Potential Toxicity of Carbon Nanotubes

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Carbon Nanotubes (CNTs) are becoming a widely used nanomaterial because of their physical and chemical properties. These properties enable them to be used in a variety of fields ranging from consumer products to biomedical drug delivery systems (Lanone et al. 2013). As the commercialization of these products increases, so does their interactions with humans. This requires that a high degree of toxicological information on these nanomaterials is needed (Lanone et al. 2013). The toxicity of the CNTs however, depends on a multitude of factors such as the length, diameter, purity, and whether the CNTs are multi-walled carbon nanotubes (MWCNTs) or single-walled carbon nanotubes (SWCNTs). Multiple studies have been conducted on the variety of CNTs but the data remains inconclusive as to whether there is a toxicity associated with CNTs as a result of their different formations (Morimoto et al. 2009).

The physical and chemical properties of CNTs are a critical component in determining their toxicity, for as with any material, these explain the interactions between CNTs and their environment. Based on their composition, CNTs have been shown to be one of the least biodegradable materials ever created, and they exhibit extreme lipophilic behaviours (Pelka et al. 2013). As a result of lipophilia, there is a high potential for CNTs to bioaccumulate and have a high persistence (Pelka et al. 2013). These two properties are of concern because they are able to accumulate easily as well as exist in the environment for a long period of time and the toxicological data is still unknown for CNTs. A concern for CNTs is that there is a capability for them to become aerosolized in the workplace and this raises the question of CNTs becoming a workplace hazard (Chan et al. 2013; Sargent et al. 2010). The structure of CNTs resembles that of asbestos, which is a carcinogenic compound, and could suggest that there is potential for CNTs to exhibit similar toxicity (Martinez et al. 2013; Sargent et al. 2010). To further understand this, a study was conducted to see if long fibrous CNTs had similar toxic effects as asbestos (Lanone et al. 2013). The long fibrous CNTs would more likely affect the pleural membrane of the lungs, similar to how asbestos would interact with the lungs, and from this it was concluded from the study that fibrous CNTs showed a similar or even a greater effect of inflammation in the lungs than that of asbestos (Lanone et al. 2013). It also concluded that shorter asbestos and carbon nanotube fibres did not show any form of significant inflammation (Lanone et al. 2013). This evidence suggests that CNTs
have potential to asbestos-like toxicity but is very dependent on the size of the CNTs.

An *in vitro* study was conducted by Sargent and colleagues (Sargent *et al.* 2010) to determine the effects of SWCNTs on the lungs of mice, which revealed that there is an indication of genotoxicity and carcinogenicity. These findings are important due to the fact the CNTs have exhibited a potential hazard to cause cancer similar to asbestos. Further investigation by Sargent and colleagues (Sargent *et al.* 2010) revealed that CNTs could even lead to disruption in cellular division. The disruption in cellular division caused an abnormal distribution of chromosomes, and it is hypothesized that this is a result of the CNT bond strength (Sargent *et al.* 2010). The data here explains a possible cause for the formation of cancer in the lungs of the examined mice, where the errors in chromosomal distribution can lead to the loss of a specific tumor-suppressing gene (Sargent *et al.* 2010). In another study conducted by Chan and colleagues, (Chan *et al.* 2013) which sought to see the effects of CNTs compared to carbon black with respect to survivability of bacteria against predatory microorganisms and antimicrobial treatments. The microorganism ciliate selected was *Tetrahymena Thermophila* and the bacteria, which they fed on, were *E.coli* (Chan *et al.* 2013). The microorganisms were exposed to SWCNTs and the first observations revealed of the overall cell count and health of the microorganism, which was based on the ability to carry out normal cellular function (Chan *et al.* 2013). The exposed microorganism showed no significant difference in the total number of

cells compared to the control group and there was evidence of SWCNTs inside the exposed ciliates as dark granules suggesting that the SWCNTs could not be digested, but they were still considered healthy (Chan *et al.* 2013). It was shown that the CNTs caused an acute toxicity to the ciliates resulting in death at concentrations above 10µg/mL, whereas the exposure to carbon black showed no toxicity up to 7mg/mL. The ciliates were exposed to the bacteria to observe if SWCNTs would hinder the ability of the ciliate to digest and consume the bacteria (Chan *et al.* 2013). It was observed that the SWCNTs had caused the ciliates to release more vesicles than the control and that the released vesicles had contained live *E.coli* bacteria inside them (Chan *et al.* 2013). The exposed group was then administered with an antimicrobial treatment for the *E.coli* where it was observed that some of the bacteria were able to survive (Chan *et al.* 2013). The evidence found here raises health concerns for humans and other species as a result of the SWCNTs ability to interfere with the digestive capability of microorganisms, something which is related to the immune system’s ability to fend off bacteria and other foreign particles.

A number of studies have shown evidence of CNTs having positive or negative impacts on cellular function and growth (Martinez *et al.* 2013). Some studies have suggested that there are negative impacts on the growth rate of prokaryotic and eukaryotic cells from exposure to CNTs, while others suggest there was improvement of neuronal and bone cell growth rate (Martinez *et al.* 2013). To observe the effect on human cells, Pelka and colleagues...
conducted an experiment (Pelka et al. 2013) to view the potential damaging properties of SWCNTs on the human colon carcinoma cells. It was discovered that there was inhibition of cellular growth observed after 48 and 72 hours of exposure to the SWCNTs (Pelka et al. 2013). Pelka and colleagues (Pelka et al. 2013) also observed that there was a decrease in mitochondrial activity after 24 hours of incubation. The findings here are important due to the fact that the mitochondria provide the power for the entire cell and any decrease in activity could result and inefficient functioning of the cell or even cell death. Moore and colleagues conducted a study (Moore et al. 2009) to compare the effects of CNTs and C60-fullerene on the immune system of marine mussels. The lysosomes of the red blood cells were the target of toxicity measurements as they are necessary to the immune system and reduction in stability of these organelles would impair the immune system (Moore et al. 2009). It was observed from the C60-fullerene exposed group a decrease in the stability of the lysosome membrane was significantly different compared to the control group (Moore et al. 2009). However, in the CNTs exposed group there was no significant difference in the stability of the lysosome membrane compared to the control group (Moore et al. 2009). The differences in the conclusions that each study brings forth is the issue of classifying CNTs as a toxic material.

As a result of the diverse structural characteristics, it is difficult to classify CNTs as toxic materials. Individual CNTs from different studies are potentially different in their physical properties such as length, diameter, and purity of the CNTs (Lanone et al. 2013; Morimoto et al. 2009). These differences in physical properties are important because the mechanism of toxicity is highly dependent on the length and diameter of the CNTs, thus making it difficult to determine whether CNTs considered toxic in one study to be toxic in a different study (Lanone et al. 2013; Morimoto et al 2009). The other consideration is the purity of the CNTs because depending on the level of functionalization could result in different interactions with the cell membrane thus leading to the multiple mechanisms of toxicity (Lanone et al. 2013; Morimoto et al. 2009). Functionalization could additionally allow the CNTs to be more water-soluble and therefore more easily to accumulate in aquatic organisms or make it more susceptible to become aerosolized thus making inhalation of the particles easier as well (Lanone et al. 2013). Due to the diversity of CNTs, it is more appropriate to examine CNTs of similar properties as opposed to CNTs as a whole when determining toxicity.

Carbon nanotubes are widely used nanomaterials that have multiple applications and show a promising ability in drug delivery systems. It is important, however, to understand the physical and chemical properties of these materials in order for safe and efficient application. Further research in the underlying toxicity of CNTs is needed in order to improve our understanding of their interactions at a cellular level. With the adaptation of standard testing protocols, CNTs can prove
to be a valuable material in a variety of different fields.

References


