CHAPTER

3

TOXICOLOGICAL LANDSCAPE OF NANOMATERIALS

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3.1 INTRODUCTION

Nanomaterials are at the forefront of this revolution in scientific discovery, which the advent of nanotechnology has brought about. Today, nanomaterials have wide applications in various fields, including electronics, construction materials, biomedicals, cosmetics, pharmaceuticals, energy storage, environmental remediation, food packaging, processing, agriculture, etc. In the realm of biomedicine, nanomaterials are utilised in various applications, such as theragnostic purposes, drug delivery systems, vaccine development, cancer therapy, photomedicine, biomedical imaging, and the development of nanoscale materials for healthcare applications (Mabrouk et al., 2021).

Nanomaterials encompass structures with at least one dimension falling within the range of 1 to 100 nanometres (nm) to a broader range of materials with particle dimensions between >1 nm and <999 nm. Despite the exact definition of a nanomaterial, there is a growing recognition that the physical and morphological characteristics of such materials such as charge, size, and shape—can exert a significant influence on their toxicological effects.

Determining how the chemical and physical properties could affect their interaction with the biological system is crucial to understanding the underlying toxicological mechanism. As we continue to innovate nanomaterials, it is also crucial to comprehend the potential implications of these materials on our health and environment. Furthermore, the properties of nanomaterials can alter significantly as a result of these interactions with the biological environment, particularly in terms of their biokinetics (Konduru et al., 2017). Over recent years, nanotoxicology has gained significant traction and is currently one of the most rapidly advancing areas of toxicological interest worldwide. Nanotoxicology presents an intriguing and recent realm for toxicologists to explore and discover. Some have raised concerns that the increasing application of nanotechnology in humans could lead to severe toxicological consequences. Thus, understanding the toxicological landscape can create a safe and responsible development of nanomaterials. This approach can maximise the benefits and minimise the potential toxicity of nanomaterials.

Despite the paramount importance of navigating the toxicology of the nanomaterials, several challenges arise in assessing each nanomaterial's toxicological profile. As noted previously, the physiochemical properties of the nanomaterials are critical in analysing their complex interactions with the biological system. Furthermore, when discussing interactions with the biological system, consideration must be given to the factors originating from the living organisms themselves. The biocompatibility of the nanomaterials is equally vital in determining their biological endpoints. Additionally, to enhance practicality, emphasis should be placed on reports detailing the risk assessment and potential toxicity. This is critical to achieving a balance between the potential benefits and the safety profile of the nanomaterials. The nanotoxicological framework of the nanomaterials is shown in Figure 3.1 which consists of important components in discussing the toxicological aspect of nanomaterials. Therefore, this chapter provides insight into nanomaterial toxicity, unveiling the mechanisms governing toxicity. Additionally, it discusses the factors impacting toxicity, risk mitigation strategies, and future directions of nanotoxicology.

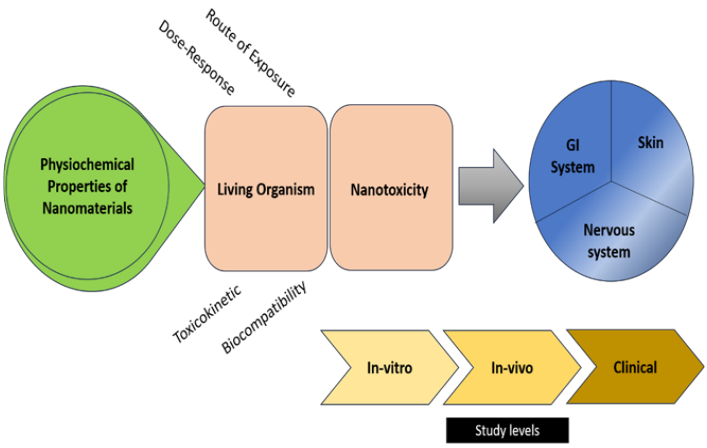

Figure 3.1 Nanotoxicological framework of the nanomaterials (Source: Hussain et al., 2020)

3.2 CELLULAR AND IMMUNOLOGICAL RESPONSES

The likelihood of human exposure to nanomaterials is steadily increasing alongside their expanding array of applications. Numerous studies have extensively documented the toxicological impacts of these materials on biological systems, including detailed examinations of their toxicity mechanisms. The toxicity assessment applies to *in vitro, in vivo*, and *in silico* assays. In *in vitro* assays, various cell lines are employed to simulate cellular responses within the human body following exposure to nanomaterials but often fail to provide the original physiological outcome compared to *in vivo* assay. However, these methods provide faster observations than the other two assays (Ganguly et al., 2018).

Assessment using *in vivo* assays is crucial to understand the physiological outcome better. Crucially, comprehending biological systems' cellular and molecular responses to nanomaterials is imperative for these materials' safe advancement and application. Nowadays, an *in-silico* assay enhances the rapidity and reliability of toxicity analysis to meet the varied demands of material testing. This method relies on theoretical models to anticipate the physicochemical characteristics of molecules, referred to as quantitative structure–activity relationships.