On Ischemic Brain Injury in Genetically Altered Mice

In recent years, genetically altered mice, either overexpressing or deficient in specific gene products, have come to play a vital role in experimental studies designed to probe the molecular pathophysiology of ischemic brain injury. More than 100 such studies have been reported to date, and notable successes have been achieved in elucidating the roles of the neuronal, \( \text{1,2} \) endothelial, \( \text{3} \) and inducible \( \text{4,5} \) isoforms of nitric oxide synthase and of the cytosolic (CuZn) \( \text{6-8} \) and mitochondrial (Mn) forms \( \text{9-11} \) of the antioxidant-defense enzyme superoxide dismutase in brain ischemia. Other studies of cerebral ischemia have used mutant mice to assess altered glutamate-receptor subunit composition, \( \text{12-13} \) vascular adhesion molecules, \( \text{14-19} \) gene products related to nuclear factors and early-response genes, \( \text{24-27} \) cytokines, \( \text{28,29} \) and apolipoprotein E. \( \text{30,31} \)

Experimental studies of cerebral ischemia are fraught with pitfalls, however, and this is particularly the case in studies comparing the responses of wild-type and mutant mice, in which it becomes essential that mice of all groups be bred on a similar genetic background. The importance of rigorous control of genetic background in mutant mouse studies has been emphasized repeatedly in recent publications. \( \text{32,33} \) Elsewhere in this issue, Tabrizi and coworkers \( \text{34} \) confront this problem in a careful study designed to assess whether endogenous tissue plasminogen activator (tPA), in fact, is beneficial or detrimental in focal cerebral ischemia. An impetus to their study is the recent report of Wang et al. \( \text{35} \) which purported to demonstrate that mice deficient in tPA exhibited 50% smaller cerebral infarcts than did wild-type mice. As noted by Tabrizi et al. \( \text{34} \) however, interpretation of that study was complicated by the fact that it compared C57BL/6 wild-type mice against mixed-strain (129/Sv and C57BL/6) tPA-deficient animals. In the present study, Tabrizi et al. \( \text{34} \) show that C57BL/6 wild-type mice develop almost 10-fold larger infarcts than do mixed 129/Sv–C57BL/6 wild-type mice after middle cerebral artery (MCA) occlusion. By using genetically matched mixed-strain (129/Sv–C57BL/6) mice to compare tPA-deficient and wild-type animals and by the use of a nonsiliconized filament (which promotes thrombosis), Tabrizi et al. \( \text{34} \) convincingly demonstrate that endogenous tPA deficiency in fact \textit{exacerbates} the consequences of focal cerebrovascular occlusion by encouraging vascular fibrin deposition, enhancing ischemia-induced brain blood-flow decrements, and increasing the volume of the resulting brain infarct compared with wild-type animals. These results tend to vindicate tPA by alleviating the potential concerns raised by the earlier study \( \text{35} \) and by demonstrating that endogenous tPA likely protects the ischemic brain by promoting thrombolysis. Nonetheless, points of confusion remain, in that Tabrizi et al. \( \text{34} \) do not precisely explain what they mean by a “matched mixed 129/Sv and C57BL/6 genetic background” in their study. Were their tPA \(-/-\) and tPA \(+/+\) animals, in fact, genetically identical except for the mutant allele? Or was there animal-to-animal variation in the extent of contribution of the genes from each genome? These issues deserve clarification.

Of interest, a recent experimental study designed to evaluate the putative neurotoxicity of exogenous tPA in standardized rat models of both global and focal cerebral ischemia has also convincingly shown that tPA administered at clinically relevant doses fails to exacerbate ischemic injury in either setting. \( \text{36} \) These studies exonerating tPA have considerable practical import, in that recombinant tPA (rtPA) administered to patients within 3 hours of the onset of an ischemic stroke has recently been shown in an exemplary multicenter trial to improve neurological and functional outcome significantly, \( \text{37} \) and this pharmacological agent is now in routine clinical use as a therapy for acute ischemic stroke.

The report of Tabrizi et al. \( \text{34} \) also highlights a number of other issues crucial to the proper experimental study of brain ischemia. Precise monitoring and regulation of multiple physiological variables—notably blood pressure, arterial oxygenation, and pH, and systemic as well as brain temperatures—is essential to avoid the confounding influence of physiological variations (eg, brain temperature \( \text{38,39} \)) on the outcome of an ischemic insult. Consistency of experimental technique is also crucial in ensuring reproducible infarct volume in intraluminal filament-occlusion models of focal cerebral ischemia. We have shown in the rat that coating the filament with poly-L-lysine markedly enhances the reproducibility and consistency of the resulting cerebral infarct, presumably by strengthening the adherence of the occluding filament to the adjacent endothelial surface \( \text{40} \); and we have extended this method to the mouse. \( \text{41} \)

The concerns expressed above can be raised in respect to the recent study of Nagai et al. \( \text{42} \) who used an MCA permanent-ligation model to demonstrate that inactivation of the tPA gene led to significantly \textit{reduced} infarct size compared with that in wild-type mice. These workers, it should be noted, reported a 45% larger mean infarct volume in wild-type C57BL/6 mice than in S129 mice and an intermediate infarct size in mice with 50%/50% mixed wild-type backgrounds. However, they did not specify the genetic background of their tPA-knockout animals, and they did not
appear to monitor or control physiological variables (apart from body temperature).

In experimental models of focal cerebral ischemia, apparently “minor” differences in the extent of decline of local cerebral blood flow (CBF) may result, in fact, in major differences in infarct volume. By using pixel-based autodiagnostic and histopathological image-mapping strategies, our group has shown that the precise extent of local CBF decrement during a 2-hour period of MCA occlusion exquisitely determines the probability of histopathologic infarction at the same site 3 days later. Thus, regions having flow in the “ischemic core” range (ie, CBF 0% to 20% of control values) have a 96% probability of undergoing infarction. By contrast, tissue zones with only slightly higher ischemic CBF levels (30% to 40% of control) have only an 80% probability of infarction, and zones of still higher CBF are largely spared from infarction.

In the study reported in this issue, Tabrizi et al34 (Figure 2B) observed an important difference in relative CBF measured in their tPA20% of control values in tPA-deficient mice but remained measured at corresponding sites declined during ischemia to tPA mice, both during and after MCA occlusion. CBF2tPA patients with ischemic stroke.

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As the methods of molecular biology and genetics continue to be applied with increasing success to the study of ischemic brain injury, one expects not only an increasingly sophisticated understanding of pathophysiology but also major advances in the rational design and implementation of neuroprotective strategies that will be tested in the clinic and succeed, eventually, in diminishing death and disability in patients with ischemic stroke.

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References
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