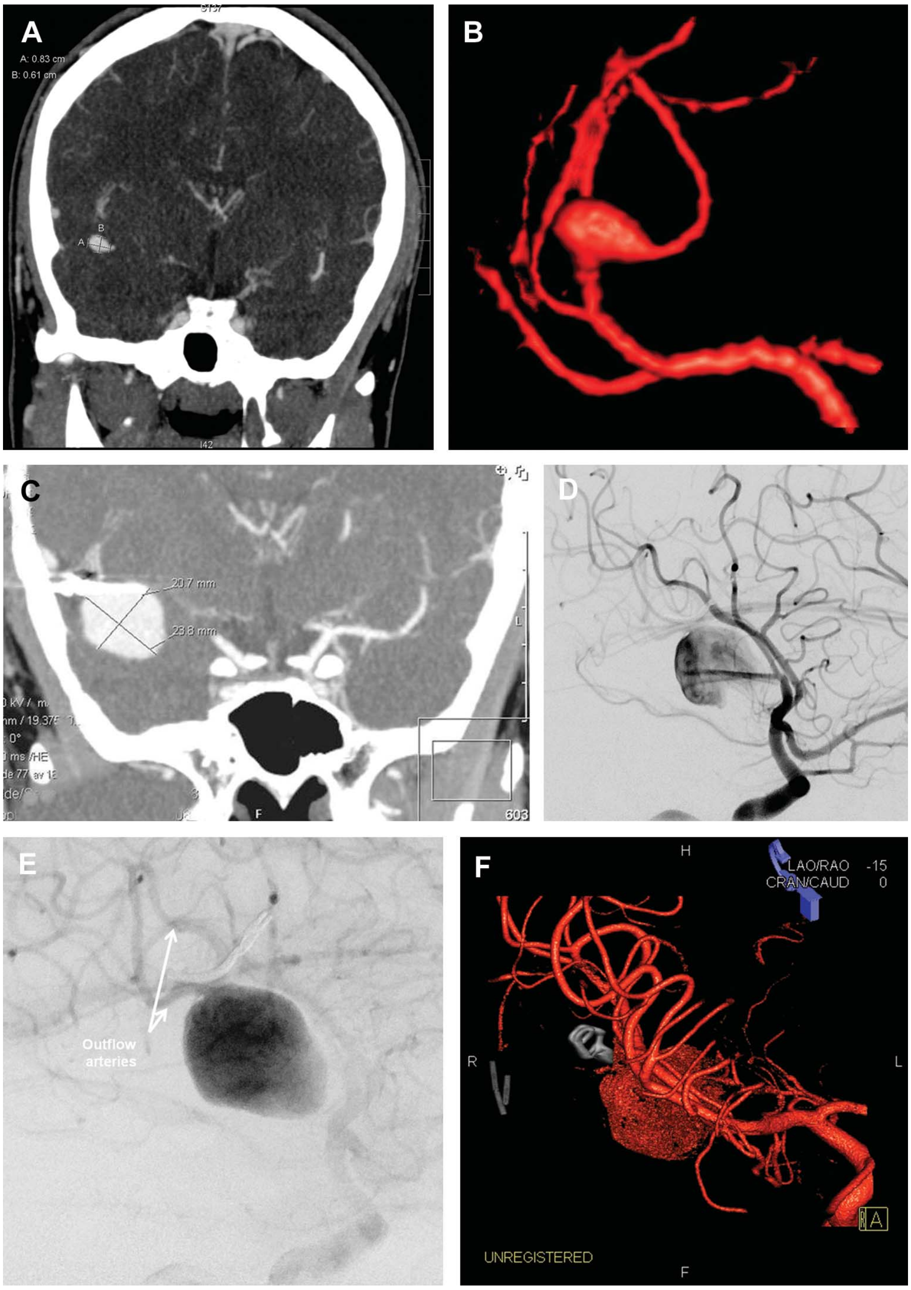

FIGURE 4. *Case 2, diagnostic studies.* **A**, *head CT angiography (coronal view) showed a right distal MCA aneurysm.* **B**, *3D CT angiography demonstrated fusiform anatomy and its location at a secondary bifurcation of the superior trunk.* **C**, *follow-up head CT angiography (coronal view) showed aneurysm recurrence below the clip.* **D**, *catheter angiography (right internal carotid artery injection, lateral view) showed a giant aneurysm with a jet of inflow from the inferior trunk.* **E**, *the late phase of this angiogram demonstrated 2 outflow arteries (angular and posterior temporal arteries) originating from a common trunk below the aneurysm clip.* **F**, *angiography with 3D reconstruction showed the uninvolved superior trunk and the anterior branch of the inferior trunk coursing along the anterior wall of the aneurysm.*

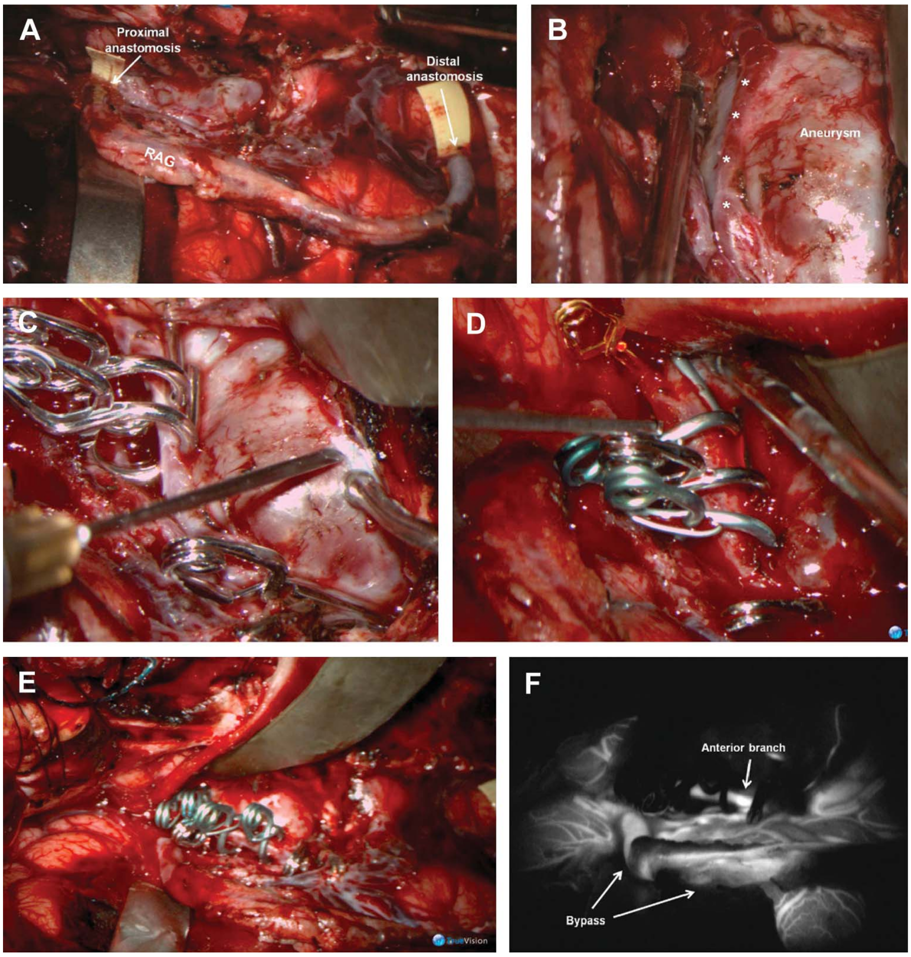

FIGURE 5. *Case 2, intraoperative photographs. The posterior temporal artery was selected as the bypass recipient based on the flash fluorescence technique, and a radial artery graft was anastomosed end-to-side fashion to this artery. The proximal end of the graft was then anastomosed end-to-side to the superior trunk.* **A**, *an overview of the MCA-MCA bypass is shown.* **B**, *the anterior branch of the inferior MCA trunk (see *) adhered to the aneurysm wall with no plane of separation.* **C**, *tandem fenestrated clips slid and compromised this anterior branch. The aneurysm was trapped with temporary clips and punctured with a 19-gauge needle for suction decompression.* **D**, *readjustment of the tandem fenestrated clips reopened the anterior branch within the fenestrations of the clips.* **E**, *overview showed the aneurysm clipping and the course of the bypass.* **F**, *ICG videoangiography demonstrated patency of the bypass, preservation of the flow in the anterior branch within the fenestrated clips, and no filling of the aneurysm. MCA, middle cerebral artery; ICG, indocyanine green.*

Postoperative angiography demonstrated complete thrombosis of the aneurysm and a patent STA-MCA bypass (Figure 3). The patient was discharged home on the third postoperative day and remained neurologically intact at 1 year follow-up.

Case 2

A 15-year-old boy with a recurrent, giant distal MCA aneurysm was referred for treatment. He had presented 2 years earlier with a right-sided, 8-mm-diameter distal MCA aneurysm arising from a bifurcation in the superior division of the MCA along the insular M2 segment (Figure 4). He underwent right pterional craniotomy and direct clipping in Norway, with no surgical complications. Recent headaches prompted a follow-up CT scan of the head, which revealed aneurysm recurrence with marked enlargement. The results of his neurological examination at presentation were completely normal.

Cerebral angiography demonstrated a right M2 segment dolichoectatic aneurysm measuring 2.6 × 2.1 × 2.2 cm. The superior

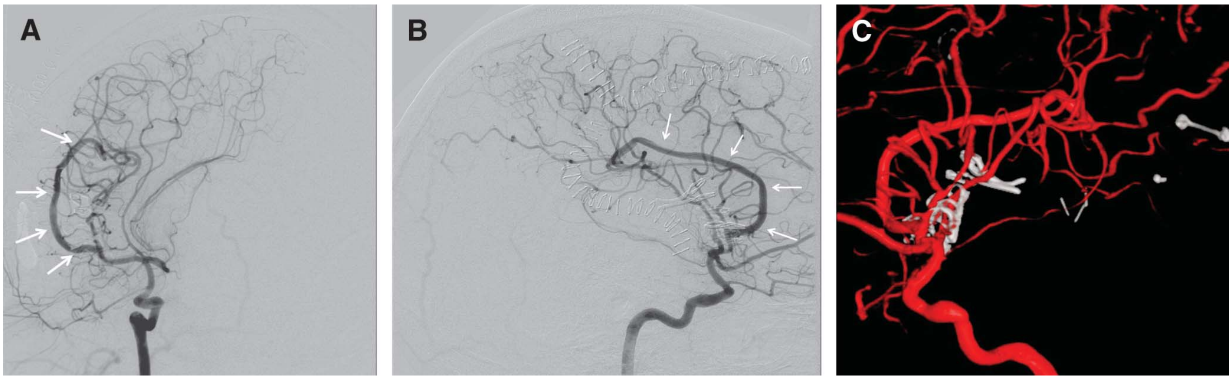

FIGURE 6. *Case 2, postoperative angiogram. Right internal carotid artery injection (anterior oblique [A] and lateral views [B]) confirmed patency of the bypass graft (arrows) with no aneurysm filling. C, angiography with 3D reconstruction depicted the patent anterior branch running trough the clip fenestrations.*

trunk was uninvolved, and the aneurysm originated at a bifurcation in the inferior trunk. A posterior branch filled the aneurysm with a jet of contrast, with delayed outflow into an efferent trunk that bifurcated just distal to the aneurysm into the angular and posterior temporal arteries. The previous clip was located adjacent to the efferent trunk. The other anterior branch of the inferior trunk coursed along the anterior wall of the aneurysm and branched into operculofrontal and central sulcus arteries. The STA was absent as a consequence of the previous surgery.

The surgical plan was to trap the aneurysm and bypass distally with an intracranial-to-intracranial radial artery graft from the superior trunk to the angular artery. A right orbitopterional craniotomy was performed, scarred dura was elevated, and the sylvian fissure was opened widely. The uninvolved superior trunk was separated from the aneurysm. The inferior trunk was observed to flow directly into the aneurysm, with the anterior branch adhered to the aneurysm wall with no plane of separation (Figure 5). The previous clip and the efferent trunk were identified on the distal side of the aneurysm. The efferent arteries could not be traced to the cortical surface because of their depth in the insular recess and scarring from previous surgery that made it difficult to open the distal sylvian fissure. Instead, a recipient was selected by using the flash fluorescence technique.

The inferior trunk was occluded with a temporary clip to close aneurysm inflow (direct technique). ICG videoangiography demonstrated fluorescence in the anterior frontal branches and absence of fluorescence in the temporal arteries. The temporary clip was then removed and flash fluorescence was observed in the angular and posterior temporal arteries (see Video 1, Supplemental Digital Content 1, http://links.lww.com/NEU/A426, in which ICG videoangiography demonstrates the flash fluorescence technique for case 2). The posterior temporal artery was selected as the bypass recipient based on this technique. The radial artery was harvested from the left forearm, and the distal end-to-side anastomosis was performed. The proximal end of the radial artery was then brought into the sylvian fissure and sized appropriately. An end-to-side anastomosis connected the proximal end of the graft to the superior trunk to complete the bypass.

A temporary clip was placed on the inferior trunk, and a permanent clip was placed on the efferent trunk to trap the aneurysm. Tandem right-angled fenestrated clips were applied across the anterior base of the aneurysm to close the afferent artery while preserving the adherent anterior branch. The aneurysm base was so broad that the clips slid and compromised flow in this anterior branch. The aneurysm was then punctured, deflated with suction decompression, and the clips were repositioned successfully. The temporary clip was removed, and a second ICG videoangiography demonstrated patency of the anterior branch within the tandem fenestrated clips, patency of the bypass graft, and no filling of the aneurysm.

The postoperative angiogram confirmed patency of the MCA-MCA bypass graft, good flow in the adherent anterior branch, and complete trapping of the aneurysm (Figure 6). The patient recovered from the surgery without any new neurological deficits. He traveled back to Norway on postoperative day 7 and was intact at 3 months follow-up.

Case 3

A 59-year-old woman presented to an outside hospital with 2 episodes of transient dysarthria. At presentation, she had a mild headache and a normal neurological examination results. CT scan revealed a hyperdense lesion in the distal left sylvian fissure measuring 1.8 × 1.1 cm (Figure 7). CT angiography and catheter angiography both revealed a fusiform aneurysm located on the M2-M3 junction of a branch from the superior trunk of the left MCA. An infectious MCA aneurysm was suspected, but evaluation with blood cultures and echocardiogram were negative.

The surgical plan was to trap the aneurysm and bypass distally with an STA-MCA bypass. The STA was harvested, a left pterional craniotomy was performed, and the sylvian fissure was widely split.

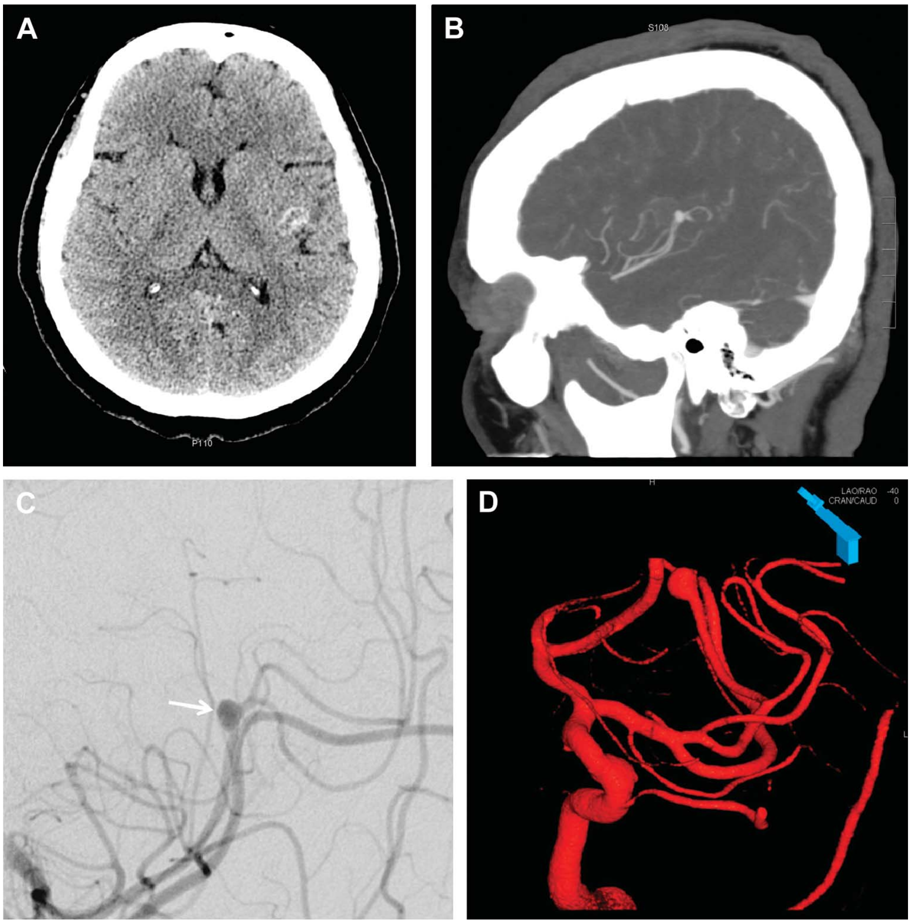

FIGURE 7. *Case 3, diagnostic studies.* **A**, *noncontrast, axial head CT showed a hyperdense lesion in the left insular region.* **B**, *CT angiography (sagittal view), and* **C**, *catheter angiography (left common carotid injection, anterior oblique view). Both revealed a fusiform aneurysm (arrow) located at the M2-M3 junction that was smaller than the lesion seen on CT scans, consistent with intraluminal thrombus.* **D**, *angiography with 3D reconstruction showed this aneurysm to be on a branch from the superior trunk of the left MCA. MCA, middle cerebral artery.*

The MCA trunks were followed into the insular recess where the aneurysm was encountered. The afferent artery was identified, but the efferent artery was not visualized. The flash fluorescence technique was used to select the cortical recipient artery from 3 angular arteries exiting the distal sylvian fissure (Figure 8). Temporary clips were placed proximally on 3 arteries that were uninvolved with the aneurysm, leaving the afferent artery to the aneurysm open (indirect technique). ICG videoangiography illuminated 2 of the angular arteries on the frontal side of the sylvian fissure. The temporary clips were then removed, with flash fluorescence in the uninvolved arteries on the temporal side of the fissure (see Video 2, Supplemental Digital Content 2, http://links.lww.com/NEU/A427, in which ICG videoangiography demonstrates the flash fluorescence technique for case 3). The STA-MCA bypass was completed and the aneurysm clip occluded proximally.

Postoperative angiography revealed complete thrombosis of the distal MCA aneurysm and patency of the STA-MCA bypass (Figure 9). The patient was discharged home on postoperative day 4 and was neurologically intact at the 6-week follow-up evaluation.

DISCUSSION

Distal MCA aneurysms are rare, accounting for 3.6% of the total number of MCA aneurysms in our surgical experience. Half of these aneurysms required bypass as part of their treatment,

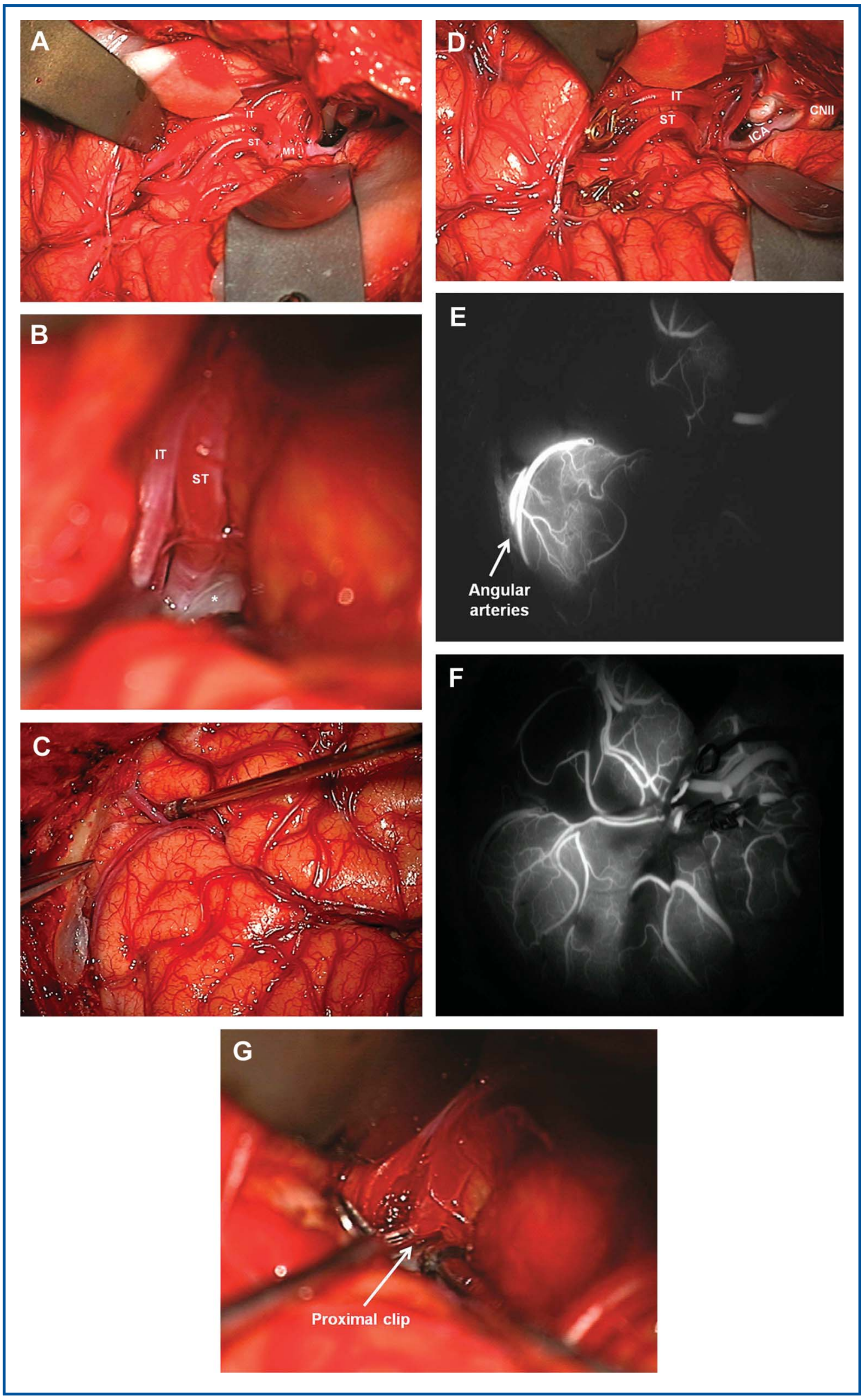
A
IT
ST
M1
B
IT
ST
*
C
D
IT
ST
ICA
CNII
E
Angular arteries
F
G
Proximal clip

FIGURE 8. *Case 3, intraoperative pictures.* **A**, *wide splitting of the sylvian fissure identified the superior and inferior trunks of MCA.* **B**, *the afferent artery was traced to the aneurysm (*), which was white in color and fusiform, located deep in the insular recess.* **C**, *3 potential recipient arteries were observed exiting the distal sylvian fissure.* **D**, *temporary clips were placed on 3 arteries that were uninvolved with the aneurysm, leaving the afferent artery open to supply the aneurysm.* **E**, *ICG videoangiography illuminated 2 of the angular arteries on the frontal side of the sylvian fissure.* **F**, *the temporary clips were then removed and flash fluorescence was observed in the uninvolved arteries on the temporal side of the fissure (indirect technique).* **G**, *after performing the STA-MCA bypass, the afferent artery was clip occluded proximally. ST, superior trunk; IT, inferior trunk; MCA, middle cerebral artery; ICG, indocyanine green; STA, superficial temporal artery; ICA, internal carotid artery; CNII, optic nerve.*

because of fusiform or dolichoectatic morphology, giant size, infectious etiology, and/or intraluminal thrombus that prevented direct clipping. Extracranial-intracranial bypass techniques are useful because the superficial temporal artery is so applicable to MCA territory revascularization.[6,11] Intracranial-intracranial bypass techniques that reconstruct efferent arteries using parent or adjacent arteries are also applicable to distal MCA aneurysms,[12,13]. Primary reanastomosis of the afferent and efferent arteries, reimplantation of efferent arteries, and intracranial bypass with radial artery grafts were all used in our experience.[12,14] A critical

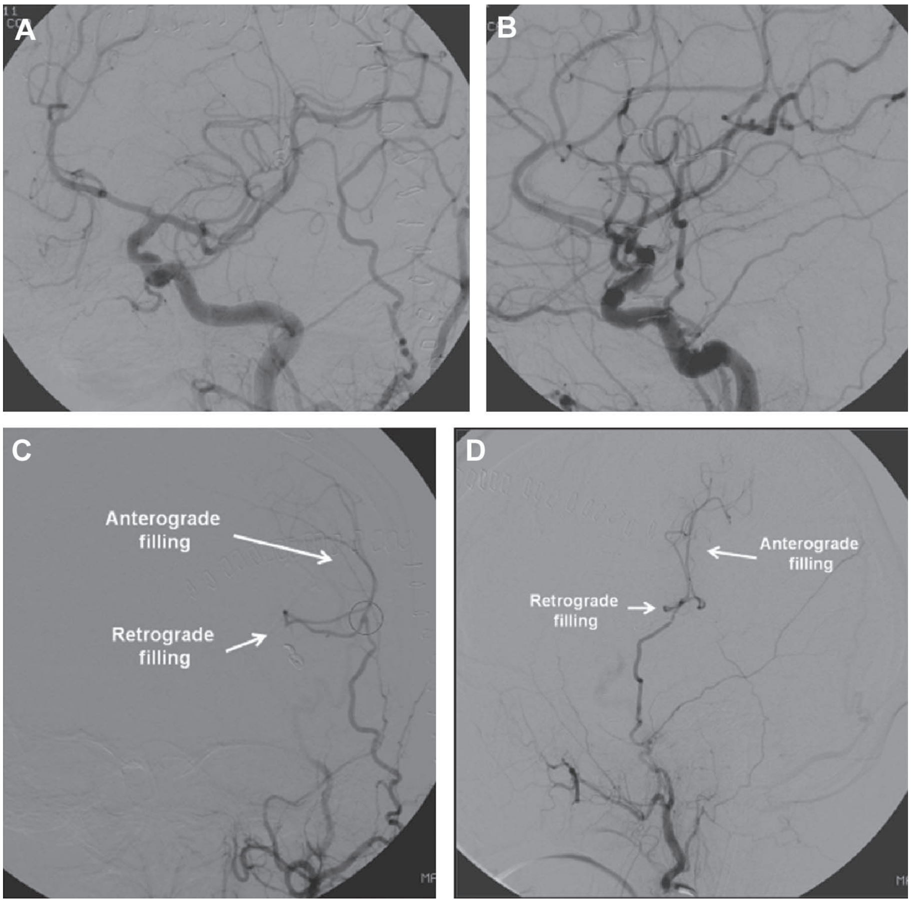

FIGURE 9. *Case 3, postoperative angiogram. Left common carotid artery angiography (anteroposterior [*__A__*] and lateral views [*__B__*]) demonstrated no aneurysm filling. Left external carotid artery angiography (anteroposterior [*__C__*] and lateral views [*__D__*]) demonstrated patency of the STA-MCA bypass (red circle) and retrograde filling back to the site of the thrombosed aneurysm. MCA, middle cerebral artery; STA, superficial temporal artery.*

element of the procedure is the appropriate selection of the recipient artery,[15,16] regardless of the bypass technique selected.

The obvious way to select the recipient artery is to trace the efferent artery from the aneurysm to an open surgical corridor where the bypass can be performed comfortably. However, efferent arteries from distal MCA aneurysms are difficult to visualize deep in the insular recess or circular sulcus.[2,6] Large or giant aneurysms can cover or hide this outflow anatomy. Overlying brain consists of pars triangularis, pars opercularis, pre- and postcentral gyri, and superior temporal gyrus, which harbor eloquent function, particularly in the dominant hemisphere.[1] Splitting the sylvian fissure and separating frontal and temporal lobe is more difficult distally than proximally because the sylvian cistern ends and opercular surfaces are adherent. Opercular arteries help define the subarachnoid dissection plane, but are smaller in caliber than the sphenoidal and insular segments and provide less plane of separation. An overlying confluence of superficial middle cerebral, frontoparietal (Trolard), and posterior temporal (Labbe) veins can also impair access to the distal fissure.[2] These anatomic and technical limitations often result in a distal sylvian corridor around the efferent artery that is narrow, confining, and not favorable for a bypass. Some neurosurgeons have suggested using navigation and awake craniotomy to overcome some of these limitiations.[17] Others have proposed intraoperative angiography or superselective ICG angiography to select the recipient artery, but these techniques require endovascular access, catheterization of the afferent artery under fluoroscopic guidance, and systemic heparinization.[18]

The flash fluorescence technique offers a simple alternative to efferent artery dissection or intraoperative catheter angiography. This technique clearly identifies the efferent artery on the cortical surface, often several centimeters downstream from the artery's exit from the aneurysm. Identification of the recipient on the cortical surface makes additional dissection deep in the distal sylvian fissure unnecessary and spares patients the associated morbidity. The anastomosis is significantly easier to perform on the cortical surface than in a narrow sylvian corridor. Brain retraction is not necessary, and the overall procedure is quicker. The more distal location of the anastomosis requires extending the craniotomy further posteriorly than the standard pterional craniotomy; failure to extend the craniotomy may position the recipient artery beyond the exposed brain surface. The bypass provides flow in the recipient artery that is both antegrade and retrograde, back to its junction with the trapped aneurysm. The flash fluorescence technique is useful with all types of bypasses, including the STA-MCA and radial artery interposition bypasses shown here. The technique is also applicable with other in situ bypasses, and we recently used it for an M3-to-M3 side-to-side bypass in a patient with a diminutive STA.

The flash fluorescence technique minimizes the dissection on the distal side of the aneurysm. In cases 1 and 3, proximal occlusion was sufficient because the aneurysms were unruptured and thick-walled. Proximal occlusion and distal bypass induced complete aneurysm thrombosis in both cases. However, it was still necessary in case 2 to identify the efferent trunk to complete the aneurysm trapping for suction decompression. The flash fluorescence technique minimized, but did not eliminate, the need for distal aneurysm dissection in this case.

CONCLUSION

The flash fluorescence technique provides quick and reliable intraoperative localization of the appropriate recipient artery for bypass when revascularization is needed for a distal MCA aneurysm. This technique eliminates the need for extensive deep dissection of efferent arteries and enables a more superficial recipient site that makes the anastomosis safer, faster, and less technically demanding.

Disclosure

The authors have no personal financial or institutional interest in any of the drugs, materials, or devices described in this article.

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COMMENTS

This article describes distal MCA-bypass surgery supported by ICG angiography in a very selected population of aneurysm patients. Very few publications have reported similar work. The described innovation in surgical technique is of significant interest to vascular neurosurgeons. The conclusion of the authors, that this technique "makes the anastomosis safer, faster and less technically demanding" is very true. The article is relatively short and clear in design. The case description is concise. The surgical technique is well illustrated via radiological scans, images of the intraoperative site, and short videos. This publication represents a valuable addition to the current literature on this topic.

Jacek Szczygielski
Joachim Oertel
Mainz, Germany

This article describes a very useful and innovative technique for bypass surgery in patients harboring distal MCA aneurysms. The procedure is well illustrated and represents an important adjunctive technique in the management of cerebral aneurysms by therapeutic parent artery occlusion under bypass protection.

Aneurysm dissection in the depth of the sylvian fissure can be challenging and can be the source of procedural morbidity in some cases. To overcome the problem of extensive dissection, a superficial cortical branch can be chosen for bypass surgery instead. The authors present a simple and effective technique to identify the correct cortical recipient artery. We have recently described a similar technique, ie, superselective intraoperative ICG angiography, as a possible solution for the same problem.[1] In compared with our technique, the procedure reported by the authors has the clear advantage that neither intraoperative microcatheter manipulation nor intraarterial ICG dye injection is required.

Christian Dorfer
Andreas Gruber
Vienna, Austria

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The very experienced group at USF nicely introduces the "flash fluorescence" technique using ICG dye to identify an appropriate recipient cortical artery for a bypass and thereby making it safer, easier, and faster. In Helsinki, we have actively been using ICG angiography since its introduction and have found it very useful in aneurysm surgery.[1] As the authors state, distal MCA aneurysms are often challenging, not only because of the often needed bypass due to their fusiform nature, but also, when clippable and small in size, their dissection sometimes necessitates the use of neuronavigation. So far, these aneurysms are better treated by microsurgery,[2] and the current article addresses the importance of dedicated neurovascular centers being able to do that. As can be seen, there is constant ongoing development also in and around microsurgical techniques ultimately benefiting the patients.

Mika Niemelä
Juha Hernesniemi
Helsinki, Finland

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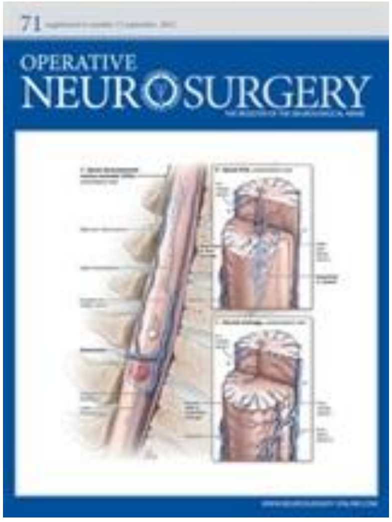

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Artículo

CEREBROVASCULAR *Technique Assessment*

Contralateral Clipping of Middle Cerebral Artery Aneurysms: Rationale, Indications, and Surgical Technique

Ana Rodríguez-Hernández, MD*

Andreu Gabarrós, MD‡

Michael T. Lawton, MD*

*Department of Neurological Surgery, University of California, San Francisco, California; ‡Department of Neurological Surgery, Hospital de Bellvitge, Barcelona, Spain

Correspondence:
Michael T. Lawton, MD,
Department of Neurological Surgery,
University of California at San Francisco,
505 Parnassus Ave, M780,
San Francisco, CA 94143-0112.
E-mail: lawtonm@neurosurg.ucsf.edu

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BACKGROUND: Contralateral clipping of middle cerebral artery (MCA) aneurysms seems dangerous and ill advised but could become an important technique because of the prevalence of MCA aneurysms, the limitations of endovascular therapy, and increasing interest in less invasive techniques.

OBJECTIVE: To define patient selection, surgical technique, and results with contralateral MCA aneurysm clipping.

METHODS: Forty-two patients with bilateral MCA aneurysms were treated either in 1 stage with a single craniotomy and contralateral aneurysm clipping (group 1, 11 patients) or in 2 stages with bilateral craniotomy (group 2, 31 patients). Surgical technique consisted of ipsilateral sylvian fissure split, subfrontal dissection, contralateral sylvian fissure split, mobilization of medial orbital gyrus, and contralateral aneurysm clipping.

RESULTS: Group 1 patients were older than group 2 patients (60.3 vs 55.4 years, respectively). Clinical presentation with subarachnoid hemorrhage was less common in group 1. Nine group 1 patients (82%) had left-sided craniotomies, and the ipsilateral aneurysm was larger than the contralateral aneurysm. All aneurysms were clipped without intraoperative complications (136 aneurysms). Mean neurosurgical charges were decreased by contralateral MCA aneurysm clipping: $39 297 in group 1 vs $57 977 in group 2.

CONCLUSION: Contralateral MCA aneurysm clipping can be viewed as an extreme microsurgical technique or as a less invasive technique that spares patients a second craniotomy in the management of bilateral aneurysms. This technique is acceptable in selected patients with contralateral aneurysms that are unruptured, have simple necks, project inferiorly or anteriorly, are associated with short M1 segments, and reside in older patients with sylvian fissures widened by brain atrophy.

KEY WORDS: Bilateral aneurysms, Contralateral clipping, Middle cerebral artery aneurysm, Minimally invasive surgery, Mirror aneurysms

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Contralateral aneurysm clipping has been well described and practiced for ophthalmic artery, superior hypophyseal artery, and internal carotid artery (ICA) bifurcation aneurysms.[1-6] An approach to the aneurysm from the opposite side might provide a better view or a medial perspective that can improve surgical treatment. For example, a medially projecting ophthalmic artery aneurysm typically requires anterior clinoidectomy and dissection of the distal dural ring with an ipsilateral approach but may not require either with a contralateral approach. Eliminating clinoidectomy and paraclinoid dissection reduces the risk of optic nerve morbidity and visual deficits. Similarly, a contralateral ICA bifurcation aneurysm associated with other ipsilateral aneurysms can be exposed with minimal additional subfrontal dissection, sparing the patient a second craniotomy. The typical superior projection of most ICA bifurcation aneurysms affords adequate views of the

ABBREVIATIONS: ACA, anterior cerebral artery; **ICA,** internal carotid artery; **MCA,** middle cerebral artery; **mRS,** modified Rankin Scale

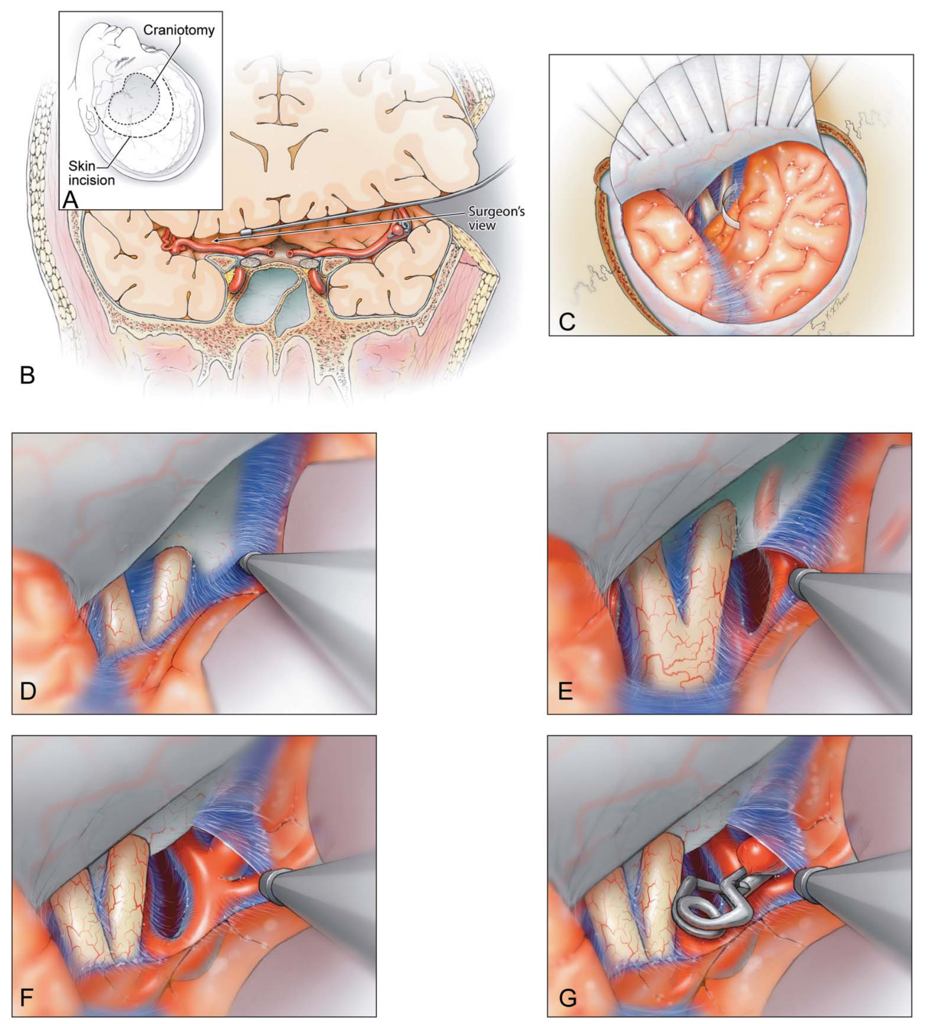

FIGURE 1. *Microsurgical technique for contralateral middle cerebral artery (MCA) aneurysm clipping.* **A**, *left pterional craniotomy and (***B***) transsylvian dissection expose the ipsilateral MCA aneurysm for clipping. Dissection to the contralateral MCA aneurysm follows a lateral subfrontal trajectory that requires minimal retraction, often just with gentle pressure from an instrument.* **C**, *the ipsilateral frontal lobe is freed from the optic tract and chiasm. The contralateral frontal lobe and olfactory tract are dissected from the contralateral optic nerve along its course from the optic canal to the chiasm.* **D**, *subfrontal exposure accesses the contralateral carotid and sylvian cisterns, which are opened widely.* **E**, *the contralateral sylvian fissure is split from its medial side, following the M1 MCA segment to the aneurysm.* **F**, *retraction on the contralateral medial orbital gyrus may be needed to expose the distal sylvian fissure and can be done with the suction rather than a fixed retractor blade.* **G**, *the aneurysm is clipped with a straight clip.*

neck and posterior perforators for safe clipping. Contralateral aneurysm clipping works well for other aneurysms located at short distances across the midline. Contralateral paramedian aneurysms include A1 segment anterior cerebral artery (ACA), A1-A2 junction, P1 segment posterior cerebral artery, and superior cerebellar artery aneurysms.

These aneurysms around or near the circle of Willis are favorable for contralateral clipping, but aneurysms outside or beyond the circle of Willis are less favorable. Contralateral clipping of middle cerebral artery (MCA) aneurysms has been described[7-10] but is not practiced widely because of long dissection distances, limited view, and impaired maneuverability

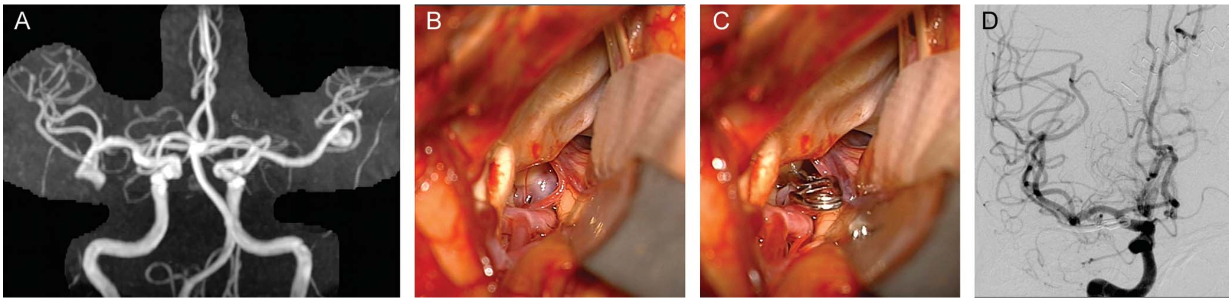

FIGURE 2. A, *preoperative magnetic resonance angiogram (anteroposterior view) demonstrated bilateral middle cerebral artery (MCA) aneurysms. The inferior projection of the right aneurysm made it ideal for contralateral clipping.* B, *through a left pterional craniotomy and subfrontal approach to the contralateral side, the right-sided aneurysm was exposed in the sylvian fissure. Note the sylvian veins bridging from the frontal lobe to the sphenoparietal sinus.* C, *the superior and inferior trunks coursed superiorly away from the neck, and the aneurysm was clipped with a simple curved clip.* D, *postoperative digital subtraction angiography (right internal carotid artery injection, anteroposterior view) demonstrated complete occlusion of the aneurysm.*

in the operative corridor. Furthermore, complications like intraoperative aneurysm rupture are difficult to manage with this approach. Contralateral clipping of MCA aneurysms seems dangerous and ill advised, and some neurosurgeons have condemned or abandoned this technique. However, others have adopted this technique because of the prevalence of MCA aneurysms, the limitations of endovascular therapy with these particular lesions, and increasing patient interest in less invasive aneurysm management. The controversy surrounding this technique demands further analysis and consensus. Our confidence in contralateral clipping of MCA aneurysms has grown, but we contend that adoption of this technique depends on patient selection and surgical technique, which are defined in this report.

PATIENTS AND METHODS

Clinical Material

This study was approved by the Institutional Review Board and conducted in compliance with Health Insurance Portability and Accountability Act regulations. The prospectively collected database of the Vascular Neurosurgery Service at the University of California, San Francisco, was searched to identify all patients with MCA aneurysms. Between August 1997 and December 2010, 566 patients harboring 606 MCA aneurysms were treated microsurgically by the senior author (M.T.L.). Forty-two of these patients (7.4%) had bilateral MCA aneurysms that were treated: 11 patients in 1 stage with a single craniotomy and contralateral MCA aneurysm clipping (group 1) and 31 patients in 2 stages with bilateral craniotomy (group 2).

Medical records, radiographic studies, intraoperative photographs, and clinical follow-up evaluations were retrospectively reviewed. Clinical outcomes were assessed by a nurse clinician under the supervision of a neurologist using the modified Rankin Scale (mRS) 6 weeks after surgery and at last follow-up. The outcome was considered improved when the difference between the preoperative mRS and the postoperative mRS was positive, unchanged when there was no difference, and worse when that difference was negative. Treatment costs were estimated by neurosurgical hospital charges.

Surgical Technique for Contralateral Clipping of MCA Aneurysms

A standard pterional craniotomy is used for contralateral MCA aneurysm clipping (Figure 1A). The side of the craniotomy is selected ipsilateral to the larger or more complex of the 2 MCA aneurysms, placing the smaller or simpler aneurysm on the contralateral side (Figure 1B). The patient is positioned supine with the head fixed in a Mayfield frame and rotated 15° to 20° away from the side of the ipsilateral MCA aneurysm, with slight extension. Mannitol is administered at the start of the operation for brain relaxation. Ventricular or lumbar drains are not used; cerebrospinal fluid is drained by widely opening the subarachnoid cisterns and fenestrating the lamina terminalis.

The incision starts at the zygomatic arch 1 cm anterior to the tragus and follows the hairline to the midline. The temporalis muscle is mobilized anteroinferiorly, and frontotemporal craniotomy is made with a single temporal burr hole. The pterion and the medial part of the sphenoid wing are drilled down to the lateral edge of the superior orbital fissure, flattening the bone connecting the anterior and middle cranial fossae. After opening of the dura, the ipsilateral sylvian fissure is opened widely under the microscope. The M1 MCA is exposed for proximal control, and the aneurysm is dissected and clipped. Ipsilateral clips can interfere with the contralateral approach, in which case ipsilateral clipping is deferred until after contralateral clipping.

The contralateral approach begins at the ipsilateral ICA bifurcation, where the A1 ACA is identified and followed to the anterior communicating artery complex (Figure 1C). Fenestration of the lamina terminalis releases cerebrospinal fluid to slacken the brain for subsequent frontal retraction. The chiasmatic and lamina terminalis cisterns are opened extensively, and arachnoidal trabeculations between the inferior frontal lobe and optic nerve are incised. The optic nerve and olfactory tract are separated for further frontal lobe elevation. This arachnoidal dissection extends anteriorly to the optic canal to free the frontal lobe and to open the subfrontal corridor (Figure 1D). Mobilization of the frontal lobe, either with a fixed retractor on the medial orbital gyrus or with dynamic retraction from a surgical instrument, exposes the contralateral A1 ACA. This segment is traced to the ICA bifurcation, which rises above the plane of the optic apparatus. The carotid cistern is opened widely to visualize the origin of M1 MCA and arachnoid of the sylvian cistern (Figure 1E).

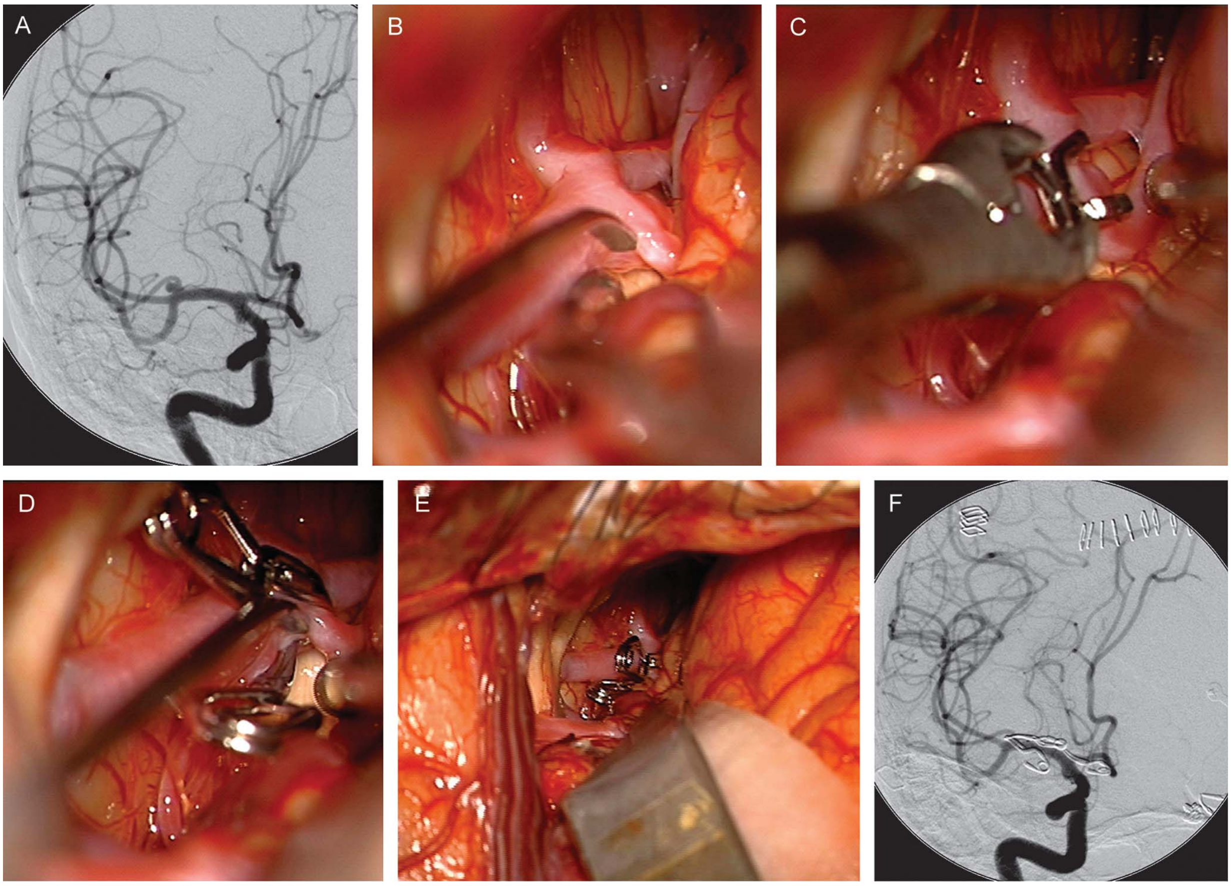

FIGURE 3. **A**, *preoperative digital subtraction angiography (right internal carotid artery [ICA] injection, anteroposterior view) demonstrated a small, laterally projecting middle cerebral artery (MCA) aneurysm.* **B**, *through a left pterional craniotomy and subfrontal approach to the contralateral side, lateral dome projection positioned the frontal trunk between the neurosurgeon and the neck.* **C**, *the aneurysm was clipped with a down-curved miniclip.* **D**, *the tips did not completely occlude the neck, and a second up-curved mini clip was applied from the opposite side.* **E**, *an overview showed the lateral dome projection to be in line with the surgical trajectory.* **F**, *postoperative digital subtraction angiography (right ICA injection, anteroposterior view) demonstrated complete occlusion of the aneurysm.*

The sylvian arachnoid is opened widely to enter the sylvian fissure. The direct surgical view into the plane between the frontal and temporal lobes facilitates this split, unlike the more tangential view on traditional ipsilateral sylvian fissure dissection. Veins can bridge from frontal to temporal lobes or from the Sylvian fissure to the sphenoparietal sinus. Small bridging veins are cauterized and divided, but larger veins are preserved. The dissection proceeds distally along the M1 MCA with a view along its axis. The anterior temporal artery originates from the inferior wall of M1 MCA and courses inferiorly, which makes it a useful landmark that is easier to visualize than the M1 MCA itself. The M1 segment can disappear as it ascends laterally, requiring progressively more retraction on the medial orbital gyrus and splitting of the sylvian fissure.

The M1 MCA is followed to the aneurysm (Figure 1F). Inferiorly and anteriorly projecting aneurysms lie in the surgical corridor and can be visualized clearly, which often enables permanent clipping with a simple straight clip (Figures 1G and 2). Laterally projecting aneurysms are difficult to visualize because the parent arteries lie between the neurosurgeon and the aneurysm neck. The aneurysm and/or the parent arteries may need to be mobilized to visualize the neck, which is facilitated with temporarily clipping of the M1 segment and softening of the aneurysm. Laterally projecting aneurysms are clipped with a curved clip, with the tips curving downward across the neck. A second curved clip, with the tips curving upward across the neck and intersecting the blades of the first clip, may be needed when the 1 clip does not completely occlude the neck (Figure 3). Superiorly projecting aneurysms may hide behind the medial orbital gyrus and are exposed by mobilizing the aneurysm inferiorly, retracting the frontal lobe superiorly, or resecting a small portion of overlying gyrus (Figure 4). Once visualized, the superior projection of these aneurysms makes them easy to clip with a straight clip. Larger aneurysms that require more aggressive mobilization are softened with a temporary clip placed on the M1 MCA somewhere between the ICA terminus and MCA bifurcation.

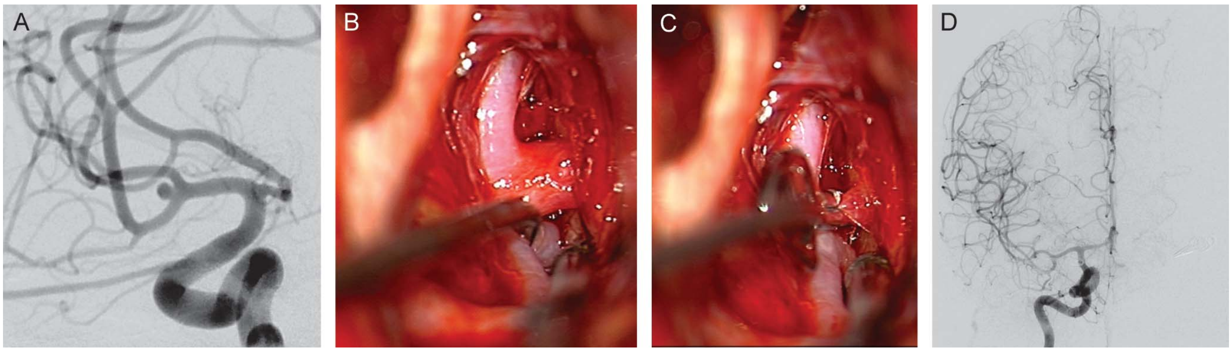

FIGURE 4. **A**, *preoperative digital subtraction angiography (right internal carotid artery [ICA] injection, anteroposterior view) demonstrated a small, superiorly projecting middle cerebral artery aneurysm.* **B**, *through a left pterional craniotomy and transsylvian approach to the contralateral side, the superior dome projection was better appreciated with gentle elevation of the frontal lobe.* **C**, *the aneurysm was clipped with a straight clip.* **D**, *postoperative digital subtraction angiography (right ICA injection, anteroposterior view) demonstrated complete occlusion of the aneurysm.*

RESULTS

The overall cohort of 42 patients included 31 women and 11 men. The 11 patients treated with contralateral MCA aneurysm clipping (group 1) were older than the 31 patients with bilateral craniotomy for MCA aneurysm clipping (group 2), with mean ages of 60.3 years (range, 41-72 years) and 55.4 years (range, 17-73 years), respectively. Clinical presentation with subarachnoid hemorrhage was less common in group 1 than in group 2: 3 patients (27%) vs 17 patients (55%), respectively. All patients had bilateral MCA aneurysms that were diagnosed and treated, and additional aneurysms were diagnosed and treated in 25 patients (136 aneurysms in total).

In the 11 patients with contralateral MCA aneurysm clipping, 9 patients (82%) had left-sided craniotomies (Table 1 and Figure 5). The mean size of the ipsilateral aneurysm was 6.0 mm (range, 3-10 mm), whereas the mean size of the contralateral aneurysm was 3.7 mm (range, 1-9 mm). In comparison, the mean size of the first aneurysm treated in group 2 patients was 6.2 mm (range, 1-25 mm), whereas the mean size of the contralateral aneurysm was 3.8 mm (range, 1-10 mm). In group 1, the mean length of the contralateral M1 segment was shorter than the ipsilateral M1 segment, with mean lengths of 17.7 mm (range, 14.0-20.0 mm) and 19.3 mm (range, 14.0-25.0 mm), respectively. In comparison, the mean length of the M1 segments in group 2 patients was 19.0 mm (range, 7.0-25.0 mm).

All contralateral MCA aneurysms were clipped without intraoperative complications or intraoperative rupture. All other ipsilateral and contralateral aneurysms were also clipped. Postoperative angiography confirmed complete clipping in all 42 patients. Mean neurosurgical charges were decreased in patients treated with 1 craniotomy and contralateral MCA aneurysm clipping: $39 297 in group 1 vs $57 977 in group 2.

Neurological outcomes were similar in both patient groups (Table 2). In group 1, good outcomes (mRS scores, 0-2) were observed in 10 patients (91%). One patient with subarachnoid hemorrhage died of myocardial infarction during treatment of vasospasm with hypertensive therapy and vasopressors. In group 2, good outcomes were observed in 26 patients (84%), and poor outcomes (mRS scores 3-5) were seen in 4 patients (13%). There was 1 perioperative death (3%). Overall, 9 patients (82%) in group 1 were improved or unchanged; 28 patients (90%) in group 2 were improved or unchanged (mean duration of follow-up, 369 days).

DISCUSSION

Bilateral MCA aneurysms can be managed in a variety of ways, the most common being bilateral craniotomy in 2 separate surgical stages. Bilateral craniotomies performed in 1 combined stage spare the patient a second operation but not a second craniotomy.[11] In contrast, unilateral craniotomy with bilateral aneurysm clipping spares the patient a second operation and a second craniotomy. Contralateral MCA aneurysm clipping is not novel. Tamargo and colleagues demonstrated the surgical anatomy of contralateral approaches to bilateral aneurysms in cadaveric specimens and correlated their work with a clinical experience in 23 patients, of which 14 had MCA aneurysms.[1,12] None of the MCA aneurysms were clipped from a contralateral approach, which the authors attributed to "complex vascular anatomy," and these aneurysms were left untreated. In the largest reported experience with contralateral MCA aneurysms, De Sousa and colleagues[7] observed excellent results in 30 patients, especially in those with fewer aneurysms (total $<$ 3). Recent reports demonstrated similar excellent results with less invasive exposures like the supraorbital keyhole craniotomy.[2,8,9]

Rationale for Contralateral MCA Aneurysm Clipping

Contralateral clipping of MCA aneurysms seems like a bad idea because dissection distances are long, visualization is restricted, and maneuverability is poor, making clip application and

TABLE 1. Summary of Patients With Contralateral Clipping of MCA Aneurysms (Group 1)[a]

Patient	Age, y	Sex	Aneurysms, n	Approach	Ipsilateral Location	Other Ipsilateral Aneurysms	Contralateral Location	Other Contralateral Aneurysms	Presentation	H&H	Fisher	Size Ipsilateral MCA Aneurysm, mm	Size Contralateral MCA Aneurysm, mm	Outcome
1	62	M	3	Right	MCA	MCA (M1)	MCA		Incidental	0	1	10.0	4.0	Unchanged
2	55	F	2	Right	MCA		MCA		Incidental	0	1	6.0	3.8	Unchanged
3	47	F	2	Left	MCA (M1)		MCA		Incidental	0	1	9.0	5.0	Unchanged
4	64	F	2	Left	MCA		MCA		Headache	0	1	4.0	4.0	Unchanged
5	66	F	2	Left	MCA		MCA		Headache	0	1	7.0	9.0	Unchanged
6	72	F	4	Left	MCA (M1)	AChA	MCA	ICAB	Incidental	0	1	3.0	3.0	Unchanged
7	51	M	2	Left	MCA		MCA		SAH	2	3	9.0	2.0	Unchanged
8	69	F	2	Left	MCA		MCA		SAH	1	3	3.8	2.4	Worse
9	69	F	4	Left	MCA	MCA	MCA	AChA	Incidental	0	1	4.0	1.0	Unchanged
10	41	F	4	Left	MCA	AChA, ACoA	MCA		SAH	2	3	3.8	3.2	Improved
11	67	F	2	Left	MCA		MCA		Headache	0	1	6.5	3.0	Worse

[a]AChA, anterior choroidal artery; ACoA, anterior communicating artery; H&H, Hunt and Hess grade; ICAB, internal carotid artery bifurcation; MCA, middle cerebral artery; SAH, subarachnoid hemorrhage.

intraoperative aneurysm rupture difficult to manage. However, our experience and other reports confirm that contralateral MCA aneurysm clipping is technically feasible, safe, and generally easier that it seems. The surgical technique is a natural extension of accepted contralateral approaches to other aneurysms. The ipsilateral sylvian fissure split and dissection of the carotid cistern required for an ipsilateral MCA aneurysm set up the additional dissection of a contralateral MCA aneurysm. Subfrontal subarachnoid dissection, contralateral sylvian fissure split, and mobilization of the medial orbital gyrus bring the contralateral aneurysm into view. These are not significant or difficult steps. The rationale for exploring a contralateral MCA aneurysm is compelling: Multiple aneurysms occur in 15% to 25% of patients and MCA aneurysms are common; successful contralateral MCA aneurysm clipping will spare a patient a second craniotomy; and the wide necks of many MCA aneurysms limit the efficacy of endovascular therapy. Thus, although contralateral MCA aneurysm clipping can be viewed as an extreme microsurgical technique, it can also be viewed as a less invasive technique in the management of bilateral aneurysms. More neurosurgeons are accepting smaller aneurysm approaches as a way to decrease operative morbidity, to improve cosmesis, and to appeal to patients. These approaches reduce operative exposures and generally make the procedure more difficult for the neurosurgeon. Contralateral clipping of MCA aneurysms is no different.

On the basis of this rationale, we changed our practice and began performing contralateral clipping of MCA aneurysms 4 years ago. Our experience demonstrates that the technique is challenging but still safe. We also documented a reduction in neurosurgical charges and would expect even greater savings in detailed analyses of hospital charges and lengths of stay. Technical expertise is critical, and the senior author's confidence with this technique developed in the context of nearly 3000 aneurysm clippings and $>$ 120 contralateral clippings.

Indications

Safety with contralateral MCA aneurysm clipping depends on discriminating patient selection and careful preoperative review of aneurysm and surgical anatomy on angiography, computed tomography scans, and magnetic resonance images. We recommend this technique only with unruptured contralateral MCA aneurysms. In patients presenting with subarachnoid hemorrhage, the ruptured aneurysm is approached ipsilaterally. The risk of intraoperative rupture with a previously ruptured MCA aneurysm is not insignificant and, if it occurs, is much easier to control on the ipsilateral side. Proximal control of the M1 MCA is easily accessible during contralateral dissection, but other limitations in visualization and maneuverability contraindicate a contralateral approach to ruptured MCA aneurysms. With unruptured aneurysms, the larger one is approached ipsilaterally and the smaller, simpler one is approached contralaterally. Ideal MCA aneurysms have simple neck anatomy that can be closed with 1 or 2 straight or curved clips. MCA aneurysms with complex anatomy (wide necks, fusiform

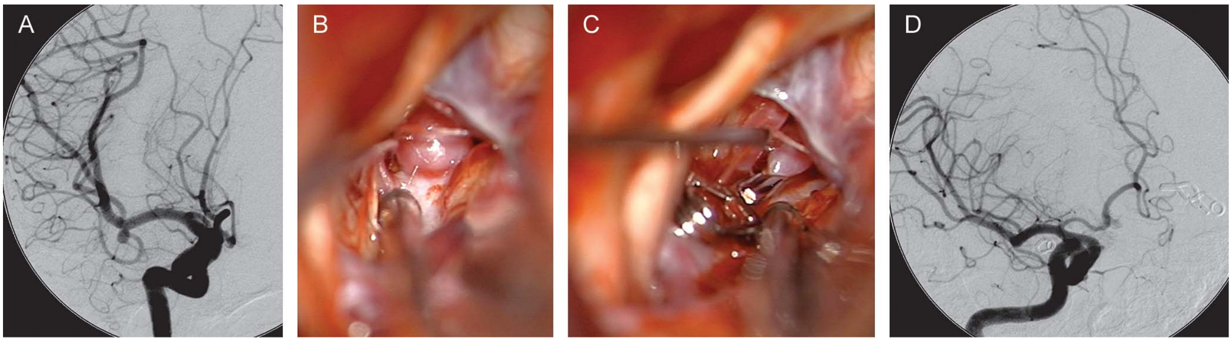

FIGURE 5. *A, preoperative digital subtraction angiography (right internal carotid artery [ICA] injection, anteroposterior view) demonstrated a small, anteriorly projecting middle cerebral artery aneurysm. B, the aneurysm was exposed through a left pterional craniotomy and transsylvian approach to the contralateral side. C, anterior dome projection afforded a good perspective of the neck, which was clipped with a straight clip. D, postoperative digital subtraction angiography (right ICA injection, anteroposterior view) demonstrated complete occlusion of the aneurysm.*

morphology, or complex branch anatomy) that might require more clips or tandem clipping are contraindicated because of decreased maneuverability of these clips and decreased visibility of arterial anatomy around them. Like the long, narrow operative corridor to the basilar apex, the operative corridor to the contralateral MCA bifurcation creates a tangential view along the clips with reduced depth perception, and simple clip configurations are safest in these conditions. Preoperative angiography is carefully reviewed for favorable aneurysm morphology.

In addition, angiography shows the length of the contralateral M1 segment and the aneurysm dome projection. Contralateral clipping is indicated with inferiorly and anteriorly projecting MCA aneurysms that are well seen subfrontally. In contrast, laterally and superiorly projecting aneurysms are more difficult; the neck of an aneurysm that projects laterally requires a more complex clip reconstruction (intersecting curved clips or an angled fenestrated clip), and the neck of an aneurysm that projects superiorly is obscured by the frontal lobe. M1 segment anatomy is important, with a short M1 segment decreasing the dissection distance and a downward-arcing M1 segment positioning the aneurysm in the surgical corridor. Long or upward-arcing M1 segments increase the dissection distances and hide the aneurysm. Finally, brain atrophy and a widened sylvian fissure in older patients facilitate contralateral clipping. Young patients with tight sylvian fissures and apposition or interdigitation of the frontal and temporal lobes can be difficult to split contralaterally. Preoperative computed tomography scans and magnetic resonance images are reviewed for this favorable anatomy of the fissure.

Severe subarachnoid hemorrhage is a contraindication for contralateral MCA aneurysm clipping. Aneurysm rupture, even when on the side ipsilateral to the craniotomy, can cause brain swelling that diminishes the subfrontal corridor. Some frontal lobe retraction is required, and edema increases retraction pressure. Aneurysm rupture can fill the contralateral sylvian fissure with subarachnoid blood and obscure the view. Contralateral MCA clipping should not be performed when there is active vasospasm because a significant portion of the circle of Willis is manipulated. MCA aneurysms that are large or have broad necks, adherent branches, intraluminal thrombus, or atherosclerotic tissues should not be clipped through a contralateral approach. Some other anatomic factors cannot be assessed preoperatively like large sylvian veins or a prominent anterior clinoid process. These structures may complicate the aneurysm exposure and halt the dissection. Drilling down the anterior clinoid process through a deep corridor and on top of the optic apparatus is not recommended.

TABLE 2. Surgical Outcomes in Patients With Bilateral Middle Cerebral Artery Aneurysms[a]

		mRS Change			
		Preoperative		Postoperative	
Group	mRS Score	n	%	n	%
1	0	9	81.8	7	63.6
	1	0	0	1	9.1
	2	2	18.2	2	18.2
	3	0	0	0	0
	4	0	0	0	0
	5	0	0	0	0
	6	0	0	1	9.1
2	0	7	22.6	12	38.7
	1	11	35.5	10	32.3
	2	6	19.4	4	12.9
	3	3	9.7	2	6.5
	4	1	3.2	1	3.2
	5	3	9.7	1	3.2
		0	0	1	3.2

[a]mRS, modified Rankin Scale.

Complications

Complications in our experience with contralateral MCA aneurysm clipping were minimal, but this approach introduces some risks. Most notable is the danger of a contralateral intraoperative aneurysm rupture, which can be more difficult to manage working at a long reach. The proximal M1 MCA is easily controlled with a temporary clip, but distal control is less accessible. In addition, limitations in visibility and maneuverability can make it difficult to determine the site of rupture and the corrective action. Dissection along the A1 ACA, ICA terminus, and M1 MCA segments should follow their anterior-inferior surfaces to avoid perforators and lenticulostriates on their posterior-superior surfaces. The path of dissection parallels the recurrent arteries of Heubner, which are carefully protected. Sacrifice of contralateral sylvian veins can cause venous infarction, but the medial splitting of the sylvian fissure typically crosses smaller veins bridging from the frontal lobe and avoids the larger venous complex on the cortical surface. Bilateral craniotomies for bilateral MCA aneurysms do not require dissection across the midline; therefore, contralateral MCA aneurysm clipping introduces additional risks to cranial nerves. Subfrontal dissection along the optic apparatus is confined meticulously to arachnoidal planes, preserving perforating arteries to the optic nerves and minimizing manipulation of the nerves. Frontal lobe retraction, whether by fixed retractors or a dissecting instrument, can avulse rootlets on the olfactory bulb and raise the risk of postoperative anosmia. These potential complications associated with contralateral clipping require caution. Not included in this report is a review of our few failed attempts at contralateral clipping. The neurosurgeon should have a low threshold to abort the technique if conditions are not favorable for safe clipping and a good outcome.

CONCLUSION

Contralateral MCA aneurysm clipping can be viewed as a less invasive technique in the management of bilateral aneurysms that spares a patient a second craniotomy. This experience demonstrates that the technique is feasible and safe. This technique is indicated only in patients with contralateral MCA aneurysms that are unruptured, have simple necks, project inferiorly or anteriorly, are associated with short M1 MCA segments, and reside in older patients with sylvian fissures widened by brain atrophy.

Disclosure

The authors have no personal financial or institutional interest in any of the drugs, materials, or devices described in this article.

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COMMENTS

From *The Godfather*:
Don Corleone: "It's an old habit. I spent my life trying not to be careless. Women and children can be careless, but not men. How's your boy?"

Michael: "He's good."

The authors report results from contralateral clipping of bilateral middle cerebral artery (MCA) aneurysms through a single craniotomy. Eleven patients are described and compared with 31 patients who had bilateral craniotomies for the same pathological entities. The report includes only cases of 1 senior neurosurgeon with vast experience in aneurysm clipping. Although statistical evaluations were not run on such a small number of patients, the authors report similar outcomes between the 2 groups of patients, with a cost savings in the patients with the single craniotomy. These 11 patients are but a small group of the 606 total MCA aneurysms in the senior author's series. The authors conclude that the procedure can be performed safely in unruptured aneurysms with favorable configuration, projection, and location.

Surgeons who have operated on contralateral aneurysms know that clipping contralateral aneurysms falls under the rubric of "bold" and really should not be attempted by the faint of heart—if at all. Preoperative counseling includes words such as "if" and "maybe." Surgical exposure is predicated on the ability to get an elegant splitting of the sylvian fissure coupled with contralateral exposure while not damaging the olfactory nerves for clipping of very "low-lying fruit." Decision making to treat these aneurysms many times occurs "on the fly" in that innumerable obstacles alter surgical treatment and can lead to aborting such approaches. For me, the prediction of these obstacles preoperatively is difficult.

I have often wondered what would happen in these cases if intraoperative rupture would occur without the "sacred" proximal and distal control. What would I want if it were a family member on the operating table? Even though this is an MCA aneurysm, could it be coiled? MCA aneurysms are notoriously difficult to clip because of their neck configuration, and is the limited corridor exposing the patient to long-term risk for recurrence?

Clearly, the surgical procedure can be done and, as the authors present, with success. Many times in vascular surgery, we do the best we can in less-than-ideal surgical circumstances and give it our best effort despite inadequacies. Enhancing all the variables, including the intangibles, leads to success. However, aneurysm surgery is very strategic, and even though it might be able to be done, should the risk be taken?

Winfield S. Fisher
Birmingham, Alabama

The authors review their institutional experience with clipping of bilateral middle cerebral artery (MCA) aneurysms through a single craniotomy. Of the 42 patients with bilateral aneurysms reviewed, only 11 had both aneurysms clipped through a single craniotomy. This actually represented a change in the authors' institutional practice in an effort to reduce associated morbidity. Although clipping of contralateral MCA aneurysms through a single exposure is not a novel concept, historically, concerns have been recognized and published regarding the additional risks one must undertake to complete such a task, as adequately referenced within this article. Interestingly, however, the authors demonstrated in their series that there were no significant differences in the neurological outcomes between patients with a single craniotomy and those with bilateral craniotomies. The authors then spell out their patient selection criteria for this procedure, namely patients with nonruptured lesions, "simple" necks, inferior or anterior projection, and "short" M1 segment and older patients, who tend to have larger subarachnoid and cisternal spaces.

Although the authors are commended for their good outcomes, clipping of contralateral MCA aneurysms is not without possible complications, namely intraoperative rupture, venous congestion/infarct/hemorrhage (from inadvertent sacrifice of important contralateral sylvian veins), perforator avulsion/injury (contralateral lenticulostriates), anosmia, and/or recurrent artery of Heubner infarct/injury, as discussed but not experienced by the authors. The visualization of the contralateral aneurysm is often minimal; thus, the ability to deal with complications is made more difficult. Although proximal control may not be problematic, distal control can be fraught with hazards and lead to adverse movements of the surgeon, resulting in additional morbidity. Finally, because of the limited visualization of the aneurysm, the risk of leaving a residual neck or dome is increased, especially with the limited ability to maneuver the clip during clipping and significantly decreased visualization of the trajectory of the clip blades.

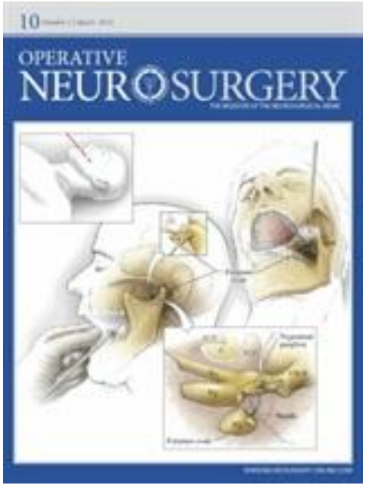
If a contralateral MCA aneurysm is judged as possibly being amenable to clipping from the contralateral side, adjunctive techniques, also mentioned by the authors, can also be used to facilitate contralateral aneurysm clipping such as the use of retractors, osmotic diuretics, and ventricular drainage. Surgeons should be aware of these possible complications and of the adjuncts that may reduce the risk of their occurrence. Even in skilled hands, this is a technically challenging approach to aneurysms that, by definition, are straightforwardly managed through an ipsilateral exposure.

Christopher S. Eddleman
Duke Samson
Dallas, Texas

In this interesting article, the authors describe 11 patients in whom bilateral middle cerebral artery (MCA) aneurysms were treated with a unilateral approach. Results were compared with 31 patients with bilateral craniotomy to treat bilateral MCA aneurysms. No patients had intraoperative events, which speaks more to the senior author's extensive experience rather than the safety of either procedure. Furthermore, it is important to note that a unilateral approach is performed in patients with favorable anatomic features. A clear cost benefit of a single craniotomy for the treatment of 2 aneurysms is delineated.

When considering unilateral craniotomy for bilateral MCA aneurysm, the surgeon must consider the potential risk in addition to the potential benefit. In the event of intraoperative rupture of a contralateral MCA aneurysm, the results would likely be unwelcome compared with the costs of a second craniotomy. It is our role as surgeons to treat our patients while minimizing harm. We believe that 1 difficult surgery does not outweigh the costs of 2 relatively simple surgeries.

Travis M. Dumont
Elad I. Levy
Buffalo, New York



4º Artículo

3-D Video

End-to-End Reanastomosis Technique for Fusiform Aneurysms: 3-Dimensional Operative Video

Ana Rodríguez-Hernández, MD, Michael T. Lawton, MD

Department of Neurological Surgery, University of California at San Francisco, San Francisco, California

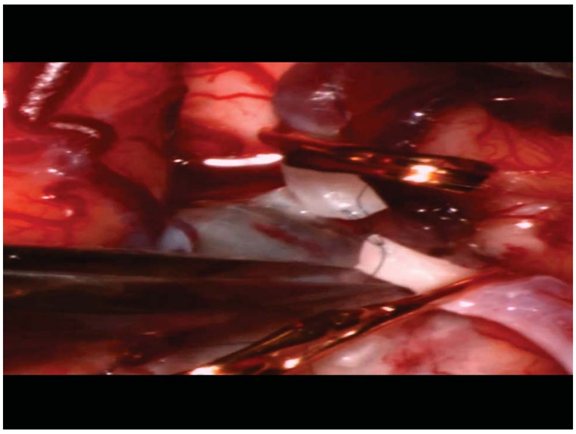
Intracranial aneurysms with a fusiform morphology are rarely amenable to direct clipping and instead require occlusion techniques that involve revascularization. One such technique is aneurysm trapping and excision with end-to-end reanastomosis of the inflow and outflow arteries. Middle cerebral artery and posterior inferior cerebellar artery (PICA) aneurysms often have redundant parent artery that allows primary reanastomosis. End-to-end anastomosis requires fewer bites than end-to-side anastomosis, and rotation of arteries helps to visualize both suture lines. In this video, we illustrate this technique with 2 different aneurysms.

In the first case, a 73-year-old man presented with expressive aphasia and a partially thrombosed, giant serpentine left middle cerebral artery aneurysm. The aneurysm was exposed through a pterional craniotomy; inflow and outflow arteries were temporary clipped; thrombectomy decompressed the aneurysm mass to bring the transected ends together; and end-to-end anastomosis was performed with running suture. Postoperative angiography confirmed filling of the middle cerebral artery territory through a patent anastomosis. In the second case, a 45-year-old woman with severe headache had a 7-mm distal p3 PICA aneurysm. A far lateral approach exposed the caudal loop of PICA harboring the aneurysm, and atherosclerosis plus fusiform morphology prevented clipping. The aneurysm was trapped and excised, and the parent artery was reanastomosed. Postoperative angiography confirmed filling of the distal PICA territory through the bypass.

End-to-end reanastomosis of the parent artery after aneurysm excision is an efficient revascularization technique for fusiform aneurysms that have 1 afferent and 1 efferent artery, obviating the need for harvesting extracranial donor arteries.

Disclosure

Dr Lawton receives a royalty from Mizuho America for surgical instruments designed for bypass. Dr Rodríguez-Hernández is supported by a grant from the La Caixa Foundation. The authors have no personal financial or institutional interest in any of the drugs, materials, or devices described in this article.



Watch now at http://bit.ly/13SXx8S

Acknowledgments

We thank Guido Hattendorf from Zeiss and Ernesto Ramirez, Magnus Classon, and William Scott from the University of California at San Francisco operating rooms for their technical support.

The 3-D video can be viewed at http://bit.ly/13SXx8S or to view the video on a mobile device, scan this QR Code to link to an anaglyph (red/green) version of this 3-D video.

COMMENTS

The authors masterfully illustrated the use of end-to-end anastomosis as part of their microsurgical armamentarium for complex brain aneurysm treatment. End-to-end anastomosis without or with graft interposition is a very useful technique for microsurgical vascular reconstruction. Although the indications for bypass during aneurysm surgery are likely diminishing because of advances in endovascular technology, it surely remains a very important tool. It is our responsibility to keep up our bypass skills, especially in times of lower use. I congratulate the authors for sharing their expertise and educating current and future generations on microanastomic techniques and their use.

Ricardo A. Hanel
Jacksonville, Florida

The authors display a nice 3-dimensional technical video of an end-to-end anastomosis for fusiform middle cerebral artery and posterior inferior cerebellar artery aneurysms. The technique and pertinent imaging are nicely demonstrated. Although current technologies have made endovascular treatment of most aneurysms possible, certain aneurysms are best managed with open microsurgery. There may be temptation to push the boundaries of endovascular techniques in each of these cases. However, we must not forget that there are instances in which open surgery is the more appropriate and less risky option. This technical video demonstrates how a simple, yet elegant, open microsurgical approach safely and effectively cures 2 fusiform aneurysms of intracranial arteries. In addition, the video highlights the importance that patients with intracranial aneurysms be treated at high-volume centers with surgeons skilled in both open and endovascular techniques who can offer an unbiased appraisal of the best treatment for each patient.

Mandy J. Binning
Erol Veznedaroglu
Hamilton, New Jersey

The authors nicely demonstrate the utility of an often-overlooked technique for excluding a difficult aneurysm that is not amenable to clip ligation. In the first case, a giant thrombosed middle cerebral aneurysm is excluded, with enough redundancy of the M1 branch to perform a direct end-to-end anastomosis. It was necessary in this case to reduce the mass of the aneurysm to enable enough length to perform the end-to-end anastomosis. This obviously adds some time to the cross-clamp time on the distal middle cerebral territory, and another option would be to consider revascularization of a more distal middle cerebral artery branch with bypass before trapping of the aneurysm. With the present technique, it may be also prudent to have a backup bypass donor vessel (eg, superficial temporal artery) if the end-to-end anastomosis cannot be performed. The second case demonstrates a distal posterior inferior cerebellar artery aneurysm, which is a perfect indication for such a technique if the anatomy and wall of the aneurysm are such that clipping will be impractical or may be associated with a risk of vessel occlusion. I commend the authors on a beautiful surgical result in both of these cases; it provides native anterograde arterial supply without the need for bypass. This technique can also be used with the internal carotid artery directly by using the redundancy of the anterior loop and performing an end-to-end anastomosis after resection of a cavernous sinus tumor (article in press).

William T. Couldwell
Salt Lake City, Utah

VI.- Discusión

VI.- DISCUSIÓN

El tratamiento quirúrgico de los aneurismas de ACM ha demostrado de forma consistente y continúa excelentes resultados clínicos y radiológicos (1, 2, 33, 34, 40, 47, 66, 67, 71, 81, 97, 105, 120, 121, 149, 153). Como se puede observar en la **tabla 5** del ***artículo 1***, las series quirúrgicas publicadas en las últimas décadas describen tasas de oclusión completa del aneurisma por encima del 90 % (2, 26, 33, 49, 97, 105, 153, 164, 175, 176). En cuanto a los resultados clínicos, desde un 88% hasta un 100% de los pacientes con aneurismas no rotos tienen un buen resultado neurológico. Para los aneurismas rotos, los resultados neurológicos son algo más variables. La experiencia con 631 aneurismas de ACM en 543 pacientes revisada en este trabajo, demuestra que la microcirugía sigue dando excelentes resultados con un amplio espectro de lesiones y pacientes que incluyen aneurismas gigantes y trombóticos, aneurismas rotos en pacientes con mal grado clínico, y aneurismas no rotos en pacientes de edad avanzada. Con la microcirugía como tratamiento de primera elección, los aneurismas de ACM fueron el aneurisma quirúrgico más común (25 % del total de aneurismas quirúrgicos) y las técnicas quirúrgicas disponibles (clipaje simple, trombectomía, reconstrucción, abordaje contralateral, bypass asistido con flash fluorescence, etc) solucionan con éxito la variedad de anatomías aneurismáticas sin necesidad de tratamiento endovascular. El análisis por subgrupos sugiere que los malos resultados se deben sobre todo a esta política quirúrgica "inclusiva" consistente en manejar de forma agresiva a pacientes Hunt-Hess grado IV y V con hemicraniectomía y evacuación del hematoma, y los aneurismas complejos con trombectomía y bypass. Los resultados de este trabajo apoyan una política consistente en seguir ofreciendo el clipaje como primera opción para los aneurismas de ACM.

1.- Argumentos a Favor de la Cirugía

Los aneurismas de la ACM se exponen correctamente con una craneotomía pterional básica. Las craneotomías más agresivas (orbitocigomáticas y orbito-pterional) se utilizan en casos seleccionados y representaron solo el 10 % de todas las craneotomías. La ubicación lateral y superficial de los aneurismas de ACM permite la miniaturización de la craneotomía pterional, opción cada vez más utilizada en los últimos años del período que ocupa el presente estudio. La craneotomía "mini – pterional" es particularmente útil en los pacientes de más edad porque a menor tamaño de la craneotomía, menor riesgo de desgarros durales y complicaciones secundarias. Además, la habitual atrofia de la cisura Silviana en pacientes mayores permite una fácil exposición del aneurisma obviando la necesidad de una craneotomía más grande.

La disección de la cisura de Silvio y la separación de los lóbulos frontal y temporal es una técnica neuroquirúrgica básica que consigue exponer fácilmente y a plena vista, la anatomía relevante para tratar un aneurisma de ACM. Los riesgos asociados con la disección silviana incluyen el sacrificio de alguna vena con el consiguiente infarto venoso, oclusión de alguna rama arterial, transgresión pial y contusiones. Aunque el presente estudio no mide específicamente estos riesgos, la percepción es que fueron mínimos. Habitualmente las venas se pueden movilizar hacia el lóbulo temporal, las ramas arteriales se separan hacia el lóbulo correspondiente y se disecan hasta llegar a los troncos arteriales, la pía se protege para evitar lesiones y los retractores no suelen ser necesarios en esta localización. Cuando los lóbulos frontal y temporal se separan, el campo quirúrgico resultante es amplio y poco profundo, lo que permite una fácil maniobrabilidad para la reparación del aneurisma. Los diferentes tipos de clip (rectos, curvos, fenestrados, en bayoneta, etc.) y las distintas configuraciones de clipaje (simple, con clips apilados, solapados, en intersección, en tándem, etc.) permiten reparar la mayoría de los aneurismas de ACM (89% en nuestra experiencia). Una amplia disección silviana también facilita técnicas más difíciles como la trombectomía/reconstrucción y el bypass/oclusión (***ver vídeo artículo 4***).

Una importante ventaja de la cirugía es la capacidad para dilucidar la compleja anatomía del cuello del aneurisma, sus ramos superior, inferior e incluso a veces medios y la disposición de las lenticulostriadas circundantes. La percepción obtenida a través de la disección in situ de esta anatomía es habitualmente más informativa que las propias imágenes angiográficas. La manipulación del saco aneurismático durante la disección resultó en un riesgo de rotura intraoperatoria que es mayor que la asociada con la terapia endovascular (5,7 % vs. 3,1 %). Sin embargo, las roturas intraoperatorias de los aneurismas de ACM son mucho más fáciles de manejar que las de otras localizaciones ya que el control proximal requiere un solo clip, el control distal es fácilmente accesible y el campo microquirúrgico es amplio. En la serie presentada, ninguna de las roturas intraoperatorias resultó en una morbilidad o mortalidad añadida.

Otra gran ventaja de la cirugía es la flexibilidad para utilizar técnicas no convencionales cuando sea necesario, ya sea de forma pre planificada basada en la anatomía del aneurisma específico o en respuesta a hallazgos intraoperatorios inesperados. La cisura de Silvio es también una puerta de entrada a otros aneurismas de todo el polígono de Willis , permitiendo el clipaje de otros 284 aneurismas en 192 pacientes, incluyendo el clipaje contralateral de aneurismas de ACM en espejo, lo cual ahorró una segunda craneotomía a un total de 30 pacientes. La reparación de un aneurisma de forma eficaz y duradera que ofrece el cierre mecánico del cuello, representa la ventaja más importante que ofrece el clipaje quirúrgico. De hecho, los resultados quirúrgicos fueron excelentes con una oclusión completa del aneurisma en el 98.3% de los casos y sólo una rotura post-tratamiento (0.2 %). Se puede argumentar también que la cirugía ofrece importantes ventajas para el paciente en mal grado clínico que presenta una presión intracraneal elevada: la evacuación de posibles hematomas, una hemicraniectomía descompresiva, y la liberación de LCR al fenestrar la lamina terminalis y la membrana de Liliequist, ayudarían a restaurar la PIC normal y a optimizar los resultados clínicos.

De entre las técnicas microquirúrgicas no convencionales, la técnica de "flash de fluorescencia" con videoangiografía descrita en el ***artículo 2*** de este estudio, facilita el tratamiento de los aneurismas distales de ACM. La mitad de los pacientes con este tipo de aneurisma requieren un bypass para revascularizar el territorio distal al aneurisma. La técnica de "flash de fluorescencia" identifica claramente la arteria eferente en la superficie cortical, a menudo varios centímetros distal a la salida de la arteria desde el aneurisma. La identificación del receptor en la superficie cortical hace innecesaria la disección profunda de la cisura de Silvio, ahorrando a los pacientes la morbilidad asociada. La anastomosis es significativamente más fácil de realizar en la superficie cortical que en un campo quirúrgico estrecho en el fondo de la cisura. La retracción del cerebro no es necesaria, y el procedimiento en general es más rápido. Una vez permeable, el bypass proporciona flujo en la arteria receptora tanto de forma retrógrada hacia el aneurisma como anterógrada.

El clipaje contralateral de aneurismas de la ACM puede ser visto como una técnica microquirúrgica extrema. Los resultados del ***artículo 3*** de este trabajo sugieren que, en vez de ser considerado una técnica extrema, en determinados casos podría considerarse como una técnica menos invasiva que evita a los pacientes una segunda craneotomía en el manejo de los aneurismas bilaterales. Esta técnica de clipaje contralateral es aceptable en pacientes seleccionados con aneurismas contralaterales no rotos, con cuellos simples, que proyecten inferior o anteriormente, se asocian con segmentos M1 cortos, y en los pacientes de edad avanzada con cisuras de Silvio más amplias por la atrofia cerebral (6).

Los aneurismas de ACM con una morfología fusiforme rara vez son susceptibles de clipaje directo, requiriéndose técnicas de oclusión que suelen implicar también la revascularización (66, 71, 81, 136, 141, 145, 151). Una de tales técnicas de revascularización, es el “trapping” del aneurisma, escisión y reanastomosis de extremo a extremo de las arterias aferente y eferente. La peculiar anatomía de los aneurismas de ACM que a menudo tienen arteria redundante, permite la reanastomosis primaria. La anastomosis término-terminal requiere menos puntos que una anastomosis término-lateral. En el ***artículo 4*** de este trabajo, se ilustra en detalle mediante un vídeo la técnica requerida para este bypass.

2.- Argumentos en Contra de la Terapia Endovascular

La anatomía de los aneurismas de la ACM es especialmente compleja. Un aneurisma con cuello ancho puede abarcar gran parte de la bi- o trifurcación. La anatomía de los troncos principales y sus ramas puede ser difícil de descifrar por angiografía, incluso con la angiografía rotacional en 3D (64, 178). Con relativa frecuencia, las ramas se originan de la base o el saco aneurismástico, aumentando el riesgo de oclusión de dichas ramas con la embolización. Los aneurismas de tamaño grande o gigante, con trombo intraluminal, morfología fusiforme o dolicoectática o con ubicación distal, pueden limitar la eficacia de la terapia endovascular. En nuestra revisión de los resultados endovasculares en 859 pacientes con aneurismas de ACM (ver **tabla 5** del ***artículo 1***), sólo 454 pacientes (53 %) tuvieron una oclusión del aneurisma completa , con tasas que van del 29% al 88 % . En total, 261 pacientes (30 %) tenían restos de cuello, 82 (10 %) fueron embolizados de forma incompleta y en 62 (7 %) se intentó la embolización sin éxito (18, 19, 41, 56, 89, 106, 115, 154, 167). Estos resultados ofrecidos por la terapia endovascular son inferiores a los resultados quirúrgicos en los que las tasas de oclusión completa descritas están por encima de 90 %.

En una revisión sistemática sobre el tratamiento endovascular de 1076 aneurismas de la ACM en 1.033 pacientes, Brinjikji et al. Demostraron que un 20.4 % necesitaba la asistencia de balón o stent para la embolización (19). La fuerte dependencia de dispositivos complementarios y técnicas complejas eleva las tasas de complicaciones asociadas. Así, en esta misma revisión, las tasas de tromboembolismo, disección, accidente cerebrovascular, hemorragia postoperatoria precoz , la recurrencia menor y recurrencia mayor que requirieron tratamiento, fueron mayores que las observadas con tratamiento quirúrgico. La morbilidad y la mortalidad total asociada con estas complicaciones fue mayor con la terapia endovascular que con el tratamiento quirúrgico (5.1 % vs. 0.9 %). La rotura intraoperatoria del aneurisma fue la única complicación que ocurrió con menos frecuencia en los pacientes endovasculares que en los pacientes quirúrgicos (3.1% vs. 5.7 %), pero la morbilidad y mortalidad asociada fue mayor (1,1 % frente a 0 %), ya que las opciones endovasculares para lidiar con esta complicación son más limitadas. Es importante destacar que Brinjikji y cols. Encontraron una tasa de 18.9 % de recurrencia del aneurisma, de los cuales en el 9.6% se consideró una recurrencia importante que requirió repetir el tratamiento.

Muchos de estos factores influyeron en la selección de los pacientes para el ISAT, que requería la presunción de equivalencia terapéutica entre clip y coil para la inclusión en el estudio. El número relativamente pequeño de pacientes con aneurismas de la ACM incluidos en el ISAT, es en sí un reconocimiento de estas dificultades con la terapia endovascular y la falta de igualdad entre los dos tratamientos (96). La disminución absoluta (6.9%) y relativa (22.6 %) del riesgo de dependencia y muerte con la embolización fueron responsables de un aumento significativo de la terapia endovascular en todo el mundo. Sin embargo, el análisis posterior de los datos del ISAT (9) reveló que las ventajas de la embolización sobre el clipaje quirúrgico en términos de muerte y discapacidad grave en 1 año se 108neurismal108 a los 5 años (proporción de supervivientes independientes, 83% y 82%, respectivamente). Además, los aneurismas embolizados tenían un mayor riesgo de resangrado, 6.9 veces más probabilidades de requerir un retratamiento, un mayor coste en el procedimiento inicial, el seguimiento con angiografía los procedimientos finales adicionales, y las complicaciones asociadas o eventos adversos. El clipaje microquirúrgico protege mejor de una HSA a los pacientes jóvenes (<40 años) con mínimas diferencias en seguridad frente a la embolización. La opción quirúrgica se traduce también en mejores resultados en los pacientes de edad avanzada con aneurismas de ACM (tasa de independencia funcional del 86.7 % con clip vs 45.5 % con coils). Estos resultados finales de ISAT han suscitado menor atención que su publicación inicial, pero son recordatorios importantes de que no se debe asumir que las supuestas ventajas iniciales de la terapia endovascular se prolonguen en el tiempo o sean generalizables a todo tipo de aneurismas. Además, el ISAT fue un estudio de aneurismas rotos por lo que continuamos sin tener evidencia de clase I que favorezca ninguno de las dos opciones de tratamiento en el caso de aneurismas no rotos. Pero incluso con aneurismas rotos, no existe evidencia suficiente a favor de la embolización en ciertos aneurismas como sería el caso de los aneurismas de ACM

3.- Limitaciones

Este estudio no es un ensayo randomizado aleatorizado comparando ambas opciones de tratamiento, sino una revisión de la experiencia de un solo cirujano en un solo centro. A pesar de la política institucional de ofrecer el clipaje como primera opción, también se trataron de forma endovascular durante el mismo período pacientes con aneurismas de ACM que habían sido envíados directamente al servicio de neurorradiología, que tenían una preferencia personal clara por la embolización o cuyo aneurisma presentaba una anatomía favorable para la embolización. Estos pacientes no fueron incluidos en la presente revisión. Este estudio, a diferencia del BRAT o el ISAT, no fue diseñado para determinar la superioridad terapéutica de una u otra técnica sino más bien para capturar la imagen completa del tratamiento de los aneurismas de la ACM desde una perspectiva de neurocirugía, incluyendo todo el espectro de pacientes: desde los que llegan intactos hasta los moribundos, con aneurismas simples y complejos, rotos y no rotos. La falta de homogeneidad hace que estos resultados sean más difíciles de interpretar que los de un ensayo controlado aleatorizado o una revisión retrospectiva de los resultados con un solo subgrupo de aneurismas rotos o no rotos. Sin embargo, una interpretación clara es que la cirugía ofrece la versatilidad necesaria para hacer frente a este amplio espectro de pacientes. Los estudios multicéntricos y “multi-cirujano” pueden no ser la mejor metodología para establecer las prácticas más adecuadas para los aneurismas de ACM, ya que la diversidad de exclusiones y la variabilidad entre los cirujanos y las instituciones pueden confundir los resultados. Aunque los estudios controlados facilitan las comparaciones de resultados de acuerdo a la modalidad de tratamiento, la revisión de la experiencia de un solo cirujano que incluya todos los casos ayuda a minimizar estas variables y refleja una práctica clínica real.

Otra interpretación clara de nuestro estudio es que el tratamiento quirúrgico puede lograr excelentes resultados, que pueden ser un punto de referencia para las terapias endovasculares a medida que evolucionan más allá de las técnicas de embolización simples. Los buenos resultados observados en esta serie son en parte atribuibles a la aplicación de los avances en las técnicas microquirúgicas tales como la disección silviana sin retractores, las técnicas de bypass, la videoangiografía intraoperatoria con verde de indocianina y, en general, el manejo intensivo de los pacientes con hemorragia subaracnoidea en el quirófano, en la unidad de cuidados intensivos, y en la sala de angiografía. Sin embargo, así como los ensayos multicéntricos introducen variabilidades que pueden confundir los resultados, las experiencias de un solo cirujano introducen las habilidades únicas, capacidad de juicio clínico y la experiencia de ese individuo. Estas cualidades varían mucho entre los cirujanos y los resultados de referencia de una experiencia pueden no ser generalizables a otros neurocirujanos o centros. Por lo tanto, los neurocirujanos deben evaluar sus propios resultados, y las competencias y los conocimientos locales se deben considerar también al determinar los protocolos de tratamiento institucionales. Los resultados de este trabajo, así como los previamente publicados en la literatura, apoyan por el momento la política de ofrecer el tratamiento microquirúrgico como primera opción para los aneurismas de ACM tanto en la institución objeto de estudio como de forma general. Los avances en la tecnología endovascular continuarán estimulando los intentos de embolizar los aneurismas de ACM. Los stents o flow diverters pueden mejorar los resultados, pero la necesidad de antiagregar al paciente limita su aplicación en pacientes con aneurismas rotos. Además, el despliegue de los flowdiverters es técnicamente difícil y su eficacia no está clara. Los resultados actuales con el dispositivo de embolización Pipeline son mejores en los aneurismas intracavernosos y paraclinoidales de la ACI, donde la arteria principal es grande y las ramas arteriales son pocas; y claramente peores en la circulación posterior, donde existen numerosas arterias perforantes. Los aneurismas de la ACM se asocian de manera similar con múltiples ramas y con las perforantes lenticuloestriadas y los resultados en esta región anatómica son desconocidos. Los avances tecnológicos y técnicos en terapia endovascular inevitablemente desafiarán la política de clipaje como primera opción para los aneurismas de la ACM, pero para ello primero deben demostrar resultados equivalentes o superiores a los del tratamiento quirúrgico. Los protocolos de tratamiento no se pueden imponer, pero el consenso entre los neurocirujanos, neurorradiólogos y neurointensivistas puede influir en las prácticas actuales. Los sistemas de clasificación u otros esquemas de guía pueden resultar demasiado complejos, mientras que las políticas que se basan simplemente en la localización del aneurisma se adoptan fácilmente. El aneurisma de ACM destaca como un ejemplo de que los protocolos terapéuticos pueden basarse exclusivamente en la localización del aneurisma.

VII.- Conclusiones

VII.- CONCLUSIONES

- La cirugía debe seguir siendo el tratamiento de elección para los aneurismas de la ACM, salvo imponderables. La morbilidad quirúrgica es baja y los resultados de los pacientes están principalmente determinados por la presentación neurológica inicial. Un mal grado en la escala Hunt- Hess es a menudo una indicación de tratamiento endovascular, pero se debe considerar que los pacientes con aneurismas de la ACM a menudo se benefician de hemicraniectomía y evacuación del coágulo.
- La cirugía abierta consigue tratar la mayoría de aneurismas de ACM mediante técnicas de clipaje convencional, pero además amplía las posibilidades a otras técnicas no convencionales como la trombectomía /reconstrucción y el bypass/oclusión.
- La técnica de flash de fluorescencia proporciona la localización intraoperatoria rápida y fiable de la arteria receptora apropiada para el bypass cuando se necesita revascularización para un aneurisma de ACM distal. Esta técnica elimina la necesidad de una amplia disección profunda de las arterias eferentes y permite a un sitio receptor más superficial que hace la anastomosis más segura, más rápida y menos exigente desde el punto de vista técnico.
- El clipaje contralateral de aneurismas de ACM puede ser visto como una técnica menos invasiva en el tratamiento de aneurismas bilaterales que ahorra al paciente una segunda craneotomía. Este trabajo demuestra que la técnica es factible y segura. Esta técnica está indicada en pacientes con aneurismas de ACM contralaterales no rotos, con cuello simple, que proyecten inferior o anteriormente, que se asocian con segmentos M1 cortos y en pacientes de edad avanzada con cisuras de Silvio amplia debido a la atrofia cerebral asociada a la edad.

- Los resultados quirúrgicos de esta revisión pueden servir como el referente al que deben aspirar los resultados endovasculares antes de considerar la terapia endovascular como alternativa para estas lesiones.

VIII.- Bibliografía

VIII.- BIBLIOGRAFIA

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Abreviaturas

3D Tres Dimensiones

ACM Arteria Cerebral Media

ASD Angiografía por Sustracción Digital

ATC Angiografía por Tomografía Computerizada

ARM Angiografía por Resonancia Magnética

BRAT “Barrow Ruptured Aneurysms Trial”

HSA Hemorragia Subaracnoidea

ISAT “International Subarachnoid Aneurysm Trial”

LCR Liquido Cefalorraquídeo

MCA “Middle Cerebral Artery”

TOF “Time of Flight”

WEB Dispositivo “Woven EndoBridge”