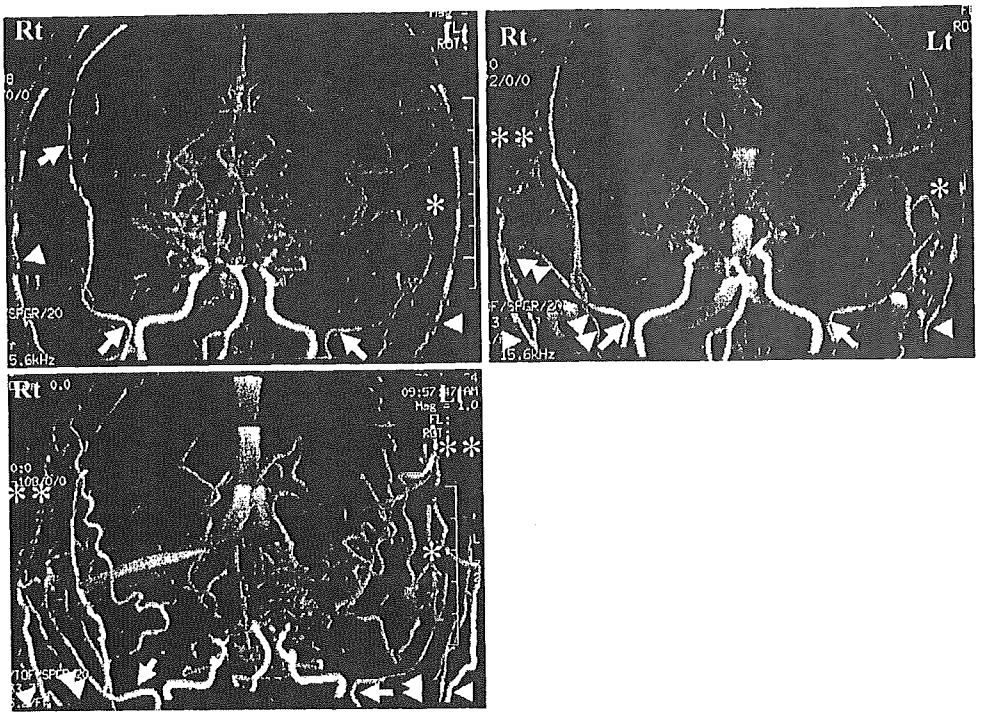


Fig. 1. Case 9. Anterior-posterior projection MRA of a 42-year-old woman who underwent bilateral STA-MCA anastomosis. Preoperative MRA showed bilateral stage 3 moyamoya diseases, STAs, middle meningeal arteries, and naturally transudural anastomosis of left side (upper row, left). MRA 2 weeks after right side surgery showed DTA and anastomosis of operated site (upper row, right). MRA 2 months after left side surgery showed anastomosis and dilatation of ECA tributaries of left side (lower row). Arrow indicates MMA; single arrowhead, STA; double arrowhead, DTA; asterisk, natural anastomosis; double asterisks, surgical anastomosis.

system were also verified using MRA in all treated hemispheres both STA-MCA anastomosis (Fig. 1) and EDAS (Fig. 2). In STA-MCA anastomosis cases, there was no difference of the visualization ability of MRA on the ECA tributaries before and after surgery and between ECA tributaries.

The mean periods of newly detected ECA tributaries and anastomosis after 6 of 7 STA-MCA anastomosis cases (7 sides) were as follows: STA 7.7, DTA 68, and MMA 90.6 days with significant differences between STA and MMA/DTA ($P < .01$ vs MMA and DTA) (Table 3). Two patients (cases 11 and 14) showed immediate dilatation of these vessels within 12 hours after surgery while studying the cause of perioperative TIA (Fig. 3).

4. Discussion

Most radical studies for moyamoya disease have focused on cerebral blood flow with contrast-enhanced MRA or dynamic MRA in combination with single photon emission computed tomography or positron emission tomography, and few reports have evaluated the ECA system with MRA [1,13,14,16]. Follow-up images of this disease have also been reported in various fashions [1-7,9-12,14-16]. DSA has been the "gold standard" of postoperative imaging. However, conventional DSA is costly, time consuming, and invasive, with a risk of complications [10,16]. Therefore, less invasive modalities such as direct palpation of STA, Doppler ultrasound, magnetic resonance imaging, and MRA have been usually used for postoperative evaluation. Although 3-dimensional–computed tomography angiography is less invasive and less time consuming than DSA, it is still invasive because contrast medium is required [7].

On MRA evaluation, the phase contrast method or time-of-flight with MIP reconstruction was recommended to check flow direction, patency, or flow intensity of vessels [13]. Among them, MRA is widely used to get a short acquisition time. In the present study, short MRA processing time prevented poor imaging caused by restlessness or body movement of patients, especially seen in children. It has been reported that it takes 3 to 6 months or more to develop newly formed collateral vessels after surgery [3-5,7,15]. Houkin et al [3,4] studied the change in ECA system after indirect bypass using DSA, and they also emphasized that not only STA and MMA but also DTA participated importantly in the formation of collateral circulation. They recently reported a prospective follow-up of infant moyamoya disease by MRA after direct bypass surgery, and reported that the decrease of moyamoya vessels and the development of STA were observed 1 month after the surgery. Development of DTA and MMA was observed 3 months after the surgery with reciprocal relation to

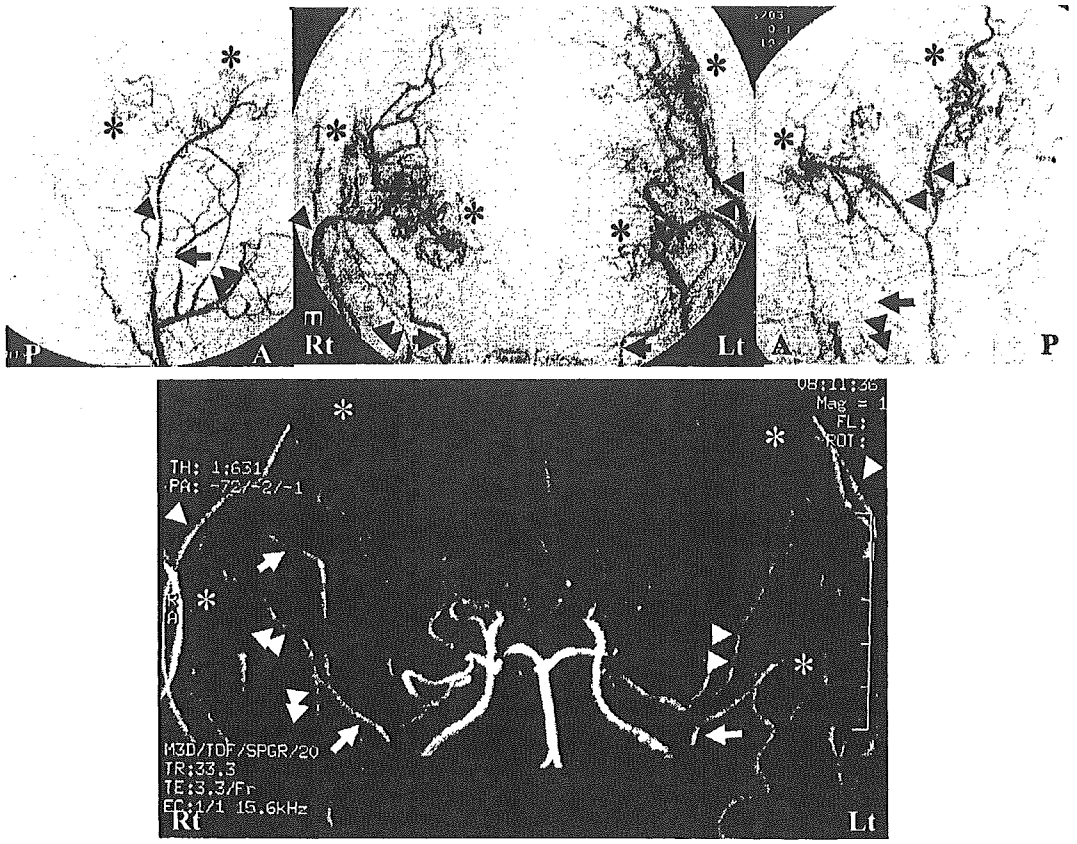
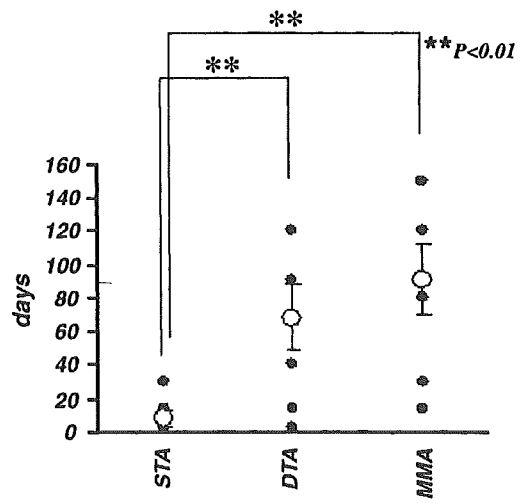


Fig. 2. Case 7. Follow up MRA and DSA at 4 years after bilateral EDAS of a 42-year-old man. DSA of anterior-posterior projection (upper row, middle left and right) and lateral projection (left: upper row right; right: upper row, left) showed well-developed bilateral STA (arrowhead) and anastomoses (asterisks). MRA (lower row) showed middle meningeal arteries (arrows), deep temporal arteries (double arrowheads), dilated STA (double arrows), and anastomoses (asterisks).

neovascularization [5]. In the present study, this dilatation of STA and DTA were detected earlier than their report (day 0 in 1 patient and day 2 in 1 patient, Fig. 1). The dilatation of DTA was well detected in addition to STA and MMA dilatations 2 weeks to 3 months after surgery [3]. But it may depend on when follow-up study is performed, and further study is needed to assess the exact time of collateral circulation establishment.

Table 3
Postoperative development of ECA tributaries of 6 patients treated with direct anastomosis



Fat suppression resulted in better visualization of STA and DTA compared with ordinary MRA in the present series. We introduced specific resonance frequency for fat before acquisition of MRA signal and succeeded with the hyper–fat-suppression effect, avoiding the diffuse flow of vessels by shorter echo time (3.3 milliseconds). Fat-suppressed MRA could eliminate the artifact by a subcutaneous fat pad, but children cases may not benefit from this technique because of their thin subcutaneous fat tissues. Therefore, the indication of this method may be controversial in children.

On the evaluation of moyamoya disease by MRA, the overestimation of stenotic lesions and underestimation of moyamoya vessels have been the main problems and sources of controversy [8,10]. MRA may diminish small vessels less than 1 mm, and artifacts caused by air in sphenoid or other paranasal sinuses obscure internal carotid arteries or ECA system. But in the present study, ECA tributaries visualization was not disturbed. We also found that occipital arteries

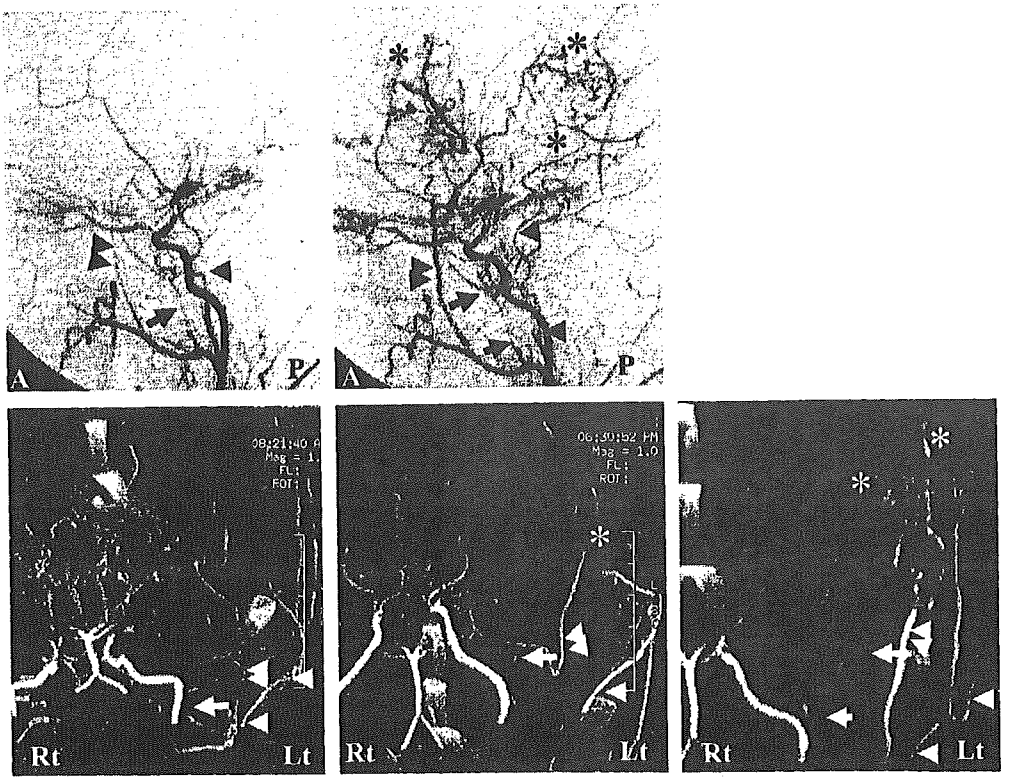


Fig. 3. Case 14. DSA and MRA of a 34-year-old woman who underwent left STA-MCA anastomosis. Preoperative left DSA of lateral projection showed stage 3 moyamoya vessels and 3 ECA tributaries (DSA: upper row, left; MRA: lower row, left). Postoperative DSA of same projection 2 months after bypass surgery (upper row, right) showed well-developed collaterals from operated sites, in particular, (double arrowheads) well-developed DTA. MRA on the same day of surgery (lower row, center) and 4 months after surgery (lower row, right) also showed that MRA could show these ECA tributaries perioperative period. Newly formed vessels (asterisks) already appeared on 4 months after surgery. Arrow indicates MMA.

were well visualized, and they sometimes hid those vessels from anterior-posterior projection. In addition to these problems, precise anatomic comprehension is needed to avoid misdiagnosis because DTA usually locates between MMA and STA.

5. Conclusion

MRA is useful for moyamoya disease follow-up, and from the neurosurgical point of view, it is also useful to detect STA dilatation and newly formed vessels from temporalis muscle and dura mater after bypass surgery.

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