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The status of nanoneusurgery investigated

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ABSTRACT

Nanoneurosurgery, introduced in 2003, aims to revolutionize neurosurgery using nanotechnology. Despite early excitement, its development has been slower than expected. The field encompasses various neurosurgical domains, utilizing advanced technologies like femtosecond laser and nanoparticle-enhanced stem cell therapies. However, challenges such as diagnostic limitations, nanoparticle toxicity, and ethical issues have impeded progress. Recent trends show a decline in research activity, suggesting a need for more interdisciplinary approaches and practical applications. The field remains distant from fully integrating nanotechnology, indicating that its future impact might be indirect and gradual. Continued research and collaboration are essential for realizing its potential.

Keywords
nanoneurosurgery,
nanotechnology,
neurosurgical innovations,
clinical translation,
interdisciplinary approach

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BACKGROUND

The concept of "nanoneurosurgery" was first introduced by Dunn and Black in 2003 to highlight the potential of molecular therapies in neuro-oncology [5]. Since then, interest in nanoneurosurgery has grown substantially, offering the possibility to transform the field. This paper was motivated by an effort to review current practical applications of nanotechnology in neurosurgery, which quickly exposed a pattern: the excitement surrounding nanotechnology's potential to revolutionize neurosurgery in the past decades has not only remained unfulfilled but also seems to have waned. Consequently, we aimed to examine the practical application of nanotechnology in neurosurgery, specifically evaluating nanotechnology's progress in the field and exploring the apparent decline in advancement, investigating the reasons behind it and possibly proposing solutions to accelerate the bench-to-bedside transition in nanoneurosurgery. We hope to answer the question "how far are we from the dawn of the nano age" or, at the very least, analyze existing obstacles and anticipated milestones.

Terminology

Generally, the terms nanotechnology and nanomedicine carry different meanings. For example, if "nano" denotes any technology involving particles with at least one dimension of 10-9 (one billionth of a meter), then many devices currently utilized in operating rooms, from monitor electro circuits to the most sophisticated robots, rely on nanoparticle incorporation [1]. However, nanomedicine and, consequently, nanoneurosurgery are used in a more contemporary sense to describe the innovative and sometimes unconventional advancements in preventing, diagnosing, and treating diseases of the central and peripheral nervous systems.

Furthermore, the term nanoneurosurgery is incredibly wide-ranging, covering various neurosurgical domains such as neuroregeneration, targeted neuromodulation, non-surgical repair, prognostic medicine, and molecular imaging, as well as numerous neurosurgical subspecialties like traumatic brain and spine injuries, neurovascular, neurooncology, functional and stereotactic radiosurgery, and peripheral nerve, all while incorporating an array of nano fields. Moreover, the potential is extensive within neurosurgical practice, from hemostasis and wound closure in the operating room to enhanced operating room ergonomics, targeted drug delivery to metastatic tumor cells and stroke therapy, and aneurysm formation prevention [1,3].

Nanomedicine applications

Nanomedicine is an interdisciplinary field in which nanotechnology is involved in diagnosing, treating, and monitoring medical diseases. However, applying nanotechnology to the cellular and subcellular levels of engineering and surgery might be challenging. Specific progress has occurred in this direction. Femtosecond (fs) laser multiphoton technology has been used in high-precision surgery, which can be performed on tissues, cells, intracellular organelles, and molecules. Tängenomo et al. examined the biochemical synthesis of the Golgi complex by using the fs laser technique. The Golgi apparatus was also being dissected and manipulated by the similar technique. Such manipulations occur without destabilization of the cell membranes. It is usually performed by focusing fs laser using an objective microscope lens on the Golgi complex. Therefore, forming a cell-depleted Golgi apparatus result in a status where its biosynthesis can be thoroughly studied. Nevertheless, future expansion of this technique is highly probable to be included in the various nanosurgery applications [2]. Choi et al. utilized the same method to stimulate the cell membrane, resulting in the generation of calcium waves. They used an fs laser to enhance astrocytes' function in the mouse brain. As the laser is directed on the cell membrane, the flow of Calcium ions occurs, resulting in astrocyte-mediated vasodilation. This application has potential usage as astrocytes are the most abundant cell in the brain [6]. Furthermore, nanotechnology has extended applications to the molecular level, i.e., DNA.

Stem cell therapy is another field which Nanotechnology has the potential of revolutionizing. Mesenchymal stem cells can accelerate the recovery, axon regeneration, and remyelination in the case of peripheral nerve injury due to their anti-inflammatory and anti-apoptotic effects, autophagy reduction, and optimization of Schwann cell function. A limitation of stem cell therapy, however, is the migration of stem cells after transplantation which reduces their therapeutic effects. nanoparticles such as that superparamagnetic iron oxide nanoparticles can potentially facilitate the homing of mesenchymal stem cells at the injury site [4,7].

Nanotechnology in diagnostics has not advanced significantly. Nevertheless, progress in radiology has been noticed. 7 Tesla (7T) field's strength Magnetic resonance imaging which can process imaging reaching 10 microns details, has been applied in managing certain brain diseases, including Multiple sclerosis, brain tumors, and cerebrovascular diseases. However, besides high cost and limited availability, the disadvantages of this technology include imaging artifacts and the recognition of the details of anatomy and disease characteristics in imaging under such high field strength. An accurate test using nanotechnology to aid in the management of patients is still in its infancy.

The current concept of surgery as a therapeutic option probably will fade with the end of the 21st century. High precision surgery, as an example in precision medicine, may occupy the vacuum of traditional surgery. The precision that comes with the nano-level manipulations may give us the sense that it is the surgery's future. However, doubts still exist in the clinical field about such advances.

Current Trend

In this context, an analysis of the most recent systematic review on nanoneurosurgery reveals that publications on the subject have steadily increased since around 2003, peaked in 2015, then rapidly declined, and have gradually continued to decline since then, possibly reflecting an early period of unmatched enthusiasm followed by conceptual and practical stagnation [3]. Additionally, the relative scarcity of human research in comparison to a promising collection of bench-top and in-vitro applications indicates that nanoscience discoveries will take time to convert into clinical nanoneurosurgery, at least in the direct sense originally anticipated.

There are various reasons for the sluggish progress of nanomedicine toward nanoneurosurgery, and roadblocks will almost certainly continue to follow each discovery in nanoscience or nanomaterials. These difficulties may be categorized as follows, from specific to general: (1) those associated with each potential advancement in nanotechnology or nanomaterials, (2) those related to the intricate complexity of the nervous system and our current limited understanding of neuroanatomy and neuropathophysiology, (3) those linked to neurosurgical practice, given the unmatched diversity and complexity of neurosurgical diseases, as well as their frequently uncertain prognosis. (4) difficulties posed by the inherent physical, chemical, and biological properties of nanoparticles, with concerns about short- and long-term toxicity impeding their entry into clinical studies, and (5) a slew of ethical, economic, and cultural complexities, some inherent to neurosurgery and others well documented and described in nanomedicine across a variety of medical and surgical specialties [3,8].

Transition Phase

To accelerate the bench-to-bedside transition in nanoneurosurgery, focused efforts should be made at multiple levels, emphasizing a more comprehensive interdisciplinary approach. Additionally, considering the complexity of nanoneurosurgery interactions, the term "nanoneurosurgery" might be an overly broad designation. In this context, the specific steps needed and their anticipated timeline should be assessed concerning the precise situation under examination and customized to the particular complexities of the given interaction.

Therefore, the response to the posed question is that neurosurgery still has a considerable distance to cover before fully leveraging the advantages of nanotechnology, and the reason for this promise-delivery discrepancy is not simple. Moreover, given the immense complexity of the science-to-practice interface, it is too early to dismiss the transformative potential of this emerging field or compare its progress rate to other rapidly developing advancements in neurosurgery, such as robotics or stereotactic radiosurgery. However, it may be reasonable to conclude that, based on the analysis of the predicted future versus current metrics mismatch, nanotechnology may eventually be integrated into daily neurosurgical practice. Still, this integration is more likely to follow indirect pathways rather than the direct translation initially suggested.

Future Directions

Finally, until neurosurgery is graced with the "nano era," we should maintain a critical eye on the practicalities and venues for translation of nanoneuroscientific advances, striking the balance between what is scientifically appealing and what is more likely to make its way to our patients.

References

1. Choi M, Ku T, Choi K, Choi C, Yoon J. Label-free optical activation of astrocyte in vivo. Journal of biomedical optics. 2011 Jul;16(7):075003.
2. Dunn IF, Black PM. The neurosurgeon as local oncologist: cellular and molecular neurosurgery in malignant glioma therapy. Neurosurgery. 2003 Jun 1;52(6):1411-24.
3. Giakoumettis D, Sgouros S. Nanotechnology in neurosurgery: A systematic review. Child's Nervous System. 2021 Apr;37(4):1045-54.
4. Lam FC, Salehi F, Kasper EM. Integrating Nanotechnology in Neurosurgery, Neuroradiology, and Neuro-Oncology Practice-The Clinicians' Perspective. Frontiers in Bioengineering and Biotechnology. 2022;10.
5. Nasiry D, Khalatbary AR. Stem cell-derived extracellular vesicle-based therapy for nerve injury: A review of the molecular mechanisms. World Neurosurgery: X. 2023 Apr 25:100201.
6. Nejati-Koshki K, Mortazavi Y, Pilehvar-Soltanahmadi Y, Sheoran S, Zarghami N. An update on application of nanotechnology and stem cells in spinal cord injury

regeneration. Biomedicine & pharmacotherapy. 2017 Jun 1;90:85-92.

7. T√§ngemo C, Ronchi P, Colombelli J, Haselmann U, Simpson JC, Antony C, Stelzer EH, Pepperkok R, Reynaud EG. A novel laser nanosurgery approach supports de novo Golgi biogenesis in mammalian cells. Journal of cell science. 2011 Mar 15;124(6):978-87.

8. Tan A, Jeyaraj R, Ashkan K. Nanotechnology in neurosurgery: thinking small, dreaming big. British Journal of Neurosurgery. 2017 Sep 3;31(5):538-50.