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Price tag in Nanomaterials?

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Abstract

With the evolution of the field of nanomaterials in the past number of years, it has become apparent that it will be key to future technological developments. However, whilst there are unlimited research undertakings on nanomaterials, limited research results on nanomaterial costs exist; all in spite of the generous funding that nanotechnology projects have received. There has recently been an exponential increase in the number of studies concerning health-related nanomaterials, considering the various medical applications of nanomaterials that drive medical innovation. This work aims to analyze the effect of the cost factor on acceptability of health-related nanomaterials independently or in relation to material toxicity. It appears that, from the materials studied, those used for cancer treatment applications are more expensive than the ones for drug delivery. The ability to evaluate cost implications improves the ability to undertake research mapping and develop opinions on nanomaterials that can drive innovation.

Keywords: nanomaterial, price, health, cost, toxicity,risk

1. Introduction

Innovative and underexploited? technologies like nanotechnology tend to present both risks as well as opportunities to society (Hett, 2004; Jones, 2004; Macoubrie, 2005; Renn and Graham, 2005; Roco, 2003; Stix, 2001). Nanotechnology has shown considerable potential towards progress in medicine, both in research terms as well as clinical, offering new applications on multiple fronts, such as drug delivery, diagnostics, biosensors, cancer treatment and implants (Allhoff, 2009; Archakov, 2010, 2010; “ESF Forward Look on Nanomedicine 2005,” 2004; Farokhzad and Langer, 2006; Kubik et al., 2005; Meynen et al., 2009; Nijhara and Balakrishnan, 2006), by taking advantage of the unique nature of nanomaterials.

Nanomedicine has prompted considerable risk-related questions and doubt (Bawa and Johnson, 2007; Bruce, 2006); the implications of nanomaterials have fueled the debate on their possible impact on human health and the environment among others. A lack of rigorous testing – due to time, cost and ethical considerations – means that we’re unsure of specific long-term effects posed on society and the environment. In response, researchers have been embracing hazard assessment via the assignment of nanomaterials to groups, based on structure, applications, toxicity, physicochemical characteristics or other parameters (Bos et al., 2015; Nogueira et al., 2014; Oomen et al., 2015), and subsequent gap filling, termed read-across, to postulate toxicological endpoints for materials that haven't been completely tested due to the aforementioned reasons.

Evaluation of a nanomaterial = Toxicity + physicochemical characteristics

In previous work a framework for grouping of nanomaterials have been proposed - based mainly on their applications - for risk assessment (D.A. Gkika et al., 2016). A framework for toxicology categorisation has already been established, identifying high risk materials and proposing how these materials should be handled. The grouping based on applications and toxicity information has revealed that although most of the materials, identified from a patent search, range between very low to moderate risk, some of those patented for application in health pose very high risk, such as the possibility to cause cancer, or be toxic when inhaled/digested or released in aquatic environment (D.A. Gkika et al., 2016), which appears to be counter-intuitive to their application.

In the frame of this nanomaterial evaluation, a gap was discovered in the relationship between the cost impact and the various potential risks that have arisen during the recent surge in Nanomedicine research activity. There are a number of studies that analyze the cost of materials but not of Nanomaterials (Malin, 2000). Further research is currently taking place into the cost of nanomaterials, however, so far, it has been difficult to draw any sound conclusions.

1.1. Price tag in nanomaterials? /

Although nanomaterials' science has received significant attention from researchers, the cost of those materials has not been studied in depth (Bosetti, 2015; Bosetti et al., 2013; Wagner et al., 2008). One can argue the need for an economic evaluation for nanomaterials (Clement et al., 2009; Drummond, 2007; Hartz and John, 2008)as there are various unanswered questions:

- How much does each nanomaterial cost, and what is the cost range of nanomaterials in medicine?
- Are there any special grouping criteria other than cost and application type?
- Does a change in price influence applications?
- Is there a relationship between toxicity and cost of material?

In order to proceed, the nanomaterial prices from various vendors where analyzed, and the average market price of each material was evaluated.

2. Aim & Scope

The work described here aimed at evaluation of nanomaterial cost, based on pricelists provided by several international companies. The average cost of various nanomaterials is used to group the materials, along with other parameters, such as application type and toxicity of material, in order to be able to make informed decisions in terms of their use, especially in medicine.

3. Methodology

The first step in the research was to conduct a price comparison of nanomaterials related to health, based on pricelists provided by multiple companies all over the world. The focus of the investigation was gathering data from as many companies as possible in order to get a more accurate price range. A price summary was created by examining the pricelists of companies selling these nanomaterials. The majority of the catalogues included variations of the materials and prices for various amounts, therefore all prices were adjusted to correspond to 1 gram of product. Furthermore, given the fact that multiple currencies were used by each company, all prices were converted to Euros, for a proper comparison.

The specific materials of interest were selected according to previous research, based on a search for the most popular materials mentioned in Nanomedicine-related patents approved by the USPTO and EPO patent offices, between the years 2010-2015. Those materials were also evaluated based on their toxicity and potential benefits for human health and the environment. Those results will now be evaluated with the added factor of cost into the equation (D. A. Gkika et al., 2016).

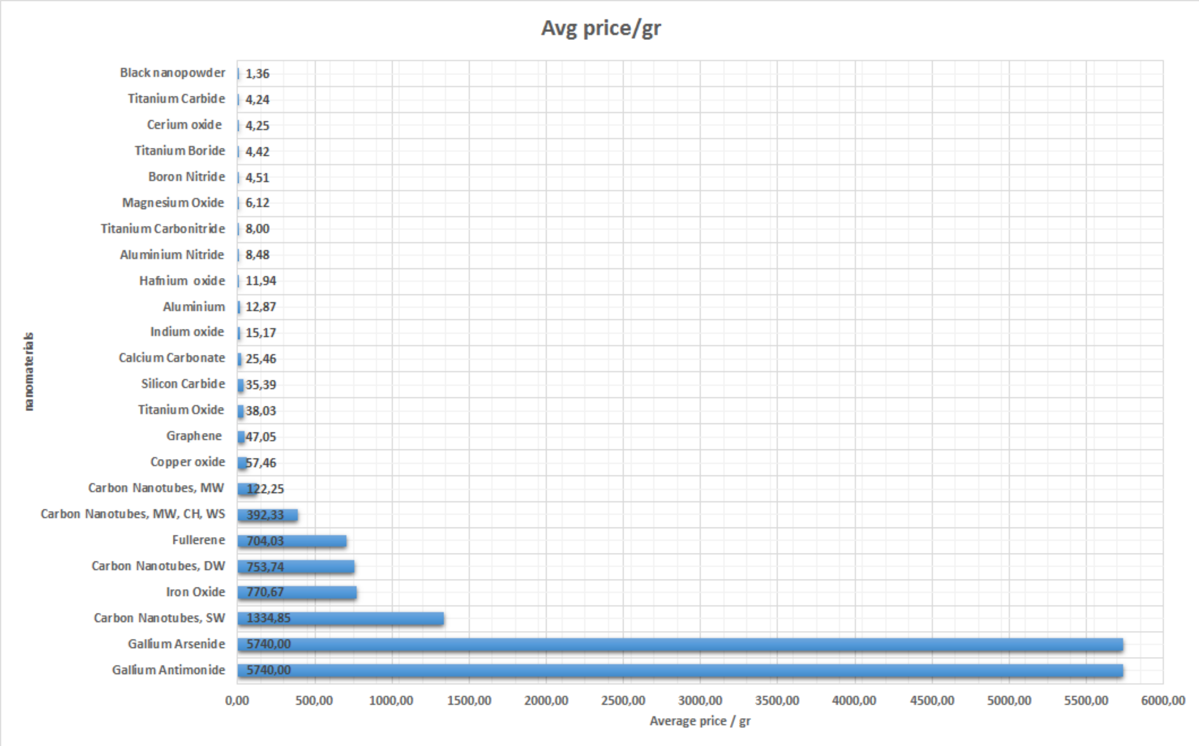
4. Results

The materials chosen were categorized based on average price and assigned a value of Very Low, Low, Medium, High, Very High cost. Then the average cost was calculated based on the type of application, and a Cost vs Risk cross-table was developed and analyzed.

4.1. Factor 1 Cost

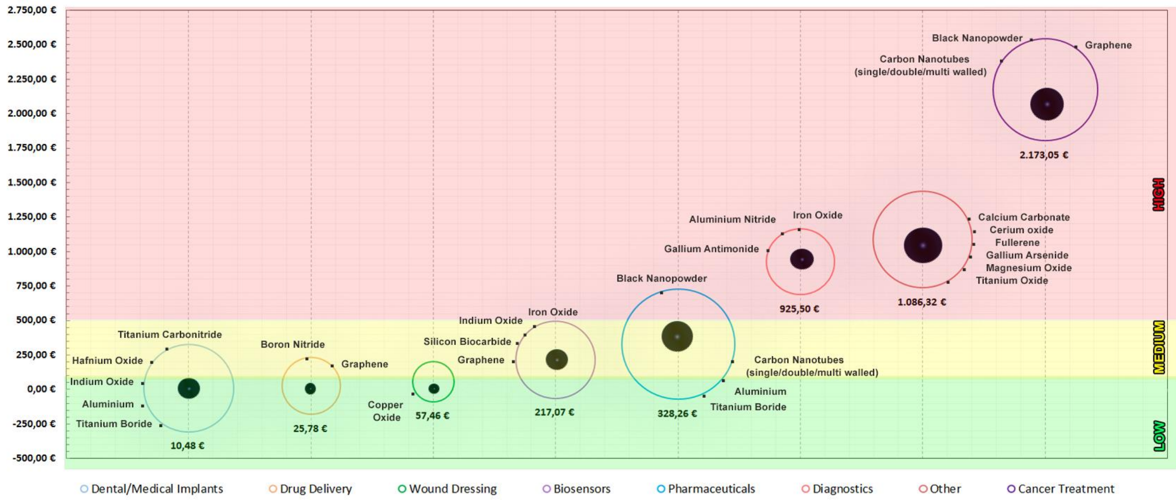
The average cost had to be calculated and transformed to a price in Euros/gr in order to obtain a single unit of comparison. This information could be used to make an initial decision about whether or not the use of a material in new applications is feasible. Figure 1 shows that there is a wide price range between the studied materials. The lowest average price ranges between 1.36 – 15.17Euros while the most expensive ones ranges between 700 – 5.750Euros.

Figure 1. Breakdown of average price of nanomaterials/gr



The majority of materials lie on the cheap side of the spectrum, considering that 16 out of 24 materials cost below 100Euros/gr and only 3 materials have an average cost of more than 1000Euros. Taking into account the application type these materials are used in (some can be used in multiple applications), the average prices by application type have also been evaluated. Figure 2 presents these results, showing the average price per application, contained in a bubble, the diameter of which is relative to the quantity of materials used for each specific application type. The materials themselves are also listed outside each bubble and a general division of low/medium/high cost applications has been depicted using distinct color ranges.

Figure 2. Breakdown of Average Price of application types of nanomaterials/gr



As can be seen, the majority of applications lie in the low-medium average nanomaterial cost ranges, with implants and drug delivery being within the lowest range, while cancer treatment and diagnostics fall within the most expensive range.

4.2. Factor 2 Risk

Based on the results of previous work, the studied nanomaterials have already been categorized in regard to their toxicity and possible risks to human health and the environment. Here this information has been combined with cost-based grouping, in order to assess the relationship between the two factors. The price ranges and possible toxicity values range from Very Low to Very High, and an appropriate color coding has been used on the comparison table for easier evaluation of the results. Green or light yellow and orange corresponds to low or moderate toxicity-cost combinations, while pink and red represent those materials that are both high risk and high cost. Table 1 contains the results of the comparison and assigns the materials on the appropriate combination of cost vs average price.

		Average Price Range				
		Very low (0-10 €/gr)	**Low (11-50 €/gr)**	**Moderate (51-150 €/gr)**	**High (151-500 €/gr)**	**Very high (501+ €/gr)**
Toxicity	**Very Low**	Titanium Carbonitride	Aluminium, Calcium Carbonate			
	Low	Cerium oxide, Boron Nitride, Magnesium Oxide	Hafnium Oxide, Indium Oxide, Silicon Carbide	Carbon Nanotubes, multiwalled (normal and charged, water soluble)	Carbon Nanotubes, double-walled, Iron Oxide	Carbon Nanotubes, single-walled
	Moderate		Graphene			
	High	Black Nanopowder, Titanium Boride, Aluminium Nitride				Gallium Antimonide
	Very High		Titanium Oxide	Copper Oxide		Gallium Arsenide

Table 1. Average price versus risk of nanomaterials

The results indicate that there are nine materials in the Low/Very Low zone, three in the moderate zone, and ten in the High/Very High zone. There are materials that are low cost but high in toxicity, or materials that have low to moderate toxicity but very high cost, along with some that are both expensive and highly toxic.

5. Discussion

Bosetti supports that cost–effectiveness analysis is an important tool to assess if nanotherapeutics' additional health effects are worth the additional costs (Bosetti, 2015; Bosetti et al., 2013; Bosetti, Rita, 2014). This study's goal was to present the importance of cost, which allowed for an evaluation of whether health related nanomaterials can be cost-effective and to assist in making informed decisions, taking into account the toxicity and the applications of said nanomaterials. The ability to evaluate cost implications improves the ability to perform research and make choices in terms of suitability for endpoint application. The challenge (Baer et al., 2008; Haase et al., 2012; Handy et al., 2008; Peijnenburg et al., 2015) that nanomaterials companies currently face is the provision of safe-to-use and economically-priced materials in volumes appropriate to meet market demands, without sacrificing quality. The use of cost is an integral factor that could improve the market introduction of health-related nanomaterials significantly.

A new cost–effectiveness framework is thus a key component for achieving the economic success of nanomedical applications and offering excellent production and efficient commercialization. The use of standardized market prices for nanomaterials could make the Nanomedicine market more interesting and easier to navigate, attracting new investments from the industry. Despite the importance of cost effectiveness, there are other factors that need to be considered, such as social considerations and the importance of the application of nanomaterials. For example, if a material is used in diagnostics or cancer treatment but is very expensive, would it be unethical to block its usage? Or if a material is high-risk due to toxicity, but no alternatives for its use exist, should its use be prevented? If a material is expensive but its utilisation is considered non-negotiable, what kind of funding should be allocated to its research? How much focus should be given to discovering cheaper, lower cost alternatives? Such questions make it apparent that simply categorizing materials by cost or toxicity or other factors are not enough for a direct decision, however they are a very reliable first step towards forming informed strategies.

These are the materials that could possibly require further evaluation in order to assess the benefits vs disadvantages of utilizing them further. For example, Gallium Arsenide is not only highly toxic, but also has an average cost of 5740Euro/gr. Is it worth using it in Nanomedicine under these circumstances? Are there other materials used for the same applications that could offer the same results but with lower cost/toxicity? This is one of the questions that would have to be examined in future research. On the other hand, those materials that pose low risk and are inexpensive, therefore having greater potential for marketability, and could be explored for new uses.

There is a gap in the cost of nanomaterials, their funding sources and public perception of their benefits and disadvantages (Vansant et al., 2015). It would be very beneficial to finally provide an answer to these questions and raise the awareness of both researchers and industry. It should also be noted that not all companies produce every commonly used material, which emphasizes the need for a comprehensive database of all materials, costs and recipes along with their applications.

6. Conclusion

Chenel, V., Boissy, P., Cloarec, J. et al. focused on the perceived impacts and their weighting within the process of arriving at an acceptability judgment (Chenel et al., 2015). We concluded that, in an attempt to contextualize acceptability judgments, the factors of cost and risk that foster variability would be utilized. Cost estimation is required for decision making in regards to nanomaterial strategies. Offering adequate consideration to these factors could add an additional layer of information to assessment processes, so that the various stakeholders can cooperate and form a clearer picture, enabling dialogue about technological innovation.

The methodological approach utilized has shown that material prices vary widely from one company to another and from one material to the next. Grouping has been performed based on the additional factors of toxicity and applications type. High costs constitute a further barrier to the use of nanomaterials. This analysis aimed to evaluate the economic advantages of some nanomaterials over others , and has revealed that there are some materials with both high cost and toxicity, whose further use could possibly be re-evaluated. On the other side, there are materials with low cost and low toxicity, whose further use by the industry and researchers could safely be promoted and encouraged.

It should be noted though that the high cost or possible toxicity are not necessarily preventing the material use, since there may currently be no other alternatives, and the significance of the application might be worth taking the risk of usage. In such cases, the materials should be studied further in order to find ways to make their production more cost efficient while taking into account all safety requirements required to face the risks.
Medicine as aof room for advancement and evolution. Inability to act now would be a waste of opportunity, since lack of action or taking measures could lead to high risk of obstruction of future nanomedical innovations (Bosetti, Rita, 2014).

Conflict of Interest

The authors declare that they have no conflict of interest.

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