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REVIEW

Nanotechnology and regenerative therapeutics in plastic surgery: The next frontier

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Summary The rapid ascent of nanotechnology and regenerative therapeutics as applied to medicine and surgery has seen an exponential rise in the scale of research generated in this field. This is evidenced not only by the sheer volume of papers dedicated to nanotechnology but also in a large number of new journals dedicated to nanotechnology and regenerative therapeutics specifically to medicine and surgery. Aspects of nanotechnology that have already brought benefits to these areas include advanced drug delivery platforms, molecular imaging and materials engineering for surgical implants. Particular areas of interest include nerve regeneration, burns and wound care, artificial skin with nanoelectronic sensors and head

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and neck surgery. This study presents a review of nanotechnology and regenerative therapeutics, with focus on its applications and implications in plastic surgery.

Contents

Introduction to nanotechnology: getting smaller and smarter

In 1959, the world-renowned physicist and Nobel laureate Richard Feynman delivered a lecture entitled *There's Plenty of Room at the Bottom* at the California Institute of Technology (Caltech), describing various thought-provoking experiments and the infinite possibilities afforded by miniaturization.[1]

> '*Why cannot we write the entire 24 volumes of the Encyclopaedia Britannica on the head of a pin?*'

Although the term nanotechnology was not coined until 1974 by Norio Taniguchi,[2] Feynman's monumental address can be said to be the impetus behind the ideas and concepts of nanoscience and nanotechnology. The prefix *nano-* is of Greek origin, meaning dwarf. However, the size of this industry has grown beyond measure, and nanotechnology has even been hailed as the 'next Industrial Revolution', with significant advances such as the invention of the scanning tunnelling microscope in 1981,[3] the discovery of fullerenes in 1985[4] and graphene in 2004.[5] Interestingly, the electronics industry was the front runner in shaping the field of nanotechnology, within which there was a constant rat race to innovate smaller, faster and more complex microprocessors and integrated circuits. In the early 1970s, International Business Machines Corporation (IBM) developed electron beam lithography technology, which was later adopted to engineer devices and nanostructures between 40 and 70 nm.[6]

The UK government saw the potential this field offered in a plethora of applications revolutionizing numerous industries, ranging from electronics to medicine. In 2003, the Royal Society and the Royal Academy of Engineering were commissioned to conduct an independent study on nanotechnology and nanoscience to appraise its current status, future challenges and its potential impact upon society.[7] The Royal Society's report defines *nanoscience* as the study and manipulation of matter at the atomic, molecular and macromolecular scales, while *nanotechnology* relates more to the application of this system to a wide range of industries. *Nanomedicine* is a term used to describe the medical application of nanotechnology. One billionth of a metre (i.e. 10^{-9} m) is equivalent to 1 nm. To put this into perspective, the width of a strand of human hair is about 80,000 nm, and the diameter of a single red blood cell is approximately 7000 nm[8] (Figure 1).

The unique feature of nanotechnology is that the material properties at a nanoscale may differ from that at a macro level, which can be attributed to two reasons: Firstly, nanomaterials have a large surface area-to-volume ratio, causing them to be highly reactive. This consequently affects their mechanical and electrical properties. Secondly, in the nanoscale, quantum effects dominate the material's behaviour, causing interesting observations in their electromagnetic and optical properties.[9] Nanomedicine covers a range of applications, including nanomaterials, nanoelectronic biosensors and molecular nanotechnology. Regenerative medicine involves the use of biological systems and material science to repair, replace or regenerate whole tissues and organs. Nanotechnology and regenerative medicine often go hand in hand. For instance, the use of nano-biomaterials, stem cells and nanoscale drug delivery systems is of great importance in the field of regenerative medicine. Indeed, there are several nanotechnology-based therapeutics that are already approved by the US Food and Drug Administration (FDA) for clinical use (Table 1). Research in these aspects warrants the need for a multidisciplinary team comprising