Use of a split dura for revascularization of ischemic hemispheres in moyamoya disease

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MOYAMOYA disease is a clinical entity characterized primarily by angiographic findings of bilateral occlusion in the terminal portion of the internal carotid artery together with an abnormal vascular network at the base of the brain. The clinical presentation of moyamoya disease usually includes repeated transient ischemic attacks in children and intracranial hemorrhage in adults.11,12 Various operative procedures have been described for treating pediatric patients with moyamoya disease.4–6,8,14 All have proved to be more or less effective. In the indirect anastomosis procedures, such as encephaloduroarteriosynangiosis (EDAS)8 and encephaloarteriosynangiosis (EAS),7 branches of the scalp arteries, most often obtained from the superficial temporal artery (STA), are used as donor arteries. Therefore, the area of revascularization is limited to the anatomical distribution of these arteries. To increase the area of revascularization, other techniques, such as encephalomyosynangiosis (EMS)14 or omental transplantation,4 are usually combined with these procedures.

Dural arteries are potential donor arteries for cortical revascularization. The natural anastomosis between dural and cortical arteries is often observed in moyamoya disease in limited areas close to the cranial suture lines and skull base. However, a surgical technique involving the use of dural arteries for cortical revascularization has not been reported.

In this article, we present our experience using the dural arterial supply for cortical revascularization in cases of childhood moyamoya disease. The results of a histological examination and a biological assay of the dura are also presented.

Clinical Material and Methods

Eighteen children (< 15 years old at clinical presentation) with moyamoya disease were treated with the novel technique that we will describe herein. Their ages ranged from 2 to 12 years (mean 6 years). The patients were evaluated pre- and postoperatively by selective cerebral angiography, cerebral blood flow measurement using stable xenon computerized tomography, and magnetic resonance imaging. To determine the contribution of the scalp and meningeal arteries separately, superselective angiograms of the STA and the middle meningeal artery (MMA) were obtained using a Tracker 18 microcatheter (Target Therapeutics, San Jose, CA) for postoperative angiography. The follow-up periods ranged from 1 to 12 years (mean 6.5 years).
Surgical Technique

Our indirect revascularization procedure consists of EDAS and a new technique, split duroencephalosynangiosis. It was applied to 25 hemispheres in 18 patients.

The patient is placed supine, with the head turned to the side opposite to the surgeon and held on a head rest. The frontal and parietal branches of the STA are palpated and marked with a Doppler ultrasound probe. A skin incision is planned along the course of the parietal branch of the STA, beginning at a point 2 cm above the zygoma in front of the tragus and extending to a point 10 cm above the zygoma, then curving anteriorly to a point 2 cm lateral to the midline and at the hairline (Fig. 1A). The STA is exposed at its proximal portion and separated from the inner surface of the skin. A plane between the skin and the STA is created and an additional skin incision is continued superficially in this plane so as not to injure the STA. The galea is cut parallel to the STA at a distance of 5 mm, so that a strip of galea is attached to the artery over its entire exposed length. The STA is carefully dissected away and isolated from the fascia below, especially at the point at which the STA crosses the skin incision. Then the skin incision is extended to the frontal region. The skin flap is turned over a sponge to prevent ischemic compression. The temporal muscle is separated from the skull and retracted posteriorly with the STA strip. Three burr holes are made to begin the craniotomy, the first one under the proximal portion of the STA strip and the second one under the distal portion of the STA strip. The third one is located 2 cm lateral to the midline, just in front of the coronal suture. The craniotomy is performed by connecting these burr holes without injuring the dural arteries. A linear dural incision is made along the course of the STA, and the galeal cuffs of the STA strip are sutured to the edges of the dural incision with interrupted silk sutures to complete the EDAS.

The course of the dural arteries, especially that of the anterior and posterior branches of the MMA, is inspected thoroughly. An H-shaped linear incision is carefully made through only the outer layer of the dura (Fig. 1B). The outer layer of the dura is separated, or split, from the inner layer and turned over (Fig. 1C). The inner layers are folded into the subdural space (Fig. 1D). The outer layers are closed with interrupted silk sutures, so that the internal surface of the outer layer is attached to the cortical surface (Fig. 1E). Bleeding from the dural incision or separation is controlled with oxycellulose and minimal use of bipolar coagulation. This procedure is conducted near the anterior and posterior branches of the MMA.

Histological Examination and Biological Assay for Angiogenesis

A small piece (5 x 30 mm) of dura was resected from the edge of the dural incision in the EDAS procedure. The
Dural defect was patched with the STA strip by suturing the galeal cuffs of the STA strip to the edges of the dura. The specimen was divided into two pieces; one was subjected to hematoxylin and eosin staining and the other to a biological assay to determine angiogenesis. Angiogenic activity was determined by means of the chorioallantoic membrane (CAM) assay. A comparison was then made between the angiogenic activity of the internal surface of the dura (the natural interface with the cortical surface) and that of the split surface, which was exposed by separation of the inner and outer layers. Fresh dural specimens were obtained from three cases. Each specimen was cut into 3 × 3-mm pieces (six pieces), which were separated into inner and outer layers. The internal surface of the inner layer or the split surface of the outer layer was placed on the chorioallantoic membranes of white leghorn chicken eggs 10 days after incubation. The eggs were incubated for an additional 3 days, following which the degree of angiogenesis was evaluated by counting the number of new vessels formed in the specimen. Statistical analysis was performed using Student's t-test. A probability value of less than 0.05 was considered significant.

Results

Clinical Outcome

Transient ischemic attacks disappeared in 85% of the cases by 1 year postsurgery and in all cases by 1.5 years. Surgical morbidity consisted of a reversible ischemic neurological deficit in three, delayed wound healing in one, and a worsening neurological deficit in one of the 25 procedures. Follow-up data (mean follow-up period 6.5 years) were obtained for 16 of the 18 patients in the outpatient clinic. Thirteen patients were leading normal lives, either attending regular schools or living independently after graduation. Three patients were mildly handicapped because of mental retardation that existed preoperatively.

Postoperative angiograms showed excellent filling of the cortical arteries through the external carotid arterial system in all cases. Superselective angiograms demonstrated revascularization of different cortical areas through the MMA and STA (Fig. 2). The STA primarily supplied the central and parietal areas (Fig. 2 left), whereas the anterior and posterior branches of the MMA supplied the areas anterior and posterior to the area supplied by the STA (Fig. 2 right), respectively.

Histological Examination and Biological Assay for Angiogenesis

Histological examination of the dura from a patient with moyamoya disease showed that the number of small blood vessels was increased in the outer layer (Fig. 3). The CAM assay demonstrated that the split surface showed significantly higher angiogenic activity than the internal surface of the dura in all examined cases (Table 1).

Discussion

Microscopically, the dura mater consists of three layers: the periosteal, meningeal, and dural border-cell layers. The periosteal, or outer layer, has fewer fibroblasts and more extracellular collagen, whereas the meningeal, or inner layer, has more fibroblasts and less collagen. The dural border-cell layer forms a transitional zone between the dura and arachnoid. The outer layer contains blood vessels and nerves. Hoshimaru, et al., reported that increased immunoreactivity of basic fibroblast growth factor (bFGF) was seen in the dural blood vessels in moyamoya disease. The expression of a larger amount of bFGF in vascular cells in the dura may induce abundant neovascularization in the external layer of the dura in cases of moyamoya disease. This neovascularization in the outer layer, however, does not extend across the inner layer to the cortical surface.

Greater angiogenic activity in the split surface of the outer layer was demonstrated by our CAM assay (Table 1). In our surgical procedure, the dura is separated into
Split duroencephalosynangiosis

<table>
<thead>
<tr>
<th>Patient Age (yrs), Sex</th>
<th>Internal Surface of Inner Layer of Dura</th>
<th>Split Surface of Outer Layer of Dura</th>
</tr>
</thead>
<tbody>
<tr>
<td>9, F</td>
<td>8.5 ± 1.0</td>
<td>39.3 ± 1.5‡</td>
</tr>
<tr>
<td>10, M</td>
<td>5.7 ± 2.1</td>
<td>11.7 ± 1.5‡</td>
</tr>
<tr>
<td>12, M</td>
<td>6.3 ± 2.2</td>
<td>22.3 ± 1.5‡</td>
</tr>
</tbody>
</table>

* Values are expressed as means ± standard deviation.
† p < 0.01. ‡ p < 0.05.

Conclusions

We have described a new technique of indirect revascularization using dural arteries as donor arteries for use in cases of pediatric moyamoya disease. In our procedure the dura was split into outer and inner layers, and the split surface of the outer layer was attached to the cortical surface. Postoperative superselective angiograms demonstrated effective cortical revascularization through the dural arteries. The outer layer contained more blood vessels and exhibited a greater angiogenic activity, which was demonstrated by the CAM assay.

Split duroencephalosynangiosis is an effective procedure for revascularizing the ischemic cortex. It is a useful addition to standard techniques such as EDAS for extending the area of revascularization over ischemic hemispheres in cases of moyamoya disease.

References


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