

ORIGINAL RESEARCH

Long-term Neurotoxic Effects of Early-life Exposure to Tetrachloroethylene-contaminated Drinking Water



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Abstract

BACKGROUND Tetrachloroethene (PCE) is a common environmental and occupational contaminant and an acknowledged neurotoxicant. From 1968 through 1983, widespread contamination of public drinking water supplies with PCE occurred in the Cape Cod region of Massachusetts. The source of the contamination was a vinyl liner applied to the inner surface of water distribution pipes.

OBJECTIVES A retrospective cohort study (the Cape Cod Health Study) was undertaken to examine possible health consequences of early-life exposure to PCE-contaminated drinking water. This review describes the study methods and findings regarding the effects of prenatal and childhood exposure on neurologic outcomes during early adulthood, including vision, neuropsychological functioning, brain structure, risky behaviors, and mental illness. The review also describes the strengths and challenges of conducting population-based epidemiologic research in this unique setting.

METHODS Participants were identified by cross-matching birth certificates and water system data. Information on health outcomes and confounding variables was collected from self-administered surveys ($n = 1689$), neuropsychological tests ($n = 63$), vision examinations ($n = 63$), and magnetic resonance imaging ($n = 42$). Early-life exposure to PCE was estimated using a leaching and transport model. The data analysis compared the occurrence of each health outcome among individuals with prenatal and early childhood PCE exposure to unexposed individuals while considering the effect of confounding variables.

FINDINGS The study found evidence that early-life exposure to PCE-contaminated drinking water has long-term neurotoxic effects. The strongest associations were seen with illicit drug use, bipolar disorder, and post-traumatic stress disorder. Key strengths of the study were availability of historical data on affected water systems, a relatively high exposure prevalence and wide range of exposure levels, and little confounding. Challenges arose mainly from the historical nature of the exposure assessments.

CONCLUSIONS The Cape Cod Health Study demonstrates how scientists can take advantage of unique “natural experiments” to learn about the health effects of environmental pollution. This body of work has improved our understanding of the long-term health effects of early-life exposure to this common environmental contaminant and will help risk assessors and policymakers ensure that drinking water supplies in the United States are safe for vulnerable populations.

KEY WORDS brain, drinking water, tetrachloroethylene, vulnerable populations

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INTRODUCTION

Tetrachloroethene (also called tetrachloroethylene, perchloroethylene, perc, or PCE) is a widely used solvent in dry cleaning, textile processing, and metal degreasing.¹ In the United States, approximately 1.5 million people are occupationally exposed each year.² Most use is in small, inadequately controlled work settings such as dry cleaning, automobile repair, and machine shops, making PCE a common drinking water contaminant from improper management and disposal.¹ US surveys of drinking water contaminants have found it in 11% of tested wells³ and 38% of surface water supplies.⁴ Thus, it is not surprising that detectable levels of PCE in biologic media were found in 77% of a general US population sample.⁵

Although the typical source for drinking water contamination with PCE is improper disposal, an unusual scenario for widespread contamination of drinking water supplies occurred in the Cape Cod region of Massachusetts. The interior surface of water mains produced between 1968 and 1980 contained a plastic liner intended to eliminate taste and odor problems plaguing asbestos-cement pipes carrying the very soft water in the Cape Cod region. The liner was sprayed as a slurry composed of vinyl resin (Piccotex,TM Johns-Manville Corporation, Denver, CO, USA) dissolved in PCE. Because PCE is volatile, it was assumed it would evaporate completely during the drying process.⁶ However, water samples taken in 1980 by the Massachusetts Department of Environment Protection (DEP) revealed that a substantial amount of PCE had remained in the liner and was leaching into the public drinking water supplies.⁶

A survey of local water departments indicated that approximately 660 miles of vinyl-lined asbestos-cement pipes (VL/AC) had been installed in 91 Massachusetts cities and towns.⁷ The largest portion was installed in the Cape Cod region due to substantial residential development. PCE levels found in water samples from affected pipes on Cape Cod ranged from 1.5 to 7750 $\mu\text{g/L}$ (ppb), depending on the rate of water flow.⁶

Digging up and replacing the VL/AC pipes was prohibitively expensive, so a program of flushing and bleeding the water distribution system was instituted in the most problematic areas. The objective was to reduce PCE levels below 40 $\mu\text{g/L}$, the suggested no-response level at the time.⁶ However, by the time these risk reduction measures were implemented, tens of thousands of residents had been drinking

PCE-contaminated water for up to 15 years. Monitoring now ensures that levels remain below the current maximum contaminant level of 5 $\mu\text{g/L}$.⁸

A few years after the PCE contamination was discovered, the Massachusetts Department of Public Health reported elevations in cancer incidence and mortality in the Cape Cod region.⁹ In response to concern about the possible relationship between the elevated cancer rates and pollution in the region, we undertook a case–control study to evaluate the carcinogenic potential of population exposure to air and water pollution, including PCE-contaminated drinking water.^{10,11}

After completing the cancer case–control studies, we initiated a new round of data collection for a retrospective birth-cohort study (the Cape Cod Health Study) to examine a more comprehensive array of possible health consequences of PCE exposure, particularly exposure early in life. The Cape Cod Health Study initially assessed the short-term effects of prenatal exposure to PCE-contaminated drinking water on reproductive outcomes, including low birth weight (BW),¹² prematurity,¹² miscarriage,¹³ stillbirth,¹⁴ and congenital anomalies.¹⁵ More recently, we extended the study to examine the long-term effects of both prenatal and childhood exposure on neurologic outcomes, including vision,¹⁶ neuropsychological functioning,¹⁷ brain structure,¹⁸ risky behaviors,¹⁹ and mental illness.²⁰ There is a dearth of information on long-term neurotoxic effects of early-life exposure despite well-established short-term effects among adults.¹ The purpose of this review is to describe the methods and findings from the Cape Cod Health Study as well as the strengths and challenges of conducting population-based epidemiologic research in this unique setting.

METHODS

Identification of Participants. Individuals born between 1969 and 1983 to women who lived in 1 of 8 Cape Cod towns with some VL/AC water pipes (Fig. 1) were eligible for enrollment in the birth cohort.¹⁹ Participants were identified as likely exposed or likely unexposed by cross-matching maternal address on birth certificates with information from local water companies on the location and installation year of the VL/AC pipes. We tentatively designated participants as “exposed” if their birth residence was either directly adjacent to a VL/AC pipe or adjacent to a pipe connected to a VL/AC pipe and the only possible water flow to the

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