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REVIEW ARTICLE

The implications and applications of nanotechnology in dentistry: A review

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Abstract The emerging science of nanotechnology, especially within the dental and medical fields, sparked a research interest in their potential applications and benefits in comparison to conventional materials used. Therefore, a better understanding of the science behind nanotechnology is essential to appreciate how these materials can be utilised in our daily practice. The present paper will help the reader understand nanoscience, and the benefits and limitations of nanotechnology by addressing its ethical, social, and health implications. Additionally, nano-applications in dental diagnostics, dental prevention, and in dental materials will be addressed, with examples of commercially available products and evidence on their clinical performance.

Contents

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1. Introduction

Nanotechnology is the art and science of material engineering in a scale of less than 100 nm (Anisa et al., 2003). It revolutionized the medical and dental fields by improving mechanical and physical properties of materials, helped introduce new diagnostic modalities and nano-delivery systems (Kanaparthy and Kanaparthy, 2011).

The first guidelines developed in the field of nanotechnology were by K Eric Drexler from the foresight institute. He presented the science of nanotechnology to the public through his published book *Engines of Creation* (Anisa et al., 2003). In an effort to create an eco-friendly socially acceptable nanotechnology, the United States National Human Genome Research Institute proposed a new approach to the development process of new technology. This was accomplished by addressing the ethical, legal, and social implications before nano-products reach the market to easily modify and adjust during the early stages of production (Ramsay, 2001; Macnaghten et al., 2005).

The ongoing research in the realm of nano, is due to the unique properties nanoparticles offer. Atoms are the building blocks in biological tissue, and these atoms are measured using the nanoscale. Introducing nano-sized particles allows for an interaction on a molecular level, by that increasing the overall efficacy and affinity in comparison to biological molecules interacting with micro or macro sized particles (Li et al., 2008). The high surface to core ratio, is a unique physical characteristic in nanoparticles, meaning that there are more atoms on the surface of the nanoparticle than deep within its core. This is particularly useful since surface atoms have unbound surfaces in comparison to core atoms, with the potential for creating new and strong bonds, and hens, nanoparticles are more reactive in comparison to micro and macro particles which have more core than surface atoms (Binns, 2010).

In comparison to the same material in bulk (macro or micro), nano particles can be easily arranged in a number of packing configurations due to their high surface to core ratio, making them easily manipulated and utilised in various applications. The greater thermal vibrations expressed by surface atoms in comparison to core atoms in any given material regardless of particle size, contribute to the lower melting temperature in nanomaterials compared to the same material in bulk (Buffat and Borel, 1976). This might be of particular importance when using nanomaterials to construct porcelain fused to metal (PFM) crowns, cast post and cores, or denture frameworks.

Many authors published review articles discussing the potential of nanotechnology in dentistry including newly developed materials, however, the literature is void of reviews addressing the science behind nanotechnology in detail and linking it to the implications and applications of nanotechnology on the field of dental sciences (Mitra et al., 2003; Raval et al., 2016). This review addresses the science, implications, and up-to-date applications of nanotechnology in dentistry, including commercially available newly developed materials and supporting literature to aid dentists in understanding the clinical relevance and effectiveness of such materials in comparison to the ones currently used in clinical practice.

2. Implications of nanotechnology

2.1. Ethical implications

After the research and development phase of any dental or medical nanoproduct, it undergoes extensive preclinical *in vitro* testing to investigate its mechanical, toxicological, and immunological properties. Many agencies such as the U.S Environmental Protection Agency and the National Institute of Occupational Safety and Health have introduced guidelines for investigating the risks of nanomaterials (Resnik and Tinkle, 2007). However, developing a multidisciplinary regulatory framework to assess and control nanotechnology and resolve ethical concerns that fall under the four categories: metaphysical, equity, privacy, and security is a constant legislative challenge (Hester et al., 2015). Although animal studies provide a reasonable understanding of what to expect when starting a phase I trial, serious adverse reactions have been recorded when human subjects were exposed to a dose of nanomedicine 500 times less than the recorded toxic limit in animal studies (Resnik and Tinkle, 2007). Therefore, subjects must understand the level of risk associated with the exposure to novel materials and data and safety monitoring boards must be appointed in every clinical trial, to carefully track and record any adverse side effects early on, pick up inconsistencies in data handling, and insure the safety and wellbeing of test subjects (Resnik and Tinkle, 2007). The unpredictability of nanomaterials create an ethical dilemma for dentists when faced with a wide range of materials to choose from, some having very long track records supporting their clinical use such as hybrid or micro filled composite resins and others such as the nanofilled composite resins that are appealing in concept and supported by short term clinical studies. The traditional ethical decision making process followed, mainly utilitarianism, is unable to keep up with the rapid pace and uncertain future of nano-technological developments. For that reason, a more in depth understanding of the science is required, including risk/benefit analysis and ethical considerations throughout the development process. This lead to the proposal of the anticipatory ethics and governance concept, developed to iden-

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