NANOMEDICINE – ADVANCES IN MEDICAL TECHNOLOGY

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Executive Summary *The medical response to the COVID-19 pandemic demonstrated how quickly promising medical technologies can experience widespread adoption and diverse application. For example, mRNA vaccine technology, implemented to great effect in combatting COVID-19, is now being investigated for use in the prevention and treatment of diseases such as cancer and malaria. This article will take a snapshot look at another promising innovation: micro/nanorobotic medical technology. Nanorobotics now in development have the potential to significantly impact human health by delivering new imaging and surgical techniques, as well as drug therapies, that are likely to improve morbidity and mortality outcomes in years to come.*

The Promise of Nanorobotics

Nanorobotics, also known as microrobotics, describes devices the size of a nanometer (nm) or one billionth of a meter (10^{-9} meters). Nanorobots are 200 times smaller than a red blood cell. Nanomedicine uses nanotechnology to prevent and treat human diseases. The miniaturization of robotic devices offers significant potential for advancing medical treatment.[1]

Specifically, nanorobots are being designed to perform biological tasks such as targeted drug delivery and microsurgery. Nanorobots have demonstrated initial proofs of concept for diagnosis, imaging, biopsy and treatment of disease.

These tiny devices could facilitate access to remote parts of the body and perform a range of surgical procedures less invasively, offering distinct advantages over larger surgical tools such as catheters and scalpels. Nanorobots can travel across the blood-brain barrier and are an important step forward in theranostic applications, which utilize targeted therapies such as radioactive drugs based on specific diagnostic test results. Additionally, robotics on the nanoscale could be used to deliver biological components such as proteins, viral vaccines or antibodies. In fact, self-propelling nanorobots have been reported to deliver an attenuated vaccine in mice. Nanorobots also have potential use in collecting bacteria inside the body, leading to greater understanding of the human biome.[2,3,4]

Nanorobots, which are made up of artificial as well as biological components, must first be delivered into the body without causing unnecessary harm. The most common methods to deliver nanorobots are injection (60%), oral administration (30%), catheter (5%) and topical administration (5%). Self-propelling magnetic nanorobots are capable of navigation in biological fluids and can operate in small, difficult-to-access spaces.

Obstacles To Overcome

Transferring nanorobotics from the experimental to the clinical phase requires overcoming some significant obstacles. For example, further research is required to determine how and if the body could identify nanorobots and nanoparticles as foreign bodies and destroy them.

Due to their incredibly small size, nanorobots are difficult to design, build and harness with power sources such as batteries and engines.[2,3] To combat these challenges, nanorobots are being programmed to convert magnetic, light, acoustic or other forms of energy into kinetic energy or propulsion forces. The other method is self-propulsion, whereby a magnetic field is applied to the robot, allowing it to make a motion like cilia in microorganisms. The nanorobot can then be accurately guided to a target location in the body for drug release. Ultrasound is another external energy power source.

Retrieval of nanorobots after completion of a procedure presents another challenge. Methods include using a magnetic catheter (since nanorobots can be discharged from the kidney and collected in urine) or using biodegradable nanorobots.[4]

Wide Range of Applications and Commercialization

Potential medical applications for nanorobots cover a wide range of fields. For example, nanorobots could enhance current imaging capabilities by using catheter cameras and light radiation, as well as enhance real-time image tracking. Such advances in imaging could be transformative in aiding diagnoses and treatment decisions.

Using nanorobots in precision medicine offers a diverse range of potential applications. The most developed application to date is targeted drug delivery, with current efforts mainly focused on animal testing. At present, the drug delivery efficacy is often hampered by short half-life and rapid drug clearance from the body, necessitating large therapeutic drug doses. The results can lead to increased toxicity and adverse side effects. However, nanorobots could overcome this outcome by delivering an exact pharmaceutical dose directly to diseased cells.

Nanorobotics also offer the potential to repair damaged cells through tissue engineering or to correct genetic deficiencies by altering or replacing DNA molecules. For example, DNA nanorobots have been developed to target and eliminate cancer cells from the human body. They are made of a single strand of DNA folded into the required shape, which are put into either an "off" position to bypass healthy cells or an "on" position to expose cancerous cells to the drug. Once the devices recognize their target, they open and deliver the drug to a particular area. The approach differs from most current cancer treatments, which cannot target as specifically. According to one study, the efficiency of destroying cancer cells using this targeted method was 35%.[5]

DNA nanorobots can now identify 12 types of cancer cells. With further research, they have huge potential to change outcomes in cancer diagnosis and treatment. However, although nanorobots have shown promising results in in vitro and in vivo studies, no human trials currently support nanotechnology use over existing gold-standard therapies. This technology is still emerging but could possibly be ready for use in 5 years' time.

Nanoparticles, which are between 1 and 100 nm in diameter, can support the transportation of chemotherapy drugs. The approach has many advantages compared to traditional cancer drugs, as they can target and penetrate specific cells with no known side effects. There are some nanorobots that have recently been developed that deliver thrombin, an enzyme which clots the blood that supplies a tumor to destroy it. They can also deliver thrombin to stop the bleeding of wounds.[3]

Sperm-driven nanorobots are expected to become a promising device for artificial insemination and other reproductive procedures. Nanorobotic arms have been reported as being able to surgically remove the nucleus from an oocyte.

Oral medicine provides another set of potential applications. Studies have shown that self-activated tubular nanorobots can remove more than 95% of dental plaque within 5 minutes. They also can assist with other oral problems, signaling significant achievements in the field of dental surgery.[2,4,6]

Nanorobots could potentially help to treat atherosclerosis by removing fatty deposits from artery walls and breaking up clots into smaller pieces through ultrasound or laser applications. The nanobots can also clean wounds and treat burns. Using them in regenerative medicine and cell-based therapy may be especially useful in older age when organs and systems start to fail.[2]

Several companies are working toward commercializing nanorobots for use in medicine. Offering this important technology for precision medicine, however, requires facing financial, technical, regulatory and market challenges. It will ultimately require human trials to prove nanorobots' efficacy in diagnosing and treating disease.

Summary

Advances in medical nanorobotics are showing promise in improving patient diagnosis, treatment and quality of life. Cancer therapy is currently the major focus of nanorobotic research, especially involving targeted drug delivery and tumor destruction. Other focused research includes microsurgery, assisted fertility, tissue engineering and cell alteration. In vivo studies are still very limited, and most research is still focused on in vitro trials, leaving much research to be carried out before achieving clinical application. However, nanorobots hold considerable promise for medical diagnostics and treatment due to their unique ability to move around the human body and perform complex tasks at very small scale.

Notes

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