Is graphene safe?

Researchers raise warning flag over health concerns

David Bradley | *www.sciencebase.com*

It is almost inevitable that the invention or discovery of a new material will be accompanied by scaremongering in the tabloid media often based on some limited tests or safety alert from researchers in the field. So, the emergence of graphene as some kind of wonder material with its great strength, size-almost-zero thickness and its fascinating optical and electronic, and, of course, optoelectronic, properties was bound to come under scrutiny. The question of the safety or otherwise of graphene was predictably going to arise especially once the notion of nano was mentioned.

Graphene has become the focus of much research since, in 2004, Andre Geim and Konstantin Novoselov of the University of Manchester, England, found they could tear a strip off using nothing more sophisticated than sticky tape, a glass slide, and a pencil. The material exists as standalone atomic monolayers of carbon arranged in the familiar hexagonal pattern of graphite that resembles chicken wire fencing, providing many a useful metaphor for a science media keen to discuss the substance. Graphene is transparent, flexible, very strong, and has already been used to create fast transistors.

But, it is the very nature of graphene that might be cause for concern: thin and lightweight, yet tough and intractable particles are notoriously worrisome in terms of the detrimental effects they can have on our health, particularly when breathed in. The negative press novel materials get often references asbestosis and the malignant mesothelioma it causes or the silicosis of exposure to silicon dust and pneumoconiosis caused by coal dust.

Certainly, we must be cautious of the release of novel materials, particularly those that lie in the brave new world of nano where bulk properties seem to fade from view yet the atomic and molecular properties are not quite manifest. On this scale, phenomena emerge that might not be predicted based on bulk or molecular properties.

Ken Donaldson is a respiratory toxicologist at the University of Edinburgh and he and his colleagues are among the first to raise the warning flag on graphene, at least for nanoscopic platelets of the material. It is not too great a leap of the imagination to imagine how such tiny flakes of carbon might be transported deep within the lungs similar to asbestos fibres and coal dust. Once lodged within, there is no likely mechanism for the removal or break down of such inert particles and they might reside on these sensitive tissues triggering a chronic inflammatory response or interfering with the normal cellular functions.

The problem with graphene flakes, according to Donaldson and colleagues, is that although they might be labelled as being a few dozen micrometres across on the shipping container from a supplier, these platelets can behave as if they were much smaller. Our bodies can usually filter particles quite effectively, but these particles behave in ways that allow them to slip past the filters and once inside can be too big for white blood cells to engulf.

Writing in the American Chemical Society journal *ACSNano* Donaldson and colleagues have used a model of pharyngeal aspiration to demonstrate that graphene nanoplatelets are most certainly "respirable and so would deposit beyond the ciliated airways following inhalation." *In vitro* tests also showed that these particles trigger the inflammatory response in lung cells and those found in the pleural space. Intriguingly, the immune response is not seen with nanoparticulate carbon black.

Earlier in 2011, Sanchez and colleagues reviewed the limited research published on graphene's putative toxicity. They suggested that, "biological response will vary across the material family depending on layer number, lateral size, stiffness, hydrophobicity, surface functionalization, and dose." They also posited that graphene might produce reactive oxygen species in target cells or interfere with membrane lipids because of its extremely high hydrophobic surface area.

Moreover, as with asbestos and coal dust, and other smooth, continuous, biopersistent particles that can enter the body, graphene may have the ability to instigate tumour growth, they say. At the time, that team emphasized that, "Complete materials characterization and mechanistic toxicity studies are essential for safer design and manufacturing of [graphene materials] in order to optimize biological applications with minimal risks for environmental health and safety."

Donaldson's work takes us another step forward in providing such characterisation. "Our data suggest that nanoplatelets pose a novel nanohazard and structure-toxicity relationship in nanoparticle toxicology," the Edinburgh team concludes.

Andrew Maynard, Director of the Risk Science Center at the University of Michigan is not entirely convinced that there is an issue. "Donaldson's work certainly demonstrates the potential for graphene flakes to present a health risk if they are able to be inhaled and enter the lungs, or penetrate to the region surrounding the lungs. But that is a big 'if'," he told *Materials Today*. Pharyngeal aspiration delivers particles – or platelets flakes – to the lungs within liquid droplets and the droplets determine where the material is deposited. "This allows early experimentation on what could occur if the material could enter the lungs under handling and use," Maynard adds. "But it doesn't provide information on the plausibility of exposure occurring." We do not yet know whether graphene flakes can become airborne and inhaled in a form that is dangerous during use." Questions concerning health risks – while important - remain speculative," Maynard says.

FURTHER READING

Donaldson *et al.*, *ACS Nano* (2012) **6**(1), 736; doi: 10.1021/nn204229f.

Sanchez *et al.*, *Chem Res Toxicol* (2012) **25**(1) 15; doi: 10.1021/tx200339h.