What Are Nanoparticles and Where Do They Go?

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Nanoparticles are of great interest to dermatologists. They offer the promise of new drug delivery systems, better camouflaging of scarring, enhanced invisible sun protection, and novel opportunities for skin imaging. Nanoparticles also bring concerns about safety and environmental challenges. Perhaps nanoparticles are like everything in life: You have to take the good with the bad. In medicine, however, an evidence-based decision means that the good must outweigh the bad in a statistically significant fashion. Is this true for nanoparticles? The answer is not yet known, but dermatologists should be critical of inconsistent and controversial new evidence that is being presented in the literature. The Socratic method is used in this article to ponder the fate of nanoparticles and their effects on the body and the environment.

What are nanoparticles?

Nanoparticles are particles with a diameter between 1 and 100 nm. They are commonly found in the environment as a by-product of fire or combustion. For instance, nanoparticles can be found in automobile exhaust, airplane exhaust, and air pollution in general. We breathe them in every day in urban environments, and over time we develop nanoparticle deposits on the walls of our alveoli. No one knows for sure if nanoparticles are a problem.

Are nanoparticles new?

No, nanoparticles are not new. The first identified use of nanoparticles by humans was in the 9th century BC when the Mesopotamians used them in glitter for clay pots. Silver and copper salts were mixed with vinegar, ocher, and clay, and heated in a kiln to 600°C to produce a highly iridescent glaze. The high temperature resulted in the formation of nanoparticles, and the nanoparticles in the glaze are still present in the pots we see in museums today.

A modern view of nanoparticles was first described in 1857 when Michael Faraday published a paper on the optical properties of nanometer-scale metals. Further work by Turner observed that thin leaves of gold or silver underwent a change at approximately 500°C with a discontinuity of the metallic film and an increase in electrical resistance. Indeed, one of the major uses of nanoparticles today is in electronics because physical material properties change at the nanoscale level in unexpected ways. The properties of metals and other elements change as the percentage of atoms at the surface increases in relation to the bulk of the material, affecting melting points, magnetic potential, and electrical conductivity, for example.

One of the best-studied nanoscale materials is gold. Yellow-gold nanoparticles appear red. Furthermore, gold nanoparticles melt at 300°C for 2.5-nm size compared to 1064°C for a gold slab, thus lowering the melting point and allowing for interesting properties. These size-dependent properties are used in gold photovoltaic cells, which are important for the future of solar-generated power, as the solar radiation absorption in gold photovoltaic cells is much higher with discontinuous nanoparticles as opposed to continuous metal film sheets.

Why are nanoparticles so important?

Nanoparticles possess interesting magnetic and electric properties. For example, superparamagnetism is possible in nanoparticle magnetic materials. Ferromagnetic materials less than 10 nm can switch magnetization direction with room temperature thermal energy, making them highly unstable but opening up potential medical opportunities. New medical imaging beyond computed tomography and magnetic resonance imaging uses injectable nanoparticles less than 10 nm, known as quantum dots, in a magnetic field. These quantum dots also are being studied for their ability to deliver targeted drugs to cancerous tissue and to make microsized digital computers.

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Are nanoparticle skin care products currently in the marketplace?

Yes, nanoparticle skin care products most definitely are in the marketplace. Fifty-four nanoparticle products were in the worldwide marketplace in 2005 compared to 1015 in 2009, and the number will continue to increase. However, concerns continue to mount. The Swedish Medical Products Agency banned 10 companies from making nanoparticle zinc oxide sunscreens,[1] and the European Union has passed legislation requiring the word nano placed in brackets on the label of products containing nanoparticles.[2] Furthermore, the European Union will require companies to notify of their intent to release nanoparticle products beginning in November 2013.

What are the basic advantages of nanoparticles in skin care products?

Nanoparticles hold much promise in dermatology. Their high surface area to volume ratio creates an increased driving force for diffusion, which means that nanoparticles could be effectively used to deliver over-the-counter or prescription chemicals to the skin surface with enhanced penetration. Their small particle size (4–7 times smaller than the wavelength of light) also makes them invisible, which is the value of nanoparticles in inorganic sunscreen filters, such as zinc oxide and titanium dioxide. Finally, nanoparticle pigments can be used to create unusual topical skin effects for camouflage and minimization of wrinkles and dyspigmentation.

Why is everyone so concerned about nanoparticle safety?

Some of the concern about nanoparticle safety is fear of the unknown due to lack of knowledge, but there are some very well-documented nanoparticle issues. The US Food and Drug Administration even formed a Nanotechnology Task Force to address its concerns.[3] The US cosmetics industry is uncertain and most large manufacturers have agreed not to use nanoparticle technology until the issues are better delineated. Consumer groups, such as the Environmental Working Group, have posted nanoparticle warnings on their Web sites.

Probably the most interesting development is the new field of nanotoxicology, which is the study of the environmental impact of nanoparticles. Nanotoxicologists are concerned with the introduction of nanoparticle zinc oxide into the environment. For instance, what happens to the nanoparticle zinc oxide in sunscreen when it is washed away while swimming in the ocean or rinsed down the drain after a day of gardening? Where do the nanoparticles go? They go into the world's water supply and, as far as we know, they stay there forever. Nanoparticle zinc oxide is actually antimicrobial and toxic to certain aquatic organisms. Will there be a new type of water pollution besides oil spills, heavy metals, and radioactive waste from nanoparticle zinc oxide? I am not sure anyone knows the effects of long-term nanoparticle buildup in the water of the world. However, there are some behavioral properties of nanoparticles that might make them less toxic to the environment. Nanoparticles do not remain as single nanoparticles in the environment. They tend to aggregate and are no longer less than 100 nm in size, which means they do not pose nanotoxicology issues.

Why is there so much conflicting information on whether nanoparticles penetrate the skin?

Much of the early research on nanoparticles was done on pigskin, as it is thought to be the closest to human skin. Although pigskin may be a good model for some skin research, it is not a good model for nanoparticle penetration research. The earliest studies demonstrating the penetration of nanoparticles were done on pigskin, while later studies on human skin showed that nanoparticles do not penetrate the skin. Dermatologists must critically evaluate the methods of any study assessing nanoparticle penetration.

Do nanoparticles penetrate the skin?

The question remains as to whether nanoparticles penetrate human skin. Based on the organization of the stratum corneum, it appears that nanoparticles must be smaller than 13 nm to penetrate the skin and possibly enter the body. Furthermore, 25-nm nanoparticles can penetrate the upper 3 to 5 layers of the stratum corneum.

One of the major safety concerns of nanoparticles has been skin penetration from application of sunscreens containing zinc oxide and titanium dioxide nanoparticles. Certain behaviors, such as bending and flexing the skin, can increase penetration, and as expected, nanoparticles more readily penetrate wounded or abraded skin with barrier damage. Nanoparticle penetration can be limited by increasing the particle size, placing an anionic coating on the nanoparticles, and applying a polymer coating over the nanoparticle. Perhaps the biggest inhibition to nanoparticle penetration is that they quickly aggregate and agglomerate in skin formulations, which means that they may be put into sunscreens, but they are no longer individual nanoparticles when they come out of the bottle onto the skin. When agglomerated, nanoparticles no longer behave as nanoparticles because they are larger than 100 nm.

What other health problems are associated with nanoparticles?

There is growing concern of the presence of nanoparticles in the body, particularly in lung tissue. The problem is that nanoparticles are so small that they escape macrophage phagocytosis, meaning that these particles cannot be removed once they enter the body. Concern has been voiced in the medical community that nanoparticles from metals might be responsible for neurologic disease; others have wondered if the chronic inflammation induced by nanoparticles might cause other degenerative diseases. It is clear that the health issues associated with nanoparticles require further study.

Summary

Nanoparticles are certainly a hot topic in dermatology. They will revolutionize electronics, medical imaging, targeted drug delivery, and solar power. They also may revolutionize sunscreens, topical drugs, and cosmetics. It is possible that nanoparticles will be the next major innovation in dermatology since the development of topical corticosteroids. Someday in the not too distant future, we may be using nanoparticle therapy, nanoemulsions, polymeric nanoparticle spheres, and nanoliposomes to cure skin disease.

References

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