The final step in the acceptance of a new medical hypothesis is often the approval of significant funding to investigate it. In the case of developmental programming (ie, the notion that the in utero environment determines susceptibility to many diseases later in life), this has recently come in the form of support by the US Congress for the National Children’s Study, a $3 billion project to follow the impact of environmental factors before, during, and after pregnancy on children up to the age of 25 years.1 This initiative will, no doubt, yield a wealth of correlative data and identify many new factors potentially affecting developmental programming.

Much of the concept underlying the National Children’s Study stems from the pioneering work of Barker and colleagues,2 whose epidemiological observation of increased cardiovascular risk in children with low birth weight has spurred a large number of retrospective studies during the past 30 years. Despite some conflicting results, most of these studies support the notion that reduced birth weight is indeed associated with increased hypertension, diabetes mellitus, and cardiovascular disease. However, the strong correlation between birth weight and duration of gestation, plus the fact that a short gestation also may be associated with cardiovascular risk,3 poses the question to what extent low birth weight is truly responsible. In this issue of Circulation, an article by Kaijser and coworkers4 at the Karolinska Institute in Stockholm provides a convincing answer.

By scanning 250 000 records of birth at 4 major delivery units in Sweden between 1925 and 1949, they identified a cohort of 6437 subjects, which included 2937 children born preterm (<37 weeks of gestation) and 2181 with a birth weight <2100 g for boys or <2100 g for girls. During the follow-up period (1987 to 2002), 617 of these subjects were treated for or died of ischemic heart disease. Statistical analysis of these prospectively collected data indicated a strong negative correlation between birth weight and duration of gestation as well as the fact that a short gestation associated with low birth weight is truly responsible. In this issue of Circulation, an article by Kaijser and coworkers4 at the Karolinska Institute in Stockholm provides a convincing answer.

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Only in reduced birth weight but more frequently in macrosomia. Even if the maternal conditions were to influence birth weight in a consistent manner, sibling competition leads to wide disparities in birth weight, complicating the search for the factors responsible for developmental programming and enhanced disease susceptibility in offspring. Finally, it is now well recognized that maternal overnutrition, not undernutrition, will be the main health threat in the coming decades. The call to shift the emphasis away from birth weight and to focus on specific maternal risk factors and outcome parameters contributing to cardiovascular disease is therefore growing louder. We also should keep in mind that correlative epidemiological studies cannot establish causal relationships. Now that the influence of developmental programming has been established beyond doubt and the translational need is becoming more urgent, we need to go beyond epidemiology and put greater emphasis on experimental models suitable to investigate the mechanisms and causal relationships.

In contrast to animal models of low birth weight, which have yielded inconsistent results, much progress has been made recently in modeling some maternal conditions enhancing atherosclerosis in human progeny such as maternal hypercholesterolemia. It has been established experimentally that maternal hypercholesterolemia and the ensuing increased oxidative stress not only accelerate atherosclerosis, as they do in humans, but also that they affect early predictors of cardiovascular disease in offspring such as arterial gene expression, endothelial function, and vascular reactivity. More important, multiple interventions in mothers have been shown to reduce or prevent this form of developmental programming. Programming by pregestational or gestational diabetes is more difficult to mimic, given the complexity of metabolic changes involved, and work on the role of maternal obesity and insulin resistance is only in its infancy. Increased inflammatory stress associated with these conditions, as well as with maternal hypercholesterolemia and smoking, is likely to be of central importance, as are immune mechanisms. Even mild inflammation may modulate immune responses in both the mother and fetus. In fact, evidence in animal models and humans indicates that maternal adaptive immunity programs B- or T-cell–dependent IgM responses in offspring. Maternal immunizations have already been shown to protect against postnatal atherogenesis, even in the absence of gestational hypercholesterolemia or hyperglycemia.
In addressing causal relationships, mechanisms, and preventive measures in experimental models, it is important to remember that maternal risk factors are not necessarily the same as those affecting the fetus. In addition to factors crossing the placental barrier by passive diffusion or active transport mechanisms (eg, maternal cholesterol), the placenta is both the target and a source of pathogenic factors reaching the fetus (the Figure). It can, for example, protect against or contribute to fetal oxidative stress induced by maternal hypercholesterolemia and/or vascular inflammation.\(^2\) The mechanisms shielding the placenta from recognition by the maternal immune system also may play a role in mediating inflammatory stress from mother to fetus. Another issue to be considered is the extent to which in utero programming is continued in the immediate postnatal period or during childhood. In humans, drastic changes in diet or exposure to environmental risk factors at birth are unlikely. We will therefore have to treat in utero programming, effects of lactation, and early postnatal programming as a single pathogenic entity.

The National Children’s Study will investigate some of the maternal conditions thought to enhance cardiovascular risk in offspring, in particular maternal diabetic conditions, oxidative stress, and inflammation, but it will focus on outcomes that are most prevalent in childhood such as diabetes mellitus, not on cardiovascular risk, which can only be extrapolated from the early consequences of developmental programming (the Figure).\(^3\) Even under the most optimistic conditions, it will not be feasible to carry out large-scale clinical trials for each putative maternal risk factor and to extend them to the onset of clinical manifestations. The contribution of the Barker hypothesis and the extensive epidemiological work validating it has been to prove, in principle, that developmental programming matters for cardiovascular disease. It is now time to complement human epidemiology by studies focusing on intervention and mechanistic studies in experimental models. This should enable us not only to elucidate the in utero programming mechanisms but also to identify potential new targets for prevention that go beyond the standard advice to treat preexisting maternal conditions. After all, interventions targeting developmental programming are most appealing because they may yield lifelong benefits yet involve very little risk for the fetus when effected before pregnancy.

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References

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