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THE USE OF STATE-OF-THE-ART COMPUTER TECHNOLOGIES IN THE DIAGNOSIS AND TREATMENT OF DISEASES IN THE FIELD OF PEDIATRIC NEUROSURGERY

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Abstract
This article presents a comprehensive analysis of modern technologies in pediatric neurosurgery, demonstrating revolutionary changes in diagnosis, surgical treatment and patient rehabilitation. The material is of interest to specialists in neurosurgery, paediatrics and medical technologies.

Keywords: 3 Tesla MRI, three-dimensional tractography, neuronavigation, GPS for brain, IOM, robotic surgeons (ROSA), PET, MRI, intrauterine surgery, CyberKnife, Gamma Knife, transcranial ultrasonography, hybrid complexes, arteriovenous malformations AVM, hemangiomas, fetal neurosurgery, ultrasound, rehabilitation, hybrid operating rooms, gene therapy, telemedicine.

Introduction

Modern technologies in pediatric neurosurgery have become a lifeline for thousands of children around the world. This field stands at the intersection of science, precision, and compassion, where every millimeter and every second determine not just the outcome of an operation, but the quality of an entire life. The child’s brain is a living and fragile system, still forming and developing, and the slightest inaccuracy can have lasting consequences. That is why the role of technological innovation here cannot be overstated — it defines the success of treatment, the child’s cognitive future, and even the emotional stability of their family.

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Today, neurosurgeons work in operating rooms equipped like space laboratories. Neuronavigation, often called a "GPS for the brain," allows surgeons to see a three-dimensional model of the patient's brain in real time. This system guides every move of the scalpel, helping doctors choose the least traumatic path to a tumor or malformation, accurately distinguish healthy and affected tissues, and avoid damaging the vital fibers responsible for movement, speech, and perception. Intraoperative neuromonitoring complements this precision: sensors track the brain's functional activity and send immediate feedback if the surgeon approaches a critical area, allowing the team to protect essential functions even during the most complex procedures.

Thanks to endoscopic and robotic surgery, many operations that once required large incisions and long recovery periods are now performed through openings just a few millimeters wide. Endoscopic neurosurgery has become a gold standard in treating conditions such as hydrocephalus or cysts, significantly reducing blood loss and infection risk while allowing faster rehabilitation. Robotic systems like ROSA bring absolute steadiness and mathematical precision to every movement, eliminating human tremor and enabling surgeons to perform delicate procedures — from taking tumor biopsies deep inside the brain to implanting electrodes for the treatment of epilepsy.

Diseases once considered untreatable have also entered the realm of possibility. Through endovascular techniques, surgeons can now repair damaged or malformed blood vessels from within, without even opening the skull. The treatment of arteriovenous malformations or aneurysms through a tiny puncture in the femoral artery drastically reduces risks for young patients. In epilepsy, modern imaging and electroencephalographic mapping make it possible to locate the exact region causing seizures and remove it safely, often freeing the child from a lifetime of medication. Even operations on unborn babies — such as fetal correction of spina bifida — have become reality, preventing irreversible nerve damage before birth.

The goal of all these technologies is not limited to eliminating disease. The true mission of modern pediatric neurosurgery is to preserve life as fully as possible — to protect movement, speech, learning, and the very potential of the growing brain. Functional MRI shows surgeons which parts of the brain control particular actions, and tractography reveals the "wiring" of white matter, helping them navigate around vital neural highways rather than through them. Three-dimensional

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modeling and augmented reality let the doctor see the invisible, merging digital precision with human intuition.

In this way, modern pediatric neurosurgery represents not just an evolution of surgical technique, but a profound shift in philosophy. It is no longer about removing what is damaged — it is about preserving what makes a child whole. Every technological breakthrough serves a single purpose: to give children not only the chance to survive, but the chance to live, grow, and dream again.

Innovative diagnostics in pediatric neurosurgery have transformed how doctors see and understand the developing brain. These technologies no longer simply capture images — they open a living map of the brain's structure and function, helping surgeons act with confidence, precision, and safety.

Magnetic resonance imaging with a 3-Tesla field has become a new standard of clarity. If the conventional 1.5-Tesla MRI could be compared to a high-definition picture, then 3 Tesla is like ultra-HD with depth, texture, and light. It reveals the finest details: the borders of tumors, cortical malformations, and subtle anomalies invisible to weaker scanners. Even more, functional MRI (fMRI) allows specialists to watch how a child's brain activates in real time — which areas "light up" during speech, movement, or even sleep. Tractography adds another dimension, showing the invisible "highways" of white-matter fibers connecting different brain regions. For a surgeon, it means the ability to plan the safest approach, bypassing these essential neural pathways instead of crossing them. This is especially vital in children, whose brains are flexible and capable of reorganization; such maps not only guide surgery but also help predict how the brain will adapt and recover afterward.

Computed tomography (CT) remains indispensable in emergencies, where speed and accuracy can save a life. Modern multislice CT scanners complete a full head scan in seconds — crucial when every moment matters, such as in cases of trauma or hemorrhage. Advanced CT angiography provides a full 3D image of the skull, brain tissue, and vascular network at once, allowing doctors to identify aneurysms, malformations, or clots with striking precision. Intraoperative CT systems, installed directly in the operating room, let surgeons verify the result of an intervention immediately, ensuring that tumors are fully removed and implants are perfectly positioned without leaving the sterile field. For children, this means reduced anesthesia time, fewer repeated procedures, and a safer recovery.

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Ultrasound diagnostics have entered a new era as well. Through the open fontanelle of infants, modern neurosonography now provides images comparable to MRI resolution. High-frequency probes, color Doppler mapping, and 3D/4D imaging make it possible to visualize blood flow, detect vascular spasms, monitor tumor perfusion, and observe changes in cysts or ventricles over time. The procedure is quick, painless, and requires no sedation — ideal for premature babies or infants with hydrocephalus who need frequent monitoring.

For older children, where the fontanelle is already closed, transcranial ultrasonography has extended these capabilities even further. Using advanced signal processing, new systems can "see through" the skull, filtering out bone interference to display the brain's structure and blood flow through the temporal bone window. Intraoperatively, it helps surgeons navigate dynamic changes during surgery; in intensive care, it provides real-time monitoring of brain swelling or shifting structures without moving the patient from bed.

These diagnostic innovations erase the line between imaging and care. They allow physicians to understand not only what the brain looks like, but how it lives, reacts, and heals — ensuring that each child receives the most precise, gentle, and forward-looking treatment possible.

Hybrid operating complexes have become one of the greatest revolutions in modern pediatric neurosurgery. Imagine an operating room where all possibilities come together — the precision of open surgery, the gentleness of endovascular radiology, and the intelligence of real-time imaging. It is not just a room filled with machines; it is a living, breathing ecosystem where doctors and technology work in perfect harmony to give a child a second chance.

Inside this space, every detail matters. The angiograph shows the vessels with absolute clarity, the surgical table adapts to any position, and MRI or CT scans appear instantly on wide digital screens. All systems are synchronized, allowing surgeons to act without hesitation. Everything happens in one session — the child is asleep only once, and all decisions are made right here, right now.

The true magic lies in the combination of methods. For example, when removing a large vascular malformation, the surgeon first blocks the feeding vessels through a microcatheter to stop the blood flow, and then immediately proceeds to open removal without moving the patient. The risk of bleeding almost disappears, and recovery becomes faster. If something unexpected happens — a bleed, a vessel

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injury — the problem can be visualized and solved on the spot, saving precious minutes that often decide the outcome.

Hybrid surgery also changes how accuracy is understood. The doctor no longer waits for a day to check the results; they see them instantly through intraoperative imaging. After a tumor is removed, the surgeon can confirm right away that it's gone completely, that critical vessels remain untouched, and that no hidden complications remain. If needed, corrections can be made immediately, while the child is still on the table.

This approach opens new horizons for pediatric neurosurgery. It allows treating vascular malformations, complex brain tumors, epilepsy, craniosynostosis, and other craniofacial anomalies — conditions where a single method is not enough. The hybrid concept makes surgery both safer and gentler, reducing trauma and blood loss, and returning children to life faster.

In the end, a hybrid operating room is more than a technological breakthrough. It is a philosophy — a way of healing that unites science, precision, and compassion. It represents the moment when medicine stops fighting the impossible and begins creating new possibilities.

Fetal neurosurgery is one of the most delicate and visionary fields of modern medicine — the art of healing a child before birth. Its essence lies in performing surgical interventions on the nervous system of a fetus inside the womb to correct severe developmental defects. Many neurological damages become irreversible by the time a baby is born, but early intervention can prevent or significantly reduce them by using the remarkable plasticity of the developing brain and body. The idea is simple yet profound: to fix the defect at the moment when it has already caused harm but before that harm becomes permanent.

One of the most well-known and studied procedures in this field is surgery for spina bifida (myelomeningocele). In this condition, the spine and spinal canal fail to close, leaving part of the spinal cord exposed to the amniotic fluid, which progressively damages nerve tissue. The goal of the operation is to close the defect and protect the spinal cord. It is usually performed between the 19th and 26th weeks of pregnancy through two main methods. The first is open fetal surgery, in which surgeons make an incision in the uterus, gently reposition the spinal cord back into the canal, and close the opening. The second, less invasive approach, is fetoscopic surgery, carried out through tiny punctures using miniature instruments and a

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camera. Studies, particularly the MOMS trial, have shown remarkable benefits: a 50% reduction in the need for brain shunting for hydrocephalus, doubled chances of independent walking, and significant improvements in motor and cognitive functions.

Another critical intervention is ventriculoamniotic shunting, performed for severe obstructive hydrocephalus, such as in Arnold–Chiari syndrome, where cerebrospinal fluid flow is blocked, compressing and damaging brain tissue. Under ultrasound guidance, a thin catheter is placed into the brain ventricle to drain excess fluid into the amniotic space, reducing intracranial pressure and allowing the brain to develop more normally.

Fetal neurosurgery also includes treating sacrococcygeal teratomas — tumors near the tailbone that can overload the fetal heart due to excessive blood flow. The goal is to stop blood circulation in the tumor or remove it entirely using open or fetoscopic methods, such as vessel coagulation or resection.

Accurate diagnosis is the foundation of fetal surgery. It begins with prenatal ultrasound screening at 18–20 weeks, followed by high-resolution fetal MRI to assess brain and spinal anatomy, measure hydrocephalus severity, and detect associated defects. Fetal echocardiography evaluates the heart's condition, which is critical for determining surgical eligibility, while genetic testing through amniocentesis helps rule out chromosomal abnormalities that may contraindicate surgery.

Such operations can only be performed in specialized centers equipped with exceptional expertise and technology. These centers unite multidisciplinary teams: fetal surgeons, pediatric neurosurgeons, obstetricians specializing in high-risk pregnancies, ultrasound and MRI diagnosticians, neonatologists, anesthesiologists, geneticists, and psychologists. They are supported by state-of-the-art facilities — operating rooms adapted for both open and fetoscopic surgery, systems for continuous maternal and fetal monitoring, and access to high-field MRI and expert ultrasound imaging. An ethical committee ensures that every case is considered with the utmost care, and parents receive full, transparent information about potential risks and benefits, including those for both mother and child.

Fetal neurosurgery represents not only a medical breakthrough but a profound expression of hope — a belief that healing can begin even before the first breath.

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It is where science meets compassion, and where life, still within the womb, is given the chance to start anew.

Rehabilitation is the most vital stage of treatment — the point where cutting-edge technologies meet human warmth to help a child's brain rewrite its story. It is not just about restoring lost functions; it is about opening a new world where limitations yield to perseverance and love.

What makes rehabilitation unique is the power of neuroplasticity — the child's brain is alive, adaptable, and ready to form new neural connections. We simply guide it, helping it find alternative pathways. Smart technologies become faithful allies in this process: robotic exoskeletons that move with the child like a part of their own body, virtual reality that turns therapy into an adventure, and biofeedback systems that make the invisible visible, showing progress in real time.

Therapy here is not routine but creativity — every motion becomes a dance, every word a song, every emotion a brushstroke on the canvas of recovery. This is a space where science and art coexist for one purpose: to help a child regain control of their body and life.

The dream team — neurologists, psychologists, physical and speech therapists — work together as one family. But the most important members are always the child and their parents, whose faith and patience make the impossible possible.

And then the true miracle unfolds before our eyes: step by step, movement returns, words blossom, smiles reappear, and belief is reborn. Rehabilitation is not a pause between the hospital and home; it is a bridge between illness and life, a journey from surgery to possibility — the possibility to live, to dream, and to be happy.

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