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Reflections on Emerging Technologies in Nanomedicine

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ABSTRACT

Nanomedicine technologies seem to play an increasing role in modern medicine. Although there are many challenges, it is important to consider emerging technologies that may impact nanomedicine. To establish a rational basis for such consideration in this review, we summarise the present state-of-the-art in nanomedicine based on a bibliometric analysis of the literature that is available in the Clarivate® Web of Science. Then, we build upon that state-of-the-art to highlight the emerging technologies that may have an impact on nanomedicine. We also reflect on these emerging technologies by highlighting examples in areas, such as gene-based biomedicine, the rational design of antimicrobial peptides, and diagnosis and therapy of the gut microbiota. In general, emerging technologies that are based on bioinspired and biomimetic approaches appear to provide important pointers to future improvements in nanomedicine.

Keywords: Gene-based biomedicine, antimicrobial peptides, gut microbiota, microbiome, bioinspired technologies, bibliometric analysis

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INTRODUCTION

The European Science Foundation (ESF) defined the field of nanomedicine as the science and technology of diagnosing, treating and preventing disease and traumatic injury, of relieving pain, and of preserving and improving human health using molecular tools and molecular knowledge of the human body (1). The ESF further described the field of nanomedicine, including the five main sub-disciplines of (i) analytical tools, (ii) nanoimaging, (iii) nanomaterials and nanodevices, (iv) novel therapeutics and drug delivery systems, and (v) clinical, regulatory and toxicological issues. In simpler terms, nanomedicine can be defined as the application of nanotechnology to medicine (2). While various nanotechnologies continue to have an impact on nanomedicine, it is tempting to try to predict the emerging technologies that might have the most significant impact on nanomedicine in the coming years. Clearly, such predictions are fraught with difficulties. For example, in 2005, it was predicted that by 2015 to 2025 physicians would be using molecular machine systems and nanorobots, which would include an artificial mechanical red blood cell, an artificial mechanical white blood cell, or medical nanorobots capable of performing *in vivo* cytosurgery for chromosome replacement therapy (2). Duncan (3) took a more measured approach to the notion of nanorobots roaming the blood circulation to detect and treat disease (3). However, such nanorobots have not yet entered routine medical practice. In 2015, a perspective on implications for health sciences suggested that over the previous 10 years from 2005 to 2015, nanotechnologies have had a major role in the emergence of omics tools and in improving the modes of drug delivery (4). Heath (4) also pointed out that the fields of single-cell biology, as applied to assay biotechnologies, for example, and the harnessing of a patient's immune system for anti-cancer therapeutics were not anticipated in 2005. He also considered that the advances that are likely to occur in the decade 2015–2025 could include (i) nanotechnologies for health-related genomics and single-cell biology, (ii) inorganic and organic nanoparticles for biomedicine, and (iii) wearable nanotechnologies for wellness monitoring (4).

It is not really possible to arbitrarily provide pointers to the specific emerging technologies that may be applied to future developments in nanomedicine. However, in this review, we seek to provide a rational basis for reflecting on the possible ways in which emerging technologies can impact nanomedicine. To establish such a rational basis, we summarise the present state-of-the-art in nanomedicine based on a bibliometric analysis of the existing published literature that is available in the Clarivate® Web of Science. We then build upon that state-of-the-art to highlight the areas of nanomedicine where we believe that emerging technologies will be influential.

One of the key drivers is to develop technologies for early detection of the molecular etiology of diseases to provide better means for timely interventions and to improve clinical outcomes. Examples of this include genome-based technologies and systems biology approaches that utilize information from the Human Genome

Table 1. Terms used for the searches of the published literature available in the Clarivate® Web of Science

Search	Terms	N
BIOINSP	TS=(biomedicine OR nanomedicine) AND TS=(biomimetic* OR bioin-spir*)	413
THERAP	(TS=(biomedicine OR nanomedicine) AND TS=(biomimetic* OR bioin-spir*)) AND TI=(disease OR therapy)	32
SYMBTEC	(TI=(*medicine OR implant* OR biocompat*) AND (TI=(disease OR therapy)) AND TS=human) AND TS=*technolog*	102
MICROBIOM	(TI=(*medicine AND (disease OR therapy)) AND TS=human) AND TS=microbio*	21

In the descriptions of the searches, the field tags are TS=topic and TI=title. The searches use the Boolean operators AND and OR. The asterisk (*) is used as the wildcard character. The number of published documents resulting from each search is given in the column headed N

Table 2. Main keywords identified in the published documents of the BIOINSP literature search

Cluster 1 (purple) Keyword (W)	Cluster 2 (green) Keyword (W)	Cluster 3 (blue) Keyword (W)	Cluster 4 (orange) Keyword (W)	Cluster 5 (red) Keyword (W)
Drug delivery (133.7)	Nanoparticles (41.8)	Erythrocyte membrane (3.9)	Biomedical applications (5.1)	Design (1.9)
Gold nanoparticles (23.7)	Delivery (19.9)	Polymeric nanoparticles (3.5)	*In vivo* (5.0)	Scaffolds (0.0)
Mechanical proper-ties (8.2)	Nanomedicine (13.5)	Magnetic nanoparticles (2.7)	Cancer therapy (3.1)	
Bone (7.1)	Cancer (7.2)	Photodynamic therapy (1.5)		
Biomimetic synthesis (7.0)	Release (5.0)	Functionalisation (0.6)		
In vitro (4.1)	Cells (2.8)	Photothermal therapy (0.2)		
Mesenchymal stem cells (1.9)	Therapy (1.6)	Vesicles (0.1)		
Gene delivery (1.1)	Adsorption (0.1)			
Iron-oxide nanoparticles (0.4)				
Green synthesis (0.0)				

Co-occurrence keywords from BIOINSP listed in clusters according to the colours shown in Figure 1. A keyword with a larger weight (W) is positioned more centrally to the cluster. Keywords with W>5 are shaded grey. These shaded keywords are more centrally clustered together

Project (HGP). Next Generation Sequence (NGS) technology that developed as an outcome of the HGP has also become an important tool for generating information about chromatin structure and genome variations in terms of genetics and epigenetics. Molecular diagnosis can be made using NGS and such genetic information can be used as a guide to potential therapy. With the recent development of Clustered Regularly InterSpaced Short Palindromic Repeats/CRISPR-associated protein9 (CRISPRCas9) genome editing technology, gene therapies are becoming progressively more accessible. It seems that emerging technologies that are based on bioinspired and biomimetic approaches appear to provide important future directions for applications in nanomedicine

Present State-of-the-Art in Nanomedicine
The state-of-the-art technologies in the field of nanomedicine were surveyed within the window of 1900 to 2019 by searching the published literature that is available in the Clarivate® Web of Science. The details of the searches are presented in Table 1. All of the BIOINSP, THERAP, SYMBTEC and MICROBIOM literature searches were analysed using the "Bibliometrix" library (5) of RStudio v1.2.5033.

BIOINSP searched published literature that included the topics of biomedicine or nanomedicine and specifically, literature that focused on aspects of biomimetic* and bioinspir* (the *symbol allowed for several "wildcard" endings to the stem of the keywords).

The bibliometric analysis of BIOINSP using the "Bibliometrix" library (5) of RStudio v1.2.5033 indicated that, within the larger search window period, there were 413 documents published in the period from 1997–2019. There were 1,856 authors for those 413 published documents, which included research articles (257), review articles (123), book chapters (12), editorial material (2) and conference proceedings/abstracts (19). Moreover, those published documents mentioned 1,906 keywords. The co-occurrence network associations for those keywords are shown as a Kamada & Kawai (6) network layout (Fig. 1). This association graph shows the most frequent keywords that are associated with multiple publications of the BIOINSP documents. This association graph highlights the connections between the keywords that categorise most common areas of interest in the present state-of-the-art in the topic areas of biomedicine, nanomedicine, bioinspiration or biomimetics. Keywords that are more closely associated appear closer together in the graph, with a larger index for centrality (W).

Table 2 summarises the keywords that are clustered closest to the central technology-related themes of the published literature identified in the BIOINSP search. Those central technologies can be interpreted to include the main themes of (*drug*) *delivery*/*release* and (*gold*) *nanoparticles*, which are applied to the *nanomedicine* areas of and cancer and bone. That interpretation is reinforced by the analysis of the trend topics in Figure 2, where the top three trending keywords of the published literature (BIOSINP) are *nanoparti-*
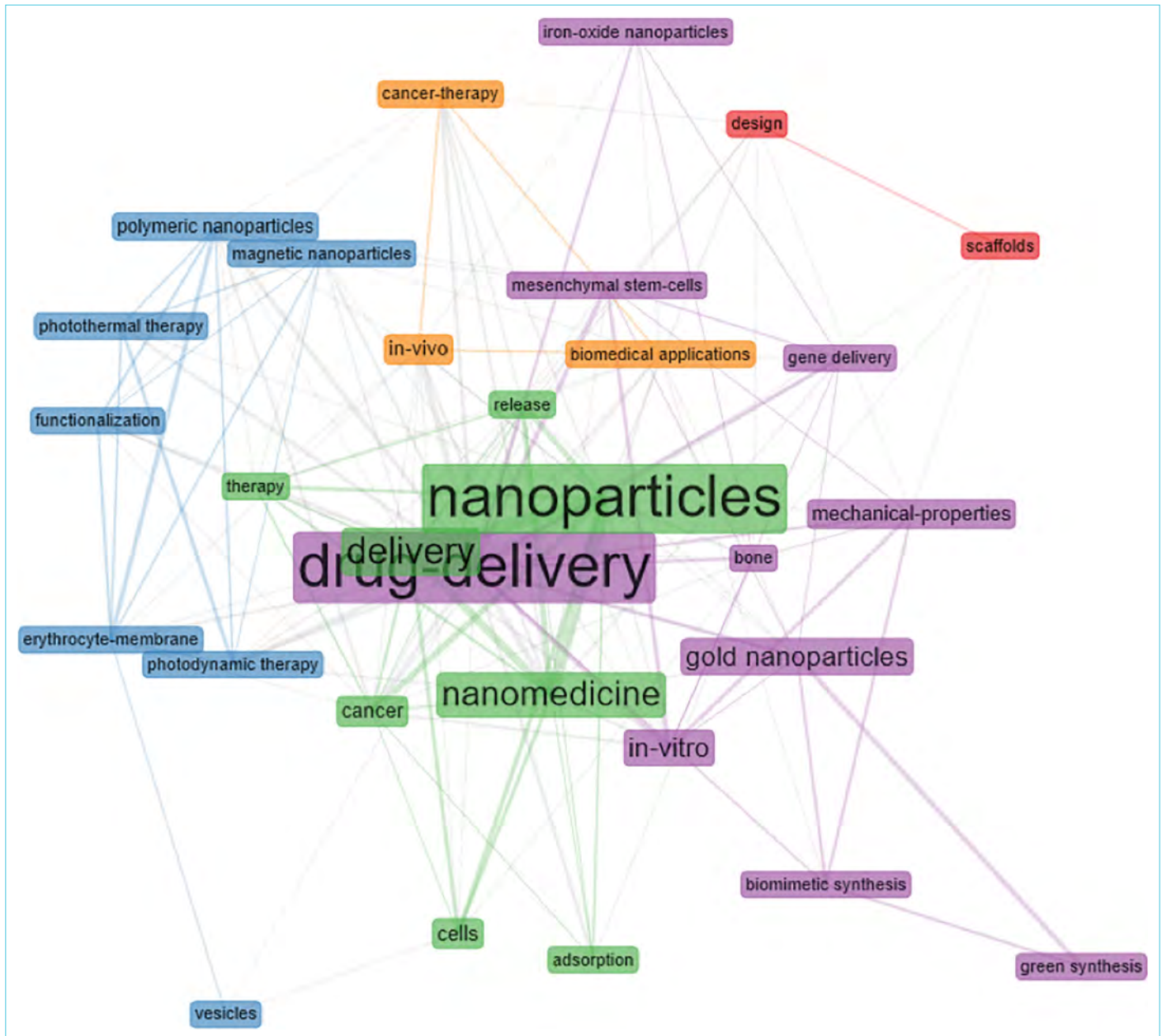
Figure 1. Co-occurrence of keywords of the published documents found by the BIOINSP search. The co-occurrence associations for those keywords are shown as a Kamada & Kawai network graph (6)

cles, *delivery* and *nanomedicine*. The other main keywords can be interpreted as being related to the method and application of those technologies.

Other areas of state-of-the-art focus in nanomedicine were further refined by analysing the THERAP, SYMBTEC and MICROBIOM literature searches to find occurrences of the most frequently used words that are common within the documents. Of those subsequent searches, THERAP focused within the BIOINSP results to search for specific published literature that included the topics of disease or therapy. The SYMBTEC searched for published literature where the topic was focused on technology. The MICROBIOM search terms focused on published literature concerning the microbiota. Those additional analyses provided information about the areas where technologies in nanomedicine are most frequently

applied. Table 3 summarizes the results of the analysing the most frequently shared words in the documents found in the THERAP, SYMBTEC and MICROBIOM searches.

The disease areas to which technologies in nanomedicine are applied most commonly include Alzheimer's disease, cardiovascular disease (also resynchronisation therapy and arrhythmia), arthritis, Human Immunodeficiency Virus (HIV), microbiome, gut microbiota, alcoholic liver disease and obesity.

Reflecting on Emerging Technologies in Nanomedicine

We can use the bibliometric analysis (particularly summarised in Table 2) to identify possible emerging technologies for future applications in nanomedicine. In trying to identify such emerging technologies, we have excluded published technologies that comprise
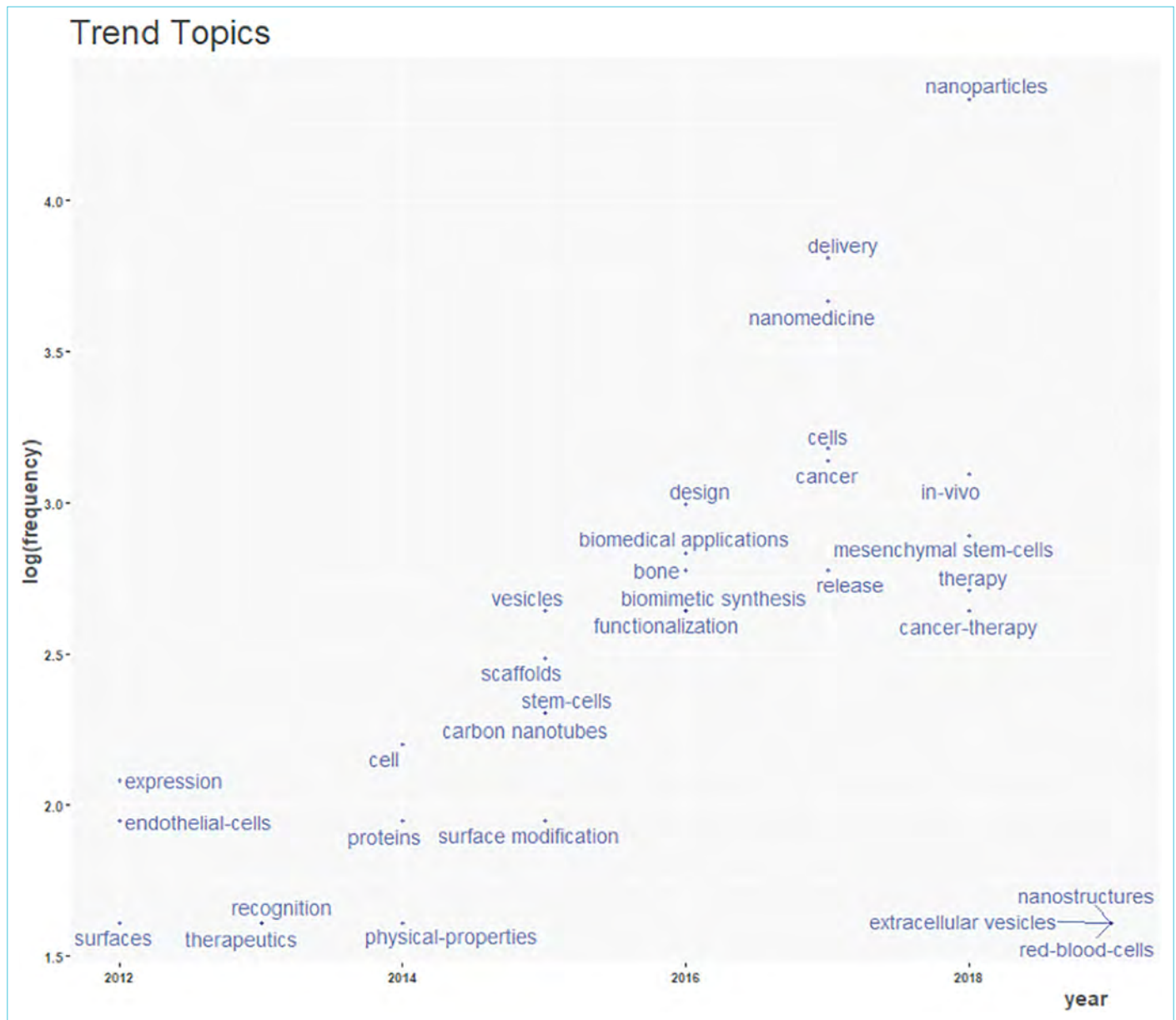
Figure 2. Trends for the keywords in the 413 documents of the BIOINSP literature. For inclusion as results plotted in this figure, we restricted the analysis to five keywords per year with a minimum word frequency of five

the most popular topics amongst scientists in the field. In Table 2 the keywords are shaded grey that are most centrally clustered in Figure 1. Those most-centrally-clustered keywords most likely categorize the most common areas of interest for technologies in biomedicine. Those technologies, particularly nanoparticles and drug delivery, have received the greatest amount of attention from physicists and engineers in applying technologies to biomedicine.

We consider an emerging technology as one that is not already mainstream but is gaining momentum in being the subject of research and publications. If we can define an emerging technology as being less likely to have been published by a majority of authors in the existing literature, we can gain insight into potential emerging technologies from the group of keywords with W<5 (Table 2 and Fig. 1). This is reinforced by their position as being less prominent as trend topics in Graph 2. These potentially emerg-

ing technologies include the topics of *gene delivery*, *mesenchymal stem cells*, *vesicles*, *erythrocyte membrane*, *photothermal and photodynamic therapies*. Those topics include technologies that are not based solely on physics and engineering and are more oriented toward bioinspired and biomimetic technologies. One could consider that such technologies have a hierarchy that includes the three levels of (i) targeting the genome with DNA, (ii) targeting the membrane with proteins, and (iii) targeting the microbiota (instead of the body) with biosinspired devices. In the remainder of this review, we reflect on such emerging technologies by discussing three examples. These examples include merging the knowledge of the human genome and novel gene-based technologies, such as CrispR-Cas9, the rational design of antimicrobial peptides, and diagnosis and therapy of the gut microbiota. The topic of the microbiota is an exploding field where there is scope for introducing new technologies for diagnosis and therapy.

Table 3. Most frequent areas of application to health and disease

Disease and health issue	Biological/health ap-plication	Technical detail
Alzheimer's disease	Anti-inflammation	Atomisation
Microbiome	Antigen presentation	Bioengineering
Gut microbiota	Apolipoprotein E	Bioinspired
Inflammatory bowel disease	Antiretroviral treatment	Early diagnosis
Human immunodeficiency virus	Biomarkers	Genomics
Obesity	Probiotics	Precision medicine
Alcoholic liver disease	Alternative therapy	Animal colitis models
Cardiovascular disease	Bacteriocin	Big data/bioinformatics
Arrhythmia	Brain repair	Personalised medicine
Cardiac resynchronisation therapy	Burden of illness	Biobank
Arthritis	Regenerative medicine	Drug discovery
	Gene therapy	Telemedicine
	Induced pluripotent stem cells	Clinical trials
	Adult stem cells	Diagnostics
	Embryonic stem cells	
	Amyloid beta	
	Infectious diseases	

These areas were the results of analysing the most frequently shared words in the documents found in the THERAP, SYMBTEC and MICROBIOM searches

Gene-based Biomedicine

Following the completion of the Human Genome Project, genome-based research is accelerating and the systems biology approach has gained crucial importance. Functional elements in the human genome have been identified that play a role in cellular activity and disease progression (7). Such identification provides a basis for gene therapy, particularly where a single gene can be linked to a particular disease. Clinical trials of gene therapy have predominately targeted different types of cancer (8). With the recent development of CRISPR-Cas9 genome editing technology, gene therapies have become progressively more accessible. CRISPR studies allow researchers to probe readily the study of gene functions in the field of health and diseases (9). In addition, the technology called DNA origami (DNA-O) is capable of performing a wide range of functions, including drug delivery. It has been applied to the repair of damaged cellular membranes by binding and subsequent release of charged biomolecules that facilitate cell membrane formation (10).

Synthetic biology is another potentially useful technology that could turn synthetic biological systems into practical applications. However, it is not easy to apply a synthetic system to humans (11). In synthetic genetic studies, a genetic circuit contains many regulatory elements and the system has a communication network within itself. Decoding these complex networks could be achieved by applying the techniques of minimal genome construction (12). Minimal genome research could accelerate the construction of specialized industrial genomes for the biodegradation of environmental toxins, the production of beneficial drugs and chemicals or the constitution of renewable energy sources (13).

We cannot omit the mention of rare diseases, which are defined as affecting fewer than 2000 people in Europe and fewer than 1250 people in the USA. Although there are many specialist researchers working on rare diseases, few clear conclusions have been reached (14). In the USA, more than 300 products for rare diseases have been market approved by the US Food and Drug Administration (FDA) since the orphan drug law came into force in 1983. Due to the high cost of treatment, attempts have been made to change legislation, especially enzyme replacement therapy and essential drugs (15).

Rational Design of Novel Antimicrobial Agents

Antibiotic-resistant bacteria have emerged in parallel with the widespread application of antibiotics (16, 17). The development of antibiotic resistance in bacteria is a natural consequence of the therapeutic use of antibacterial agents and therefore, cannot be avoided, only slowed by good dosing practices (18). While recognizing that there will always be a race between drug development and the emergence of bacterial resistance, new drugs that act in drastically different ways can buy much needed time for countering the threat of unstoppable epidemics. Antimicrobial peptides (AMPs) hold the potential to yield such a drug (19, 20). AMPs provide the first line of defense in multicellular organisms (21). In their native hosts' AMPs typically, but not always, exhibit a high degree of specificity and selectivity, targeting and killing pathogens without harming the host (22). The challenge of developing AMP drugs is that wild type peptides are not specific and selective enough in humans are often haemolytic or else not active enough to be viable in pharmacological applications (20, 23, 24). Initial efforts to design AMP drugs mostly followed medicinal chemistry principles, generating large mutant libraries and screening for activity. However, the significant efforts exerted towards turning AMPs into drugs have not delivered new therapeutic agents thus far (21, 25, 26).

AMPs are a diverse group of polypeptides, ranging from short peptides to small proteins, with a comparably diverse range of modes of action that includes intracellular activity, membrane modulation and receptor binding. It was demonstrated before that many peptides of known native or pathologic biochemical function can also show membrane specific activity (27–29). It is also known that the Curli protein of *E. coli* is amyloid that enables the bacteria to fabricate a biofilm in the gut. There is an existing link between Curli production and alpha-synuclein aggregation in rats (30). As for other pathogenic *E. coli* bacteria, *E. coli* Nissle produces Curli, which can activate complement (31). These types of proteins may provide a link between AMP and the gut microbiota. There exists a class of AMPs that disrupt the plasma membrane (32). The lytic effect correlates well with the antibiotic activity as was demonstrated for a range of peptides, such as magainin (33, 34) and cecropin (35). The lytic activity is determined by the peptide structure and the lipid composition of the target membrane (36). Rational design of AMP drugs focused on identifying the design motifs that facilitate membrane disruption, with an aim at enhancing the effects of these features (21, 37–40).

Peptide charge is believed to be one of the key factors governing AMP activity (41). Membrane disrupting AMPs are cationic, which is seen as a simple targeting motif to enable AMPs to bind to negatively charged bacterial membranes (21, 24, 42). Membrane disrupting AMPs are also amphipathic, facilitating a specific and geometrically defined interaction with the membrane core and offer the means to form a water-permeable channel (21, 24). Some specific chemical moieties were also linked to AMP activity. Phenylalanine residues were shown to act as membrane anchors and are necessary for the activity (43, 44). C-terminal amidation is often necessary for AMP action (45), but its specific role is not defined. It may help to stabilize the α-helix by providing an additional hydrogen bond (46, 47), by preventing enzymatic degradation (48), or by increasing the positive charge of the peptide (49).

The mechanism of AMP antimicrobial activity is usually classified by its outcome, which can be either complete dissolution of the membrane or the formation of transmembrane pores (50–52). In most cases, the pathway to this outcome is not well understood. It is necessarily a multi-step process, starting with specific targeting of the pathogen membrane, membrane association, membrane insertion and/or aggregation, and membrane disintegration (24, 53). Attempts have been made to rationally design an AMP targeted at the initial state, that is, specific targeting, focusing on peptide charge as the main motif. However, increasing peptide charge does not necessarily lead to increased activity (54, 55). Attempts to modulate the hydrophobicity of the peptide yielded inconclusive results while increasing α-helicity increased activity against bacteria. However, it also increased toxicity toward mammalian cells (20, 24). We should note that none of these strategies considered the membrane disruption process in its entirety; the modifications targeted the overall physicochemical properties of the peptides. The path towards developing highly active, specific and selective AMPs must involve a better, residue-level understanding of the membrane disruption process. There is scope to utilize the membrane specificity of AMPs to target not only bacteria but also specific types of cells, such as cancerous tissue, as well as enveloped viruses, such as coronaviruses or HIV. Indeed, the recent SARS-CoV-2 pandemic directs attention towards developing antiviral drugs, where the rational design of AMPs can play a crucial role.

Diagnosis and Therapy of the Gut Microbiota

There is an increasing awareness that the microbiome in general and gut microbiota, in particular, plays a significant role in controlling inflammatory and metabolic pathologies, such as obesity, type 2 diabetes, and innate and adaptative immunity during hepatic diseases (e.g., NAFLD, hepatocarcinoma) and neurodegenerative diseases (56, 57). There is also growing evidence that the intestinal immune system contributes significantly to metabolic disease (58, 59). Obesity predisposes to an altered intestinal immunity (58, 60–63). It is proven that a high fat or high fructose diet not only alters the microbiota but also increases the intestinal permeability, which leads to endotoxemia due to the activation of Kupffer cells (64). Bacterial translocation occurs in patients with advanced liver diseases (65). Both are associated with gut dysbiosis (66), which is an imbalance in the gut microbial community. Thus, the gut microbiota provides a new therapeutic target for preventing many diseases (67–69). Probiotics can be efficient stabilising the microbiota and modulating the function of immune cells. For instance, the commercialized probiotics VSL#3® and Mutaflor® (*E. coli* Nissle 1917) have provided efficient therapy in several bowel diseases (70–74). However, the therapeutic benefit is limited in time (75–79), and the probiotic needs to be ingested daily. Moreover, robust statistics from clinical trials do not prove that probiotics alter the fecal microbiota in a sustainable way (80, 81). Hence, fecal microbiota transplant (FMT) has been attempted as an alternative strategy to change the gut microbiota. FMT treats *C. difficile* infections (82, 83) with a high rate of success (around 90%) and it has also been suggested as a treatment for obesity (84, 85). However, randomized clinical trials need to be conducted to validate the effects of FMT. More importantly, since FMT introduces largely unknown and non-standardized microbiota, finding accurate measures of adverse reactions and the spread of transmissible diseases are significant issues that limit the clinical usage of FMT. Finally, although bariatric surgery is used to treat obesity and produces long-term alterations of the gut microbiota (86, 87), this procedure is associated with postoperative complications (88–90), nutritional deficiencies (91–93), chronic inflammation and is linked to higher sensitivity to infections (94, 95).

The microbiome has generated significant attention for its impact not only on the gastrointestinal tract but also on the enteric and central nervous system via the microbiome gut–brain axis, raising the premise that microbiome modulation may be an effective therapeutic strategy for treating or mitigating many human conditions, including neurodegenerative disorders. Recently, the microbiome, specifically gut microbiota, has been identified as a potential therapeutic target for managing the onset and/or progression of neurodegenerative diseases, including Alzheimer's disease (AD) (96, 97). We have recently demonstrated that a novel probiotic formulation containing *Lactobacillus plantarum* NCIMB 8826, *L. fermentum* NCIMB 5221 and *Bifidobacteria longum* spp. *infantis* NCIMB 702255 and Trifala is able to delay the onset and progression of AD in humanized transgenic *Drosophila melanogaster* by simultaneously ameliorating several stochastic risk factors of AD, including metabolic instability, accumulation of oxidative stress and mitochondrial integrity possibly through the regulation of the tran-

scription factor peroxisome proliferator-activated receptor gamma (PPARγ) (98).

Although available data suggest the significant therapeutic potential of probiotics in neurological disorders, such as Alzheimer's, Parkinsonism and aging, many barriers remain to be overcome before probiotic treatment is endorsed in medical practice. Currently, the United States Food and Drug Administration (US FDA) has approved a select list of probiotics, which are known to be considered as safe for commercial use in food and in probiotic supplements (99). However, the FDA has not approved any claims for probiotics that relate them to a reduction in the risk of disease or as a viable treatment for extant medical conditions (100). Indeed, in addition to the many health benefits of probiotics, there are risks and uncertainties associated with their use. Many reports have connected probiotic use to deleterious effects, including sepsis, immunoreactivity, and gene transfer resulting in pathogenic antibiotic resistance (100, 101). These risks are of highest concern concerning vulnerable groups, including the elderly, critically ill and immunocompromised, making probiotic use in the context of pathology especially prone to complications. Furthermore, the highly strain-specific effects of probiotic supplementation make it susceptible to pleiotropic or unanticipated metabolic outcomes. As such, there is an egregious lack of consensus in the literature and the field regarding the appropriate formulation, dose and treatment schedule that will maximize patient outcome while minimizing collateral effects. Overall, to be regulated at the level of a pharmaceutical or biological product, further work remains to be carried out to ensure probiotic therapies meet standards of safety, purity and potency appropriate for medical applications. By further understanding the mechanisms underlying both the benefits and detriments of probiotics in host health, there is an opportunity to generate safe, targeted treatment methods that maximize their potential in combatting neurological disorders.

Despite the significant contribution of gastrointestinal diseases to the global disease burden and the increasing recognition of the role played by the intestinal microbiota in human health and disease states, conventional methods of exploring and collecting samples from the gastrointestinal tract remain invasive, resource-intensive, and often unable to capture all the information contained in these heterogeneous samples. A new class of gastrointestinal sampling capsules is emerging in the literature, which contains the components required for an autonomous intra-luminal device and preserves the spatial and temporal information of the gastrointestinal samples (102). Recently, other technologies have emerged to provide opportunities for diagnosis and therapy in the gastrointestinal tract (GIT). For example, a hydrogel-based capsule system for sampling the microbiota inside the GIT (103) is close to entering the stage of pre-clinical trials in humans. That capsule system samples from locations inside the GIT and not just from fecal or rectal analysis. Also, a novel device to modulate the microbiota and establish a sustainable therapeutic effect has recently been patented (104). This device, called a "Symbiont", is installed during a short endoscopic procedure and provides an alternative to either ephemeral probiotic usage or to FMT. The "Symbiont" consists of a polymeric reactor that functions as an artificial reef to support the growth of therapeutic bacteria that form a beneficial biofilm.

CONCLUSION

It is very difficult arbitrarily to provide precise pointers to the types of specific emerging technologies that should be applied to future developments in medicine. However, such developments have the potential to improve the quality of medical care, and thus need to have a rational basis so that time and resources for research are not wasted. Here, we have tried to provide such a rational basis that is based on a bibliometric analysis of the present state-of-the-art of published research in nanomedicine. We have used that bibliometric analysis to highlight several areas where emerging technologies could be influential. We have defined an emerging technology as being less likely to have been published by a majority of authors in the existing literature, and we have gained insight into potentially emerging technologies from the bibliometric analysis of co-occurrence network associations for keywords from the existing literature. Those keywords include the topics of *gene delivery*, *mesenchymal stem cells*, *vesicles*, *erythrocyte membrane*, *photothermal and photodynamic therapies*. We have highlighted three examples of the areas of potential emerging technologies as being gene-based biomedicine, the rational design of antimicrobial peptides, and diagnosis and therapy of the gut microbiota. The topic of the microbiota is an exploding field where there is scope for introducing new technologies for diagnosis and therapy. It seems that emerging technologies that are based on bioinspired and biomimetic approaches appear to provide important directions for future improvements in medical outcomes.

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