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The Potential for Nanotechnology to Improve Community Resilience through Better Building Materials, Sensors, and Medical Applications

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Abstract

Nanotechnology is an emerging technology that has the potential to improve community resilience. Improving resilience begins in the pre-disaster phase of the disaster management cycle. This phase is located between disaster events and is where mitigation and prevention activities occur. A brief survey was conducted of relevant literature to identify the role that nanotechnology could potentially fill in disaster preparedness. Three primary uses for nanotechnology to build community resilience that stand out as the most practical and eminent are in the areas of building materials, sensors, and medicine. Applications of nanotechnology to building materials include the development of concrete that is stronger and would require less steel-reinforcement, thus making safer buildings, dams, and bridges. In regards to sensors, nanotechnology could be used to develop detection systems that could sense trace amounts of chemical and biological agents before they reached lethal concentrations and could lead to earlier evacuations of residents. Medical applications of nanotechnology include improvements in rapid diagnostics and vaccines that would improve public health decision-making and reduce the spread of disease. Stronger infrastructure, early warning, and better medical response have the potential to significantly reduce injuries, illness, and deaths. The integration of nanotechnology into the disaster management cycle, particularly in the pre-disaster phase, could revolutionize how disasters are managed and how community resilience can be strengthened.

Keywords: Nanotechnology; Disaster preparedness; Public health; Community resilience; Nanomaterials; Nanomedicine; Nanosensors

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Introduction

Disasters come in a variety of forms and fall into three principal categories. Natural disasters result from acts of nature and include earthquakes and pandemics; technological disasters occur as a result of failures from technical systems or structures; and human-caused incidents, which result from intentional actions of individuals or groups and include attacks with chemical weapons [1]. Disaster management follows a cycle, which typically includes a pre-disaster phase, the disaster itself, and a post-disaster phase. The pre-disaster phase spans the time between disaster events and includes prevention and mitigation. This covers a range of activities from improving physical infrastructure to preparedness [2]. It is in this phase where the greatest level of effort can be concentrated to improve a community's resilience to vulnerability and reducing the impact of a disaster. Resilience is the ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events [3]. The emergency management community has improved technological capabilities including advanced risk-management tools [4]. It is in the pre-disaster stage where nanotechnology has the potential to become one of these emerging risk management tools since it offers much promise to many areas of resilience including infrastructure improvement and public health preparedness.

Material studied, area descriptions, methods, techniques

The uses of nanotechnology to improve community resilience are extremely broad in scope. In order to gather more information on the applications of nanotechnology as they apply to preparedness and resilience, a brief survey of recent literature was conducted using the following combination of terms:

- Nanotechnology and emergency management.
- Nanotechnology and disasters.
- Nanotechnology and disaster response.
- Nanotechnology and disaster preparedness.
- Nanotechnology and community resilience.
- Building materials made of engineered nanomaterials.
- Nanosensors and disaster preparedness.
- Nanosensors and emergency response.

Dates for the search were set between 2010 and 2015, and a variety of databases were used.

Results

Based on the literature search, 466 matching articles were identified, with the majority of them (429) in the category of "Building Materials." The distribution of the remaining 37 articles appears to show that not much research has been conducted in these areas compared with research on nanotechnology and building materials **(Figure 1)**. Forty-four articles of relevance were selected. Based off of this information, several patterns emerged that identified common themes. Although there are potential challenges with nanomaterials regarding health and environmental issues, the intent of this search was to identify and understand applications of nanotechnology that could be used to improve community resilience.

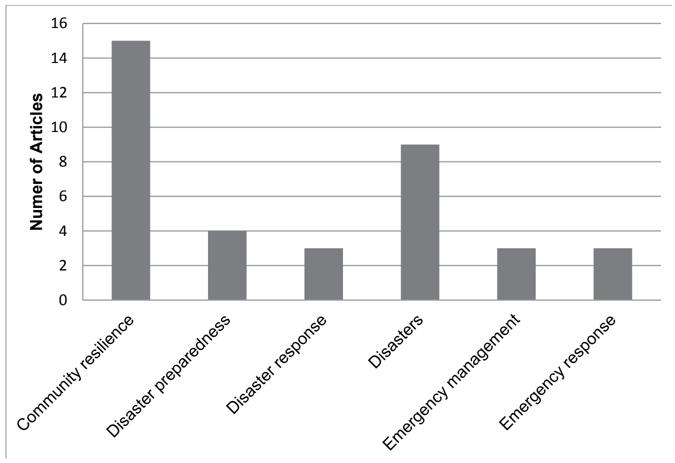

Figure 1 Number of articles identified per search term.

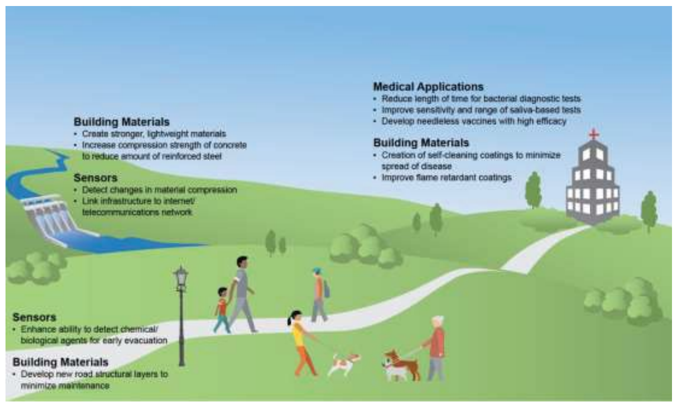

Figure 2 Applications of nanotechnology for improving community resilience.

Discussion

The applications of nanotechnology to limit the effects of disasters have the potential to be quite extensive; however there are three areas that stand out as the most promising in terms of their capacity to prevent the loss of life and the spread of disease: the use of nanotechnology to improve building materials (especially concrete), the utilization of nanotechnology to develop sensors for changes in pressure and chemical vapors, and the applications of nanotechnology in medicine for diagnostic tests and vaccines. Using nanotechnology for these applications could create an advanced network of resiliency in a community **(Figure 2).**

Building Materials

The large volume of publications that were identified in the literature regarding nanotechnology and building materials only strengthens the hypothesis that this is an extremely relevant area of current study and deserves greater attention. Nanomaterials have great potential to create new types of strong, lightweight materials such as composites, or they can be used to strengthen existing materials such as concrete. Concrete is the most commonly used building material in the world [5], and as such improving the way that concrete is engineered would vastly improve the durability and resiliency of civil engineering works and architectural design. It is believed that using nanomaterials in concrete would increase its durability from 50 years to 500 years and would increase the compressive strength thereby reducing the amount of reinforced steel needed by as much as 50% [6]. Future research directions for nanostructured concretes include [5]:

- Engineered materials using nanotechnology that will maximize the use of local materials, thereby allowing rapid construction and repair of building following large-scale disaster;
- Designing concrete mix that is resistant to the freeze-thaw cycle, corrosion, and other environmental factors; and
- Developing specialty products with blast resistant properties and advanced sensing technologies.

Researchers from the University of Missouri have developed a metamaterial cloak that can be used to transfer energy waves generated in earthquakes or tsunamis around materials such as steel and plastics to minimize the impact of shockwaves on buildings [7]. Although the large-scale use of these types of materials is still several years away, nanomaterial-reinforced concrete is very much a technology on the near-horizon.

Aside from concrete, nanomaterials can be integrated with other materials and could improve the performance of road structural layers [8], increasing the integrity of road systems, reducing the amount of potholes, and minimizing required maintenance. Other advanced uses for nanotechnology in construction and building materials would include [9]:

- Production of inexpensive corrosion free steel;
- An increase by a factor of 10 for thermal insulation materials;
- Production of coats and films with self-cleansing abilities.

Other than infrastructure and buildings, nanotechnology could be used to improve the resiliency of vehicles, especially aircraft. Advances include a superior strength-the-weight ratio, a reduction in aircraft icing, and lightning protection [10]. Better constructed aircraft reduce the risk of crashes from natural phenomena. Finally, new types of nano-engineered flame retardant coatings are being developed that limit the flammability and combustibility of existing polymers used in vehicles and buildings [11].

Sensors

Using nanotechnology to create tiny sensors that fulfill a variety of roles creates a tool called a nanosensor. Nanosensors have the potential to detect a variety of threats, including chemical and biological agents [12]. Due to their ability to detect extremely small amounts of substances, such as toxins, a network of sensors could be stood up in large, populated areas and serve as an early warning system for potential terror attacks or even disease outbreaks. This concept has been recently demonstrated by Nallon et al. [13] using graphene on a silicon dioxide base and developing a sensor that detected the chemical vapors of 11 different compounds with 96% accuracy. In addition, nanomaterials could act as sensors to detect tiny changes in pressure and movement, thus they would be ideal to use in monitoring critical infrastructure such as bridges, dams, and tunnels. A similar effect has been observed by Vaidya [14] using carbon fiber embedded in a geopolymer concrete mix, which enhanced electrical conductivity and was used to sense small compression changes in the concrete. Key breakthroughs in concrete technology will include the development of intelligent concrete materials that would include cyber infrastructure [5], particularly products with sensing abilities [9]. Early detection of unusual stress or strain could be investigated immediately and potentially prevent catastrophic failure such as the I-35W Mississippi River bridge collapse in Minneapolis, Minnesota, in August 2007, that killed 13 people and injured 145 more. Nanosensors could also be attached to goods or incorporated into food packaging so they could be tracked during transport and monitored for safety (i.e., detect tampering, identify suspected terrorist attack, etc.).

Medical Applications

One of the most highly anticipated uses of nanotechnology is for applications in medicine. In regards to community resilience, nanomedicine will allow for the development of highly sensitive point-of-care detection devices, improvements in the efficiency of pharmacotherapy, and the synthesis of novel nanomaterials for acute trauma management [15]. Current limitations in laboratory diagnostic capabilities include the length of time to receive a test result, the volume of the sample needed to obtain accurate results (i.e., how much blood, urine, etc. that must be collected from a patient to perform the test), and the ability to detect the presence of certain chemicals or biological pathogens (e.g., bacteria or viruses) in the body. These limitations do not necessarily inhibit the practice of medicine in most normal circumstances; however, during an emergency, especially one that might involve an outbreak of mass foodborne illness or a pandemic, these limitations can be crippling for healthcare systems and public health departments that rely on this information to make decisions necessary to contain the outbreak of disease.

Detecting microbial pathogens such as bacteria and viruses has always been challenging. These are the agents of infectious disease, and traditional laboratory methods often take days in order to provide the correct information regarding the presence of these organisms. Reducing diagnostic time to a matter of hours would have significant improvement on survival, and identifying the nature of an epidemic early leads to better decisions regarding quarantine measures and medical treatment. Another challenge is often that even if an individual has been exposed to a certain pathogen current methods of detection cannot identify the presence of organisms if there number is below a certain threshold value, and that varies by test and by organism. The use of certain nanoparticles, such as DNA-coated gold nanoparticles, could be used to develop laboratory tests with detection sensitives much greater that what is currently available [16].

Regarding the identification of bacteria, current methods call for the collection of a biological fluid sample which is then spread onto a culture medium and incubated for several days to observe the growth of any bacterial colonies. Once colonies appear, the bacteria are then identified through a variety of tests including staining techniques. This process can take upwards of one week to complete, which delays medical treatment. Nanotechnology-based diagnostic tools, such as the Verigene Gram-positive blood culture nucleic acid test can reduce the amount of time to isolate and identify bacteria by up to two days compared with traditional culture methods [17].

Overall, new applications of nanotechnology for diagnosis of infectious disease could include the following approaches [18]:

- Pathogen identification through surface marker recognition;
- Pathogen detection using nucleic acids;
- Detecting toxins and infectious disease secreted markers; and
- Determining drug resistance/susceptibility through the monitoring of a pathogen's metabolic activity.

One rapid improvement to detecting early onset of disease in disasters would be the development of alternative testing strategies using biological fluids such as saliva. There are many advantages to using saliva over blood and urine samples, including [19]:

- Ease of collections, storing, and shipping;

- Noninvasive techniques for collection, which reduces discomfort to patients; and
- Easier handling for sampling because saliva does not clot like blood does

Currently, saliva tests exist for some markers of cardiovascular disease, renal disease, and 23 viruses [20]. However, one drawback of using saliva as a diagnostic fluid has been the fact that analytes are typically present in lowers amounts than in blood [19], but advances in nanotechnology show that increased detection sensitivity is possible, and this has been a research priority for the National Institute of Dental and Craniofacial Research. Applications of microfluids and micro/nanoelectrochemical systems (MEMS/NEMS) to saliva-based diagnostics have led to the development of tools such as the Oral Fluid NanoSensor Test (OFNASET), which is a platform that is capable of real-time, ultrasensitive and ultraspecific detection of salivary protein and RNA biomarkers [21]. Using saliva for diagnostics in disasters would drastically improve the ability to test more people for infectious disease and other exposures quicker, especially during a suspected pandemic.

Vaccinations are still the gold standard for the prevention of infectious disease, especially viruses. However, many factors limit the ability to immunize a population including the availably of vaccines, delivery methods, and personal beliefs. New advances in bionanotechnology make it possible to develop a variety of vaccines that can be administered through the nose as a mist (i.e., the mucosal route) [22]. Many vaccines, including influenza, are currently available in this form, but nanomedical techniques using liposomes, emulsions, polymer-based nanoparticles, or carbon nanoparticles could be used to create needleless vaccine delivery systems that can be delivered directly to target tissues [23]. Recently, Li et al. [24] demonstrated that such a method is possible by using a type of lipid nanoparticle as a carrier to deliver a vaccine for Simian Immunodeficiency Virus directly to the pulmonary mucosa of mice. Nano-enabled techniques like this can increase the number of different types of vaccines that would be available this way leading to a reduction in the volume of vaccine required for individual administration, less discomfort for patients, easier transport to remote locations, and greater efficacy of the vaccine to produce an immunologic response [22].

Conclusion

Although nanotechnology is still an emerging technology, several areas have already been identified for real-world applications in engineering and medicine, and these can be used to improve community resilience. More applied research must be conducted to evaluate the feasibility of using nanotechnology in the disaster management cycle; however, testing various aspects, such as incorporating nanosensors into new bridge construction, could be done relatively easily on a small scale and monitored for effectiveness and practicality. The newness of nanotechnology should not limit its potential, as long as research and development are conducted in a safe and responsible manner. Having new tools for the disaster preparedness toolkit should be a welcome invitation to explore new avenues of improving the human condition.

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