The Dangers of Carbon Nanotubes

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Carbon nanotubes (CNTs) are one of the most significant materials engineering breakthroughs in the last quarter century. Stronger than steel and lighter than plastic, they are now being implemented to improve hundreds of very different products. CNTs are in sports products like baseball bats, golf clubs, and bicycle pedals because of their strength. Heavy-wear plastics like car bumpers and fuel lines have nanotubes too. Their resistance to heat makes them perfect for household items like spatulas, light bulbs, and computer screens. Research is now under way to integrate specific fluorescent nanotubes as an injected tracing tool in the medical field. They really are everywhere, and the rapid expansion shows no sign of slowing down.

But what exactly is a carbon nanotube? The science behind nanotechnology came with the discovery of a 60-atom carbon molecule (C_{60}) by a group of chemists at Rice University. The chemical bonding of this spherical structure gives it strength and heat conduction properties similar to those of diamonds. Since that discovery, scientists have gone on to manipulate the formation of C_{60} to open up the ends of the sphere and bond it with thousands of other C_{60} molecules, forming a tube shape from which nanotubes get their name. The result is a tiny wire with a diameter on the order of a couple of nanometers, which is so small that fifty thousand of those wires packed together would measure about the size of a human hair. The beauty of nanotubes is that the length can be exponentially larger than the diameter (up to a few millimeters) without causing the tube to tear. This strength is due to the extremely strong intermolecular forces that hold the tube sections together at the atomic level. These aspects give nanotubes some remarkable material properties. Essentially, you get a greater strength and stiffness than that of a diamond, good heat conduction, and interesting electrical properties in minuscule manufacturable fibers.

Nanotubes' properties explain the explosive increase in their commercial use. But the science is still very new, and no scientists claim to understand all of the potential applications or potential dangers of CNTs. Recent research has shown that if CNTs are absorbed into certain cells, they can be quite destructive. Some studies have even conservatively linked CNTs with internal tissue damage and mesothelioma, a type of lung cancer. That potential danger combined with the rapidly expanding public usage encourages questions about the regulation of these products as they hit the consumer market. But there is a gap in the applicability of the current research: scientists do not know how likely it is for CNTs to be inhaled or absorbed by humans in the first place. At this point, the FDA has been involved with research regarding CNTs' toxicity (potential for causing harm to living organisms), but has not invested in researching the likelihood that CNTs will be able to get into living organisms in the first place. The FDA also has no unique approach to regulating carbon nanotubes or nanotechnology in general. Instead, new nanotechnology products using nanotubes are only loosely regulated by ambiguous safety guidelines and recommendations. The FDA does not even have a formal definition of nanotechnology that would provide the foundation for specific regulation or further research on CNT products. The purpose of this paper is to examine the potential dangers of CNTs and the appropriateness of the FDA's stance in light of those dangers.

The big question right now is, how dangerous are CNTs? One study at the University of Edinburgh examined the effect of injected CNTs on the pleura (inside lining of the lung) of test mice. The scientists hypothesized that, like the inhalation of asbestos fibers, the inhalation of CNTs produces inflammation and the initial scarring signs of mesothelioma (cancer of the pleura). The study results demonstrate that some CNTs behave like asbestos fibers in the lungs, and could cause mesothelioma after exposure. Ultimately, the longer the CNT is, the higher the risk is for lung damage after inhalation. Short CNTs did not cause an abnormal amount of inflammation (7).

The Edinburgh study's methods define the limits of the results. Unlike many CNT toxicity studies that have been performed in vitro (examining test tube results instead of results in living animals or humans), the Edinburgh study was conducted on live mice (in vivo). Because of the many factors that a living organism's biology can add to a system, in vitro results are often less applicable than in vivo ones to the human body. Because its experiment was conducted in vivo, the Edinburgh study's results are more relevant to the general public than those of in vitro toxicity studies. On the other hand, the CNTs were injected into the mice's pleura, not inhaled, ingested, or absorbed through the skin. Here is where the applicability of the danger presented by the study becomes questionable. The Edinburgh study finds that there could be a potential for mesothelioma, given that the CNTs find their way to the pleura; but it says nothing about how likely it is that CNTs could get into the pleura on their own. The lack of data describing CNT absorption by living organisms represents a gap in the current research that limits the results of several toxicity studies.

Another study conducted at the University of Cambridge looks at the effect CNTs have on macrophages, which are cells in the immune system that fight pathogens (disease-causing bacteria) by absorbing and neutralizing them. These cells work all over the body as the immune system's scavengers. Macrophages have long life spans for immune system cells, some lasting several months before dying and being replaced. The Cambridge study used energy-filtered transmission electron microscopy (EFTEM) to examine the reaction of human macrophages after they absorb CNTs. The researchers used macrophages because they represent the immune system's "first line of defense" (8, p1) and would likely be the body's first effort to fight CNTs following absorption. Because macrophages are stationed all over the body (liver, bone, kidney, spleen, lungs, neural tissue, etc.), the results of the study demonstrate the immune system's reaction to CNTs in many areas. The study found that the CNTs did not do significant damage within the first two days. But, after 4 days, about 23% of the exposed cells were dead compared to the 4% that died in the control sample (8, p2). The macrophages at first performed their usual task, absorbing the nanotubes, but could not break them down like other bacteria. The findings highlight a serious threat to the immune system. Even if the macrophages are able to stop the progression of the CNTs into the internal organs of the body, CNT absorption will significantly hinder the body's ability to defend itself against other pathogens.

However, like the Edinburgh study, the Cambridge study did not examine how the macrophages could become exposed to CNTs in the first place. The cells in the experiment were exposed to CNTs at a variety of dosages that were not supported by real-life exposure data, because none are available. This gap again indicates that without exposure data, the toxicity results cannot yet be applied to public usage of CNTs. It is entirely possible that even in environments with high levels of CNTs like manufacturing centers, the inhaled or absorbed CNTs could be in much lower doses than were introduced in the Edinburgh or Cambridge studies. But, if the dosages used in those studies accurately represent actual human absorption rates, the studies' results could suggest a serious health concern.

Several in vitro studies present results similar to the two findings described above in terms of CNT toxicity and danger to the human body. In a direct comparison with asbestos fibers, one Swiss study found that CNTs can damage cells in many of the same ways that asbestos can, as did the Edinburgh study. This Swiss study was performed in vitro on mesothelial cells (cells found in the lining of the lungs) (11). Yet another study examines the absorption of nanoparticles through in vitro studies of fibroblasts (another type of cell found in the lung), with results similar to those of the other toxicity studies (5). The list of toxicity studies can become redundant, and many other studies not cited here present similar toxicity results for a variety of CNT types and experimental situations. All of this data could be summarized for simplicity's sake into three main points. First, CNTs can be absorbed by several different cell types in the human body. Second, once absorbed, CNTs are toxic to many types of cells and can cause a significant amount of damage to the human body. Third, no one knows the true likelihood of CNT absorption into the human system, but the primary possibilities are inhalation, dermal absorption, and digestion.

Human exposure and absorption data either will be the capstone to the case for new regulation of CNT production and usage, or will reduce all of the toxicity studies to limited application outside the general public. Currently, there is no available generally accepted information that describes the levels at which CNT absorption would be dangerous to humans. The science is so new that there has not been time for any long-term research measuring the damage everyday CNT exposure can cause. There are only limited data showing that humans are exposed to CNTs at all. One very recent study in Seoul, Korea measured the levels of CNTs in the air at three different laboratories. The study presents some of the first real CNT exposure data, but without any real knowledge of the harm various exposure levels can cause, those data are not yet very useful for any kind of risk analysis. The study's results describe the levels of airborne CNTs in the research centers, but the study did not investigate the amount of those airborne CNTs that is inhaled or absorbed by employees. The study's discussion section says that those who work in industrial CNT facilities and laboratories are in danger of significant levels of CNT exposure, but "the lack of extensive exposure data makes the risk assessment of nanomaterials more difficult" (4, p7). This lack of data by no means suggests there is no danger. Rather, the newness of the science and the rapid expansion of CNT products into the public sector make the potential physical danger and lack of exposure data even more publicly relevant.

The lack of research and examination of the dangers of CNTs resembles the asbestos crisis of the early1900s. In the Industrial Revolution (late 1800s), asbestos was used extensively as an insulator because of its excellent heat resistance properties. By the early twentieth century, asbestos miners who had been exposed to asbestos for 15 or more years began to die at young ages. Scientists then began to study the correlation of these deaths and asbestos exposure. They found out too late how dangerous extensive asbestos inhalation could be, causing mesothelioma several years later. Asbestos usage continued unregulated until the late 1900s, and resulted in one of the most expensive set of court cases in the history of workers' safety. An estimated 250 billion dollars in payments and court fees resulted from over 200,000 court cases related to asbestos safety. Much like the unregulated use of asbestos, the rapid expansion of CNT manufacturing and public usage in the last decade has gone essentially unstudied and unregulated.

Currently, the Food and Drug Administration (FDA) does not even have an agreed-upon definition of nanotechnology, much less a set of data to support any standard of CNT regulations. The FDA's website redirects concerns about nanotechnology to the National Nanotechnology Initiative (NNI), which similarly lacks data regarding CNT exposure and merely suggests a few precautionary steps based on limited analysis of the situation. Without a proper investigation of the associated risks of CNT exposure, no conclusions or regulatory structures can be constructed regarding CNT manufacturing. In light of the potential dangers of CNT exposure presented by the toxicity studies shown here, the FDA needs to take dramatic steps toward investigating human exposure to CNTs, starting with those working daily in CNT manufacturing centers. This should begin with the establishment of an FDA definition of nanotechnology and carbon nanotubes. I believe the FDA should accept the NNI's definition of nanotechnology: "the manipulation of matter on a near-atomic scale to produce new structures, materials, and devices." With an established definition, the FDA then needs to focus its research funds on gathering CNT exposure and risk assessment data, not on further redundant toxicity studies. Only then can any future regulation of CNT manufacturing facilities and public usage be evaluated with long-term safety in mind.

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