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This perspectives article discusses the authors' views of the impacts of unconventional oil and gas extraction on animal health and food safety.

Increasing use of unconventional methods for oil and gas extraction, particularly in agricultural or residential areas, has raised concerns for human and animal health as well as for the safety of our food supply. Because of the complexity of the process, the variety of toxic chemicals that can potentially be introduced into the environment by multiple routes, and the difficulties inherent in definitively linking environmental pollution to specific illnesses, neither the safety of the process nor unassailable proof of harm has been established. Nevertheless strong associations between unconventional oil and gas operations and adverse health effects have been reported. Effective protection of public health requires policy based on nuanced approaches to risk management rather than requiring definitive proof for the lack of harm.

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PERSPECTIVE

Unconventional oil and gas extraction and animal health[†‡]

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The extraction of hydrocarbons from shale formations using horizontal drilling with high volume hydraulic fracturing (unconventional shale gas and tight oil extraction), while derived from methods that have been used for decades, is a relatively new innovation that was introduced first in the United States and has more recently spread worldwide. Although this has led to the availability of new sources of fossil fuels for domestic consumption and export, important issues have been raised concerning the safety of the process relative to public health, animal health, and our food supply. Because of the multiple toxicants used and generated, and because of the complexity of the drilling, hydraulic fracturing, and completion processes including associated infrastructure such as pipelines, compressor stations and processing plants, impacts on the health of humans and animals are difficult to assess definitively. We discuss here findings concerning the safety of unconventional oil and gas extraction from the perspectives of public health, veterinary medicine, and food safety.

Introduction

With the decreasing supplies of conventional oil and gas, the energy industry has, in recent years, promoted the extraction of hydrocarbons from increasingly challenging formations.[1, 2] The best known of these controversial processes are the extraction of shale gas and tight oil using horizontal drilling with high volume hydraulic fracturing and the energy-intensive extraction of hydrocarbons from oil sands. Although one cannot ignore the drastic environmental consequences of the oil sands operations and the associated pipelines, we have been largely concerned with the health impacts of unconventional gas and oil extraction from shale formations. The extraction of hydrocarbons from shale layers has opened up vast tracks of land throughout the world to this industrialized process,[3, 4] and of particular concern are areas of high population density and farmland. Since the shale gas and tight oil revolution started in North America, we have more information on the impacts in the United States and, to a lesser extent, Canada, but lessons learned can be applied to the expansion of unconventional hydrocarbon extraction into other regions of the globe.

The introduction of hydrocarbon extraction using high volume hydraulic fracturing and horizontal drilling has industrialized the landscape in areas of the United States, such has North Dakota and Southwestern and Northeastern Pennsylvania, that were largely agricultural.[5-7] Drilling has brought an influx of workers, traffic and large quantities of toxic chemicals into farming communities[8] that produce food that is then distributed widely. This has brought the potential for contamination of water, air and the food supply by drilling chemicals and substances extracted from ancient shale layers (organic compounds, heavy metals, radioactive substances, bacteria, archaea, *etc*.). The question we are asking is to what extent is this a health issue for animals and people living in shale gas and tight oil regions and to what extent can this affect our food supply. Answers are surprisingly difficult to obtain for reasons discussed below.

Human and Animal Health

Understanding the health impact of industrial activity in the midst of human and animal habitation or a new disease can be approached initially by descriptive epidemiology, that is the phase during which a potential problem is described using case studies and hypotheses generated. This can be followed by more quantitative epidemiological studies to test hypotheses and determine prevalence, and toxicological studies to determine the source of the problem and its impact on biological systems. Ideally this might be a point source of pollution due to a single toxic compound that has a defined and well-documented route of exposure and subsequent health consequence. The celebrated case of Erin Brockovich and Edward Masry, who exposed the release of hexavalent chromium from the Hinkley Compressor Station near San Francisco, is a good example.[9] In the case of unconventional hydrocarbon extraction, none of these conditions exist. In a typical intensively drilled shale gas area, multiple wells are present in close proximity, with pipelines, compressor stations, and processing plants in the area. The identities of potential toxicants are not well defined nor are the routes of exposure (air, water, soil, food, etc.). To add to this, humans and animals may well be exposed to multiple toxicants from multiple routes and sources of exposure, the concentrations of which vary over time. Furthermore preexisting pollution has rarely been characterized, so that teasing out the health effects of widespread industrialized gas extraction from, for example, the widespread effects of coal mining in Pennsylvania is a difficult task. Neither can all of the environmental health impacts near shale gas operations be ascribed to this activity nor can we dismiss any impact simply because the possibility exists that another source of pollution may be the culprit. While uncertainty will always be present, it is possible to generate evidence sufficient to begin to assess risk.

One can approach the question of health risk by testing for environmental toxicants or by studying changes in health parameters following the introduction of unconventional hydrocarbon extraction. Environmental testing suffers from many drawbacks and is often controversial. As noted above, the identity of chemicals that could impact health are not always well understood. This goes far beyond the simple after-the-fact, voluntary disclosure of some of the chemicals used in drilling (FracFocus.org); perhaps as much or more of a concern are the substances released from the shale layers and the changes in chemical composition of drilling fluids due to chemical reactions within the well. In many, but not all, cases, testing is done on a sample collected at a single time point (water sample or grab sample of air), despite the fact that toxicant levels can vary over time, particularly in the case of air contamination. A more realistic measure of the toxicant load for any individual (human or animal) is an integrated measure taken over a time scale that is long relative to the fluctuations in concentrations of toxicants. This is largely an unknown, so the best one can do is collect integrated samples over many days and then assess contaminant levels. Examples of this are the passive sampling devices that have been successfully used to characterize exposure to PAHs (polycyclic aromatic hydrocarbons) and other compounds following the Gulf of Mexico oil spill[10] and a Superfund site on the Willamette River, Portland, Oregon.[11] An alternative approach is to use a biological integration device, such as a living human body or a living cow body.

A large study using passive air monitors in conventional oil and gas production areas of western Canada was done to understand the effects of emissions on beef cattle health and reproduction.[12-15] An increased risk of calf mortality was associated with exposure of dams to sulfur dioxide during the last three months of gestation, and there was an increased occurrence of degeneration and necrosis in the skeletal and heart muscle of necropsied calves with increasing exposure to sulfur dioxide.[12] These researchers noted that increasing exposures of volatile organic compounds (VOCs) measured as benzene and toluene were associated with an increase in respiratory lesions in live-born calves,[12] and that as calves aged, there was an increased risk of respiratory lesions associated with increasing exposures to benzene.[14] Dams exposed to increasing VOCs measured as benzene and toluene produced neonatal calves with significantly reduced CD4 T-lymphocyte counts,[13] and the CD8 T-lymphocyte counts in these calves were likewise affected in association with exposure of the dams to increasing VOCs measured as toluene.[13] A similar chronic effect was noted in the immune system of yearling beef cattle: a significant reduction in CD4 T-lymphocyte counts associated with increasing VOCs measured as toluene.[15]

Health studies of unconventional oil and gas extraction have only recently been reported. Using descriptive epidemiology, we reported twenty-four cases of companion and food animal illnesses associated spatially and temporally with drilling operations.[16] These were not randomly selected cases, but an investigation of cases that had suspected impacts due to nearby drilling activity. In several cases, the cow herds were separated and kept on different pastures that inadvertently had different degrees of exposure to chemicals associated with the gas well (either due to wastewater leaks, illegal dumping or well contamination). Those animals exposed to the drilling chemicals were far more likely to experience reproductive failure, stillbirths, and sudden death. Overall, reproductive problems were most commonly reported in temporal and spatial association with gas drilling operations both for companion and food animals.[16] Preliminary results from a more recent longitudinal analysis of our cases suggests that in food animals, after the initial exposures, the incidences of respiratory and growth-related problems increased relative to reproductive problems. In cases where families relocated to areas of little or no drilling activity, symptoms decreased in both the people and the animals the people brought with them (companion animals).

Similar to the reproductive failures seen in animals exposed to drilling chemicals, recent studies indicate a potential association between maternal proximity to oil and gas operations and adverse human birth outcomes. Despite privacy laws (HIPAA), human epidemiology can be pursued at a much more detailed level than animal studies largely because of the detailed records that are kept. In particular, three studies have investigated the link between proximity to oil and gas operations and infant health. Elaine Hill[17] showed an association between low birth weight and low APGAR (assessment of appearance, pulse, grimace, activity, and respiration at birth) scores with proximity to gas wells in Pennsylvania. Janet Currie and collaborators subsequently presented similar results.[18] Lisa McKenzie and collaborators[19] demonstrated an association between some birth defects (e.g., congenital heart defects) and proximity to gas wells in Colorado. These are associations rather than definitive cause-and-effect studies, but that is inherent in the study design and they are necessary first steps in understanding the health consequences of these complex processes. Detailed studies of cause-and-effect are impossible to pursue without having plausible hypotheses and these studies were designed precisely for that reason. However, taking this a step further, recent studies conducted by Susan Nagel and collaborators[20] have demonstrated the presence of agonists and antagonists of estrogen receptors in intensively drilled areas of Colorado that are absent in areas that have not experienced drilling activity. Although these estrogen receptor effectors were measured using a biological assay and were not identified, the presence of such substances in the water could well be related to effects on infant health noted in the above studies, as well as effects on adult human health and animal health.

Food Safety

One of the biggest questions is whether food raised in the vicinity of shale gas or tight oil operations is safe to consume. We have documented a range of impacts from the obvious to the less obvious.[16] In 2009, 17 cows died from direct exposure to hydraulic fracturing fluid in Louisiana and were very appropriately not sent to slaughter. In 2010, a herd in Pennsylvania was quarantined due to direct exposure to drilling wastewater. The length of the quarantine was not based on hard science, but was the best guess of the regulators in consultation with FARAD (Food Animal Residue Avoidance Databank). The following season, this herd experienced an abnormally high level of reproductive failure but some were eventually sent to slaughter once off quarantine. Since the cows did not show any gross abnormalities (i.e., they could walk), no further testing was done and the meat products derived from these cattle became an indistinguishable part of the food chain. We reported other herds that experienced morbidity and mortality after exposure to drilling muds and fluids, wastewater or water contaminated from drilling, but no quarantine was imposed, no testing was done, and the animals were sent to the slaughterhouse. These are animals directly exposed to water contaminated by drilling operations, and the prevalence of problems such as these is not known.

The question of how this impacts our food supply is not simple and cannot be answered with the available data. In the United States, meat is given a visual inspection by the USDA (U.S. Department of Agriculture), and processing plants are required to file a HACCP (hazard analysis & critical control points) plan that is checked for compliance to the protocol. The CDC (Centers for Disease Control and Prevention) may step in to do further testing following the outbreak of food-borne disease, or the FDA (U.S. Food and Drug Administration) may order tests in the case of suspected chemical contamination (e.g., the lead in candies from Mexico[21] or contaminants in seafood from the Deepwater Horizon blowout[22]). Certified organic operations remain one of the few areas of agriculture in which lab tests are required to be run on random samples of food and not simply in response to a food-borne illness outbreak. USDA National Organic Program requires that certifying agents do spot testing for pesticides (lab tests), as well as testing products where there is a reasonable suspicion that organic practices have not been followed. No specific testing is done on food products from intensively drilled areas, and as noted above, we are aware of only one case in the U.S. where livestock exposed to contaminants from drilling operations have been quarantined.[16]

Particularly given the recent revelation[20] that endocrine disrupting chemicals (EDCs) are likely to be found in proximity to oil and gas operations (particularly those with a known accidental release of toxicants), we believe that consistent monitoring of agricultural areas near drilling and processing operations is necessary to assess potential impacts on our food supply. However, the task is rather daunting for at least four reasons: **(1)** multiple routes of exposure are possible, **(2)** we don't know the chemical toxicants that should be monitored, **(3)** the levels of chemical toxicants are not necessarily constant so that a single sample may not reflect the risk over time, and **(4)** we do not know the MCLs (maximum contaminant levels) or ESLs (effective screening levels) for the majority of individual chemical toxicants associated with unconventional oil and gas operations or what the levels might be for multiple exposures to mixtures of chemical toxicants. We know even less about the presence of microorganisms extracted with the oil and gas products and the introduction of those organisms into the environment. These issues are largely unexplored and deserve much additional research. Another issue beyond that of impacts on water quality is the problem of water use in areas experiencing drought or groundwater depletion. This may become an important issue in light of the fact that, since 2011, approximately half of the hydraulically fractured wells in the United States were drilled in areas of high water stress.[23]

Decisions in Light of Inadequate Proof

Although health studies are moving forward, the difficulty of doing careful scientific investigations in a politically charged atmosphere cannot be overestimated, as illustrated by the aborted attempt to provide a serious Health Impact Assessment for the community of Battlement Mesa, Colorado.[24] This is an area of scientific investigation that has many stakeholders with divergent agendas. Getting beyond the inevitable accusations of investigator bias arising from opposition groups who do not like the results, there is little agreement on what can be considered useful information and how it can be applied. Industry groups and government have, in many cases, decided to move forward with intensive drilling in heavily populated areas citing a lack of evidence for any dangers.[25] While it is true that, until recently, little has been published on the health effects, good or bad, of unconventional drilling and hydraulic fracturing, one might pause to question whether this is evidence for the safety of the process. One might maintain this record of absence of harm, or at least maintain such a pretence, by dismissing any new study to the contrary. Indeed any new study by itself will not prove or disprove the safety of this large and complex process. It is the weight of evidence over a number of years using a variety of methods employed by different investigators that generates scientific consensus. The goal should not be to "debunk" each individual study but rather encourage new and more innovative approaches to studying the health effects of this new and complex process. If the process is indeed safe, the weight of evidence will eventually fall on the side of the oil and gas industry. Of course, this would be a pyrrhic victory in the sense that burning all of the extractable carbon currently held by industry will ultimately be far more economically devastating due to climate change than could be offset by the short term gains provided to the shareholders.

In any event, we are now left with more questions than answers. It may be useful to reflect on how public health concerns were successfully dealt with in the past. One example is the bovine spongiform encephalopathy (BSE; "mad cow disease") outbreak in the UK in the late 1980's. Like the shale gas and tight oil issues, the BSE outbreak was complicated by incomplete understanding of the cause and transmission of the disease and policy makers had to act in the absence of a clear scientific understanding. Although the solutions could have been viewed as too costly based on the available evidence, the thoughtful approach to risk taken by regulators in the UK can in retrospect be viewed as a major public health victory in that the number of new cases since the peak in 1992 has fallen precipitously.[26] Likewise, the approval of new drugs in the United States by the FDA is a long and arduous process designed to protect public health. Despite the extensive testing required, new drugs are always something of an unknown when released to the public because the much larger population exposed to a drug can unmask previously unrecognized side effects. So in the drug approval process, the burden of proof that the drug is safe and effective is on the pharmaceutical company, but realistic milestones are defined to meet a reasonable standard. The BSE response and the drug approval process are both examples of making decisions based on inadequate proof that have, for the most part, been beneficial to public health.

In the United States, most industries are regulated by more general rules, such as the workplace safety regulations of OSHA and environmental protection laws of the EPA. Although such regulations are often under attack by lawmakers purchased by specific industries, the fact remains that environmental protection laws and workplace safety laws provide important protections to the public and the environment. The oil and gas industry is exempt from the OSHA Process Safety Management and Prevention of Major

Chemical Accidents standard[27] and at least some aspects of oil and gas exploration and extraction are exempt from major federal environmental protection laws (Safe Drinking Water Act; Clean Air Act; Clean Water Act; Resource Conservation and Recovery Act; Comprehensive Environmental Response, Compensation, and Liability Act; National Environmental Policy Act; and Toxic Release Inventory).[28, 29] For example, the U.S. EPA (Environmental Protection Agency) regulations specifically state: "Drilling fluids, produced waters, and other wastes associated with the exploration, development, or production of … natural gas [are considered] … solid wastes which are not hazardous wastes".[27] That is, no matter how toxic, these substances are not defined as hazardous if they are associated with the production of natural gas. Thus, although specific state laws can be passed to regulate this industry, it does enjoy somewhat of a privileged position. The potential for harm, however, is great, since this is not an industry concentrated into a handful of factories, but one that is distributed across the landscape, coexisting with farms, homes, schools and churches. In that sense, one might expect greater scrutiny as is the case for the pharmaceutical industry. The introduction of a new, large-scale industrial process (i.e., horizontal drilling with high volume hydraulic fracturing) in close proximity to large populations should be viewed as seriously as, or arguably more seriously than, the introduction of a new drug. Like the pharmaceutical industry, the oil and gas industry should be held to reasonable standards of proof of safety, but the absence of unassailable proof of harm is not an acceptable standard for the protection of public health. Sadly, however, that is the norm in the United States and, for that matter, in the United Kingdom.

de Melo-Martín and collaborators[30] frame the argument by starting with the null hypothesis that "shale gas development has no effect on human health." A false positive occurs when the hypothesis is true but is rejected, and a false negative occurs when one fails to reject the null hypothesis despite the fact that it is false. Minimizing a false positive may impede the development of a safe technology; whereas, minimizing a false negative would minimize the possibility of allowing a harmful technology. The authors argue, in what is essentially a nuanced form of the precautionary principle, that false negatives should be minimized in order to protect public health because of the notion that protecting from harm is more important than enhancing welfare. Such minimization of false negatives, they argue can take the form of local bans on drilling or regulatory schemes that match the inspection and enforcement capabilities with the number of permits issued (an approach that has not been employed in any jurisdiction within the United States or Canada). Such an orientation would also support further unbiased research into the health effects of shale gas extraction and the development of alternative forms of energy with fewer health risks and lower carbon footprint.

Conclusions

Research done to date has raised significant questions about the safety of shale gas development that need to be explored in much greater detail, preferably in the absence of a politically charged environment. However, discussions of the safety of unconventional oil and gas extraction, lead to the inevitable question of what the alternative might be. Certainly, one cannot reject all forms of energy generation. When considering our energy choices, the issues raised in this commentary pale in comparison with the larger issue of climate change due to excess release of carbon into the atmosphere. Methane is sold to the public as a clean fossil fuel largely because the energy released per carbon atom is greater than other fossil fuels (due to the larger energy of the carbon-hydrogen bond relative to the carbon-carbon bond). But the principles of high school chemistry are not the end of the story. Methane has a much greater greenhouse gas potential than carbon dioxide (at least 100-fold greater over twenty years[31]), so that leaks in the distribution system and during production and storage must be factored in to understand the effects of natural gas on climate change. This analysis is controversial, but methane seems to be worse as a transportation fuel than the typical longer chain hydrocarbons,[32] and that for electricity generation and heating, it may or may not be better than coal depending upon the assumptions used.[33-37] We do have other options that are better for mitigating climate change and for avoiding health consequences from shale gas or tight oil extraction. Energy conservation, a smarter and larger electrical grid, and increased deployment of solar, wind, hydroelectric and wave energy can decrease our dependence on fossil fuels.[38] Essentially, fossil fuels might be relegated to a minor role in taking up the slack during cloudy or windless times. The argument against this has typically been that alternative energies are too expensive and have to be subsidized. The truth is that all energy is currently subsidized, and by historical standards, the current subsidies to alternative fuels are comparatively low.[39] Despite the fact that the fossil fuel industry has been with us for more than 150 years, it still commands substantial subsidies that dwarf the subsidies given to alternative energies. The International Monetary Fund placed the worldwide fossil fuel subsidizes for 2011 at 1.9 trillion dollars.[40] But the bigger question is what the cost will be of maintaining the status quo. Perhaps the more rationale approach would be to transition to alternative low-carbon forms of energy as soon as possible; the experience in Germany[41] and recent analysis in the United States[38] demonstrates that the transition is feasible and economically viable. This would begin to mitigate not only issues associated with climate change but also problems concerning the health effects of unconventional extraction of oil and gas.

Notes and references

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