Therapeutic Modulation of Cerebral Microhemorrhage in a Mouse Model of Cerebral Amyloid Angiopathy

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Background and Purpose—The aging brain demonstrates frequent MRI and pathological evidence of cerebral microbleeds, which are often associated with cerebral amyloid angiopathy. To develop new therapeutic strategies for this disorder, we studied cerebral microhemorrhage in a well-characterized mouse model of cerebral amyloid angiopathy.

Methods—Tg2576 mice were studied at ages ranging from 2 to 21 months. Spontaneous and induced microscopic bleeds were analyzed with and without a passive anti-amyloid immunization regimen and dietary supplementation of ischemic stroke prevention medication dipyridamole.

Results—Areas of microhemorrhage were easily demonstrated and were significantly more prominent in the oldest mice and in animals treated with anti-amyloid immunotherapy. Dipyridamole supplementation in the diet generated plasma levels >790 ng/mL within the range seen clinically. Dipyridamole treatment did not worsen frequency and size of cerebral microscopic bleeding.

Conclusions—The Tg2576 mouse is a useful model to study progression and modification of spontaneous and immunotherapy-induced cerebral microhemorrhage. Absence of microhemorrhage worsening with dipyridamole treatment suggests a potential therapeutic role of this agent when ischemic and microhemorrhagic lesions coexist. (Stroke. 2011;42:00-00.)

Key Words: Alzheimer amyloid angiopathy animal models antiplatelet drugs basic science experimental intracerebral hemorrhage microcirculation
value in the clinical efforts directed against mixed cerebrovascular disease.

Methods

All animal studies were performed in accordance with Institutional Animal Care and Use Committee-approved protocols at the University of California Irvine.

Animals and Treatment Protocols

Experiment 1

To determine achievable plasma levels with dipyridamole supplementation, 2-month-old female Tg2576 mice (n=6; University of California Irvine, Irvine CA) were treated with a dipyridamole-supplemented high-fat diet (HFD, 40% fat, 40% carbohydrate, and 20% protein with dipyridamole 5 g/kg chow) for 2 weeks. Age-matched female wild-type littersmates were used as controls. HFD was used due to poor oral intake by mice when bitter-tasting dipyridamole was incorporated into a standard diet.

Experiment 2

Twelve-month-old female Tg2576 mice were divided into 2 groups: (1) Tg2576-control (Control) mice (n=9) fed HFD; and (2) Tg2576+dipyridamole mice (n=11) fed HFD supplemented with dipyridamole (5 g/kg of chow). Animals were treated for 3 months.

Experiment 3

Twenty-one-month-old Tg2576 were divided into 4 groups: (1) Tg2576-control mice (n=9) fed HFD; (2) Tg2576+dipyridamole mice (n=11) fed HFD supplemented with dipyridamole (5 g/kg of chow); (3) Tg2576 mice (n=9) on HFD were treated with anti-Ab40 antibodies clone 1313 (10 mg/kg, intraperitoneally, weekly; Abody); and (4) Tg2576+dipyridamole mice (n=9) treated with anti-Ab40 antibodies clone 1313 (10 mg/kg, intraperitoneally, weekly; dipyridamole+Abody). There were 2 males with 7 or 9 female mice in each of the 4 groups. Mice were pretreated with the diets for 2 weeks before the antibody injections, which continued for 9 weeks together with the diet supplement.

Behavioral Test and Blood Pressure Monitoring

Cognition was assessed at end of treatment using the Novel Object Recognition task as described.1 Blood pressure was assessed noninvasively in conscious restrained mice by the tail cuff technique using the CODA System (Kent Scientific) for 3 days at the end of the experiment.

Immunohistochemistry

Phosphate-buffered saline perfused 4% paraformaldehyde-fixed brain sections were immunostained for Ab using 6E10 and 4G8 mouse monoclonal antibodies (Signet Laboratories, Dedham, MA) at 1:1000 dilution, as previously described.1,2

Hemorrhage Detection

Determination of hemorrhages was performed using Prussian blue staining of ferric acid, as previously described.2 Coronal sections of experimental and control mouse brains were collected from 3 different planes of the brain (approximately 2.5 mm apart). The sections were mounted on Superfrost Plus microscopic slides (Fisher Scientific, Pittsburgh, PA). Staining was performed using Prussian blue solution: freshly made 5% potassium hexacyanoferrate tribdate and 5% hydrochloric acid (Sigma, St Louis, MO). Thirty minutes later, sections were rinsed in water and counterstained with Nuclear Fast Red (Sigma), dehydrated, and covered using DPX (BDH Laboratory Supplies). Hemorrhage profiles were counted by 3 independent observers using an Olympus BX40 microscope at 20× original magnification. For each brain section, the average number and size of Prussian blue-positive deposits were calculated. We used a scale of 1 to 4 to determine the size of microhemorrhage, in which 1 was 1 to 5 grains of iron or small microvessel involvement; 2 was multiple grains of iron and microvessel involvement; 3 was several positive microvessels in 1 area; and 4 was large blood vessel involvement. Results were averaged between investigators and presented as a mean±SEM.

Beta-Amyloid Enzyme-Linked Immunosorbent Assay

Enzyme-linked immunosorbent assay of detergent-soluble and 70% formic acid-soluble Ab brain fractions was performed using our established assay, as previously described.1,2

Statistical Analysis

All data are expressed as mean±SEM. The statistical evaluation was carried out using Student t test or analysis of variance. After significant analyses of variance, multiple post hoc comparisons were performed using the Bonferroni test.

Results

Tg2576 mice showed progressive accumulation of microhemorrhages with aging, which ranged from 1.76±0.25 microhemorrhages per brain section in 15-month-old mice to 4.54±0.6 microhemorrhages in 24-month-old animals (Figure 1A). The average size of spontaneous microhemorrhage also significantly increased with age (Figure 1B). Dipyridamole supplementation in a HFD was well-tolerated by mice. After 2 weeks, plasma levels of dipyridamole reached 794±246 ng/mL and 793±97 ng/mL in wild-type and Tg2576 mice, respectively. We then studied the effects of 3 months of dipyridamole-supplemented diet on blood pressure, object recognition, and Ab40 and Ab42 in 15-month-old mice. In these studies, there were no effects of dipyridamole on novel object recognition, blood pressure, and Ab40 and Ab42 levels (data not shown). The latter were measured in both detergent-soluble and detergent-insoluble brain fractions. In addition, there was no significant difference in spontaneous microhemorrhage size or number observed in mice receiving a dipyridamole-supplemented diet (Figure 2). There was also no significant difference in microhemorrhage size and number between animals fed a HFD and animals (N=9) fed a standard (10% fat, 70% carbohydrate, and 20% protein) diet for 3 months (data not shown).

Finally, we studied the effects of 11 weeks of a dipyridamole-supplemented diet on aged (21 months old) mice with and without passive immunization to Ab40. The latter was achieved by 9 weekly injections beginning 2 weeks after the start of the experiments. There were no significant effects of
Dipyridamole on novel object recognition and biochemical levels of \( \text{A/}\text{H}9252\text{40} \) and \( \text{A/}\text{H}9252\text{42} \), and there were no significant male–female differences in dipyridamole effects (data not shown). There was a significant increase in the number and size of microhemorrhages in antibody-treated mice on the control diet (Figure 3). Antibody-treated mice fed a dipyridamole-supplemented diet demonstrated a significant increase in number, but not size, of microhemorrhages (Figure 3).

**Discussion**

Cerebral microscopic bleeding was easily demonstrable in this transgenic mouse model of cerebral amyloid angiopathy with microhemorrhages more than twice as frequent in elderly compared with younger adult mice. These microhemorrhages tended to be exacerbated by our passive immunotherapy regimen. Treatment with dipyridamole did not worsen microhemorrhages, and the significantly increased microhemorrhage size of immunized mice was not seen after dipyridamole treatment. Plasma dipyridamole levels achievable were within the range encountered clinically, 0.5 to 2.0 \( \mu \text{g/mL} \).\(^{13}\)

The \( \text{Tg2576} \) mouse expresses mutant amyloid precursor protein from which pathogenic \( \beta \)-amyloid fragments 1-40 and 1-42 are easily generated.\(^{7}\) \( \text{Tg2576} \) is characterized by predictable progression of band-like vascular amyloid deposits in leptomeningeal and cortical arteries and arterioles, notable by age 12 months.\(^{14,15}\) Immunotherapy directed at \( \beta \)-amyloid fragments tends to lessen parenchymal \( \beta \)-amyloid but may worsen vascular amyloid deposition and exacerbate microhemorrhages, perhaps by direct antibody targeting of vascular wall.\(^{9,16}\)

The relative ease of demonstrating cerebral microhemorrhages makes the \( \text{Tg2576} \) mouse an attractive model to study progression and treatment of these lesions. The latter issue is of particular importance where there is coexistence of ischemic and microhemorrhagic lesions, the typical picture of mixed cerebrovascular disease.\(^{6}\) Use of platelet agents, particularly aspirin, has been associated with a higher prevalence of microbleeds on MRI\(^{17}\) and increased risk of intracerebral hemorrhage in patients with cerebral amyloid angiopathy.\(^{18}\)

Dipyridamole, shown to be effective as monotherapy for prevention of ischemic stroke,\(^{10}\) has therapeutic actions largely directed at the vessel wall rather than platelets alone\(^{19}\); these vessel wall effects include vasodilation through cGMP potentiation, antioxidant and anti-inflammatory actions, and enhancement of endothelial nitric oxide.\(^{19}\) Moreover, acute treatment with dipyridamole at the time of reperfusion tends to reduce hemorrhagic conversion of ischemic stroke in a rodent model of experimental stroke.\(^{20}\)

**Figure 2.** Dipyridamole diet (5 g/kg of chow) does not affect the number (A) nor the size (B) of spontaneous microhemorrhages in 15-month-old \( \text{Tg2576} \) mice receiving 3 months of dipyridamole (DIP).

**Figure 3.** Immunotherapy effects on number (A) and size (B) of microhemorrhages. Twenty-one-month-old mice were treated for 11 weeks with a control (high fat) diet or with a diet supplemented with dipyridamole (DIP; 5 g/kg chow). Two weeks after initiation of the diet, mice were given anti-A\( \beta \)40 antibody (Abody, 10 mg/kg, intraperitoneally, weekly for 9 weeks). After immunotherapy, a significantly increased number of microhemorrhages was seen in both antibody-treated groups. Microhemorrhage size after immunotherapy was significantly increased with the control diet only. Representative photomicrographs were taken from the cortex (C). Magnification \( \times 100 \). **\(^{2}\)P<0.01; *\(^{2}\)P<0.05.
are limited by a lack of aspirin treatment arm. Nevertheless, absence of microhemorrhage worsening with dipyridamole treatment in this model suggests a potential role for this agent in patients with coexisting ischemic and microhemorrhagic disease.

Acknowledgments
We thank Dr Wolfgang Eisert for assistance.

Sources of Funding
Supported by National Institutes of Health (NIH) NS20989 (M.F.), NIH AG020241 (D.H.C.), NIH AG00538 (D.H.C.), Alzheimer’s Association grant IIRG 91822 (D.H.C.) NIH summer student fellowship GM-69337 (C.V.), and a research grant from Boehringer-Ingelheim (M.F., D.H.C.). Aβ peptides and anti-Aβ monoclonal antibodies were provided by the UCI Alzheimer’s Disease Research Center funded by NIH P50AG16573.

Disclosures
M.F. has received support from Boehringer-Ingelheim (research grant and honoraria) and Otsuka Pharmaceutical Company (research grant and honoraria). D.H.C. has received grants, speakers’ bureau, honoraria) and Otsuka Pharmaceutical. M.F. has received support from Boehringer-Ingelheim (research grant).

References
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Stroke. published online September 8, 2011;
Stroke is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 0039-2499. Online ISSN: 1524-4628

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://stroke.ahajournals.org/content/early/2011/09/08/STROKEAHA.111.626655

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