


## REVIEW ARTICLE


# Use of 3D printing in pediatric neurosurgery: a narrative review

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## Uso de la impresión 3D en neurocirugía pediátrica: una revisión narrativa

**RESUMEN****Objetivo:** Analizar las aplicaciones de la impresión 3D en neurocirugía pediátrica, particularmente en la planificación preoperatoria, la simulación y entrenamiento quirúrgico, y la reconstrucción craneal mediante implantes personalizados.**Métodos:** Se realizó una revisión narrativa de la literatura científica. La búsqueda se efectuó el 20 de enero de 2026 en las bases de datos PubMed, Scopus y Google Scholar, incluyendo estudios publicados entre 2016 y 2025 sin restricción de idioma. Se consideraron estudios sobre el uso de la impresión 3D en neurocirugía pediátrica. Se incluyeron estudios de desarrollo y validación técnica, series de casos y reportes de caso. En total se seleccionaron 5 estudios.**Resultados:** Los estudios incluidos describieron aplicaciones de la impresión 3D en la planificación preoperatoria de deformidades vertebrales complejas y abordajes orbitarios, el desarrollo de simuladores anatómicos para entrenamiento en procedimientos mínimamente invasivos y la fabricación de implantes personalizados para la reconstrucción de defectos craneales.**Conclusiones:** La impresión 3D tiene aplicaciones prometedoras en neurocirugía pediátrica para la planificación quirúrgica, la formación de cirujanos y la reconstrucción craneal personalizada. Sin embargo, su implementación puede verse limitada por requerimientos tecnológicos, costos y tiempos de fabricación.**Palabras clave:** Impresión Tridimensional; Modelos Anatómicos; Neurocirugía; Pediatría; Procedimientos Neuroquirúrgicos (Fuente: DeCS)

## INTRODUCTION

Three-dimensional (3D) printing, also known as additive manufacturing or rapid prototyping, has undergone significant development since its introduction in the 1980s with stereolithography. This technology enables the fabrication of 3D objects through the successive deposition of material layers based on a digital model, which has significantly expanded its applications across multiple fields, including medicine (1).

In the clinical setting, 3D printing enables the transformation of medical images obtained through computed tomography or magnetic resonance imaging into patient-specific physical anatomical models. The process includes image acquisition, segmentation and 3D reconstruction, preparation of the digital model, and subsequent fabrication using different printing techniques. As a result, the patient's anatomy can be reproduced with high fidelity, enabling new applications in diagnosis, surgical planning, and medical education (2).

The development of various printing technologies, such as fused deposition modeling, stereolithography, and selective laser sintering, has improved model accuracy and expanded the range of materials used. These advances, together with cost reduction and increased printer availability, have facilitated the expansion of 3D printing use across multiple medical and surgical specialties (3).

In particular, neurosurgery has experienced a significant increase in the application of this technology. Neurosurgical pathologies often involve complex anatomical structures that are difficult to visualize using two-dimensional imaging. In this context, 3D-printed anatomical models provide a tangible representation of the patient's anatomy, facilitating spatial understanding of the involved structures and contributing to more precise surgical planning. Several studies have reported that this technology may improve anatomical visualization, support preoperative decision-making, and optimize the execution of complex neurosurgical procedures (4).

In addition to surgical planning, 3D printing has been used in medical education, the development of surgical simulators, and the fabrication of customized devices. Recent reviews have described applications in different neurosurgical subspecialties, including spine surgery, neurovascular pathology, neuro-oncology, neuroendoscopy, and cranioplasty. These applications have been shown to improve procedural accuracy, promote treatment personalization, and facilitate the training of surgeons and residents (5).

Among these applications, spine surgery represents one of the fields where 3D printing has demonstrated relevant benefits. In patients with spinal deformities, such as congenital scoliosis, pedicle screw placement is a technically complex procedure due to vertebral anatomical alterations and the risk of misplacement when conventional techniques are used. In this context, the use of 3D-printed models and navigation templates has been shown to improve the accuracy of pedicle screw placement and increase procedural safety (6). Furthermore, systematic reviews have highlighted that 3D printing improves the understanding of complex pathological processes, facilitates preoperative planning, and supports the design of surgical guides and customized implants in spinal surgery (7).

The applications of this technology have also gained increasing importance in the pediatric population. Pediatric patients present particular anatomical characteristics associated with growth and development, resulting in greater morphological variability and the need for highly individualized therapeutic approaches. In this context, 3D printing allows the creation of personalized anatomical models tailored to the specific needs of each patient, which is especially useful in rare or complex pathologies requiring detailed surgical planning (8).

One of the pediatric conditions in which 3D printing has demonstrated particular utility is craniosynostosis, a condition characterized by the premature fusion of one or more cranial sutures, which may result in cranial deformities and affect brain growth. Because the treatment of this condition requires highly individualized surgical interventions, 3D-printed anatomical models enable reproduction of the patient's anatomy and facilitate the planning of osteotomies and cranial remodeling (9).

Several studies have demonstrated that models printed from computed tomography images can adequately reproduce the patient's cranial anatomy and serve as useful tools for surgical planning. In particular, the use of models printed in materials such as acrylonitrile butadiene styrene, which exhibit mechanical properties similar to bone tissue, has been reported to enable simulation of surgical procedures before their execution in patients (10). Likewise, the use of 3D planning tools based on computer-aided design and manufacturing has improved the precision of bone cuts, optimized the positioning of cranial segments, and contributed to better surgical outcomes in cranial reconstruction procedures (11).

In addition to its usefulness in surgical planning, 3D printing has also demonstrated benefits in medical education and communication between the medical team and patients or their families. Physical anatomical models can be used as educational tools that facilitate understanding of anatomy, pathology, and the proposed surgical procedure, thereby improving the preoperative counseling process and informed consent, especially in the pediatric context (8).

Despite the growth in the use of this technology in different surgical fields, the available scientific evidence still presents limitations. Many published studies correspond to literature reviews, observational studies, or case series with small sample sizes, which makes it difficult to compare results and systematically evaluate the clinical benefits of 3D printing in different neurosurgical contexts (7).

In this context, it is necessary to analyze in a structured manner the available evidence on the use of 3D printing in pediatric neurosurgery. Therefore, this review aims to synthesize the existing scientific evidence on the applications of 3D printing in this field.

## METHODS

A narrative review of the scientific literature was conducted. The literature search was carried out in the PubMed, Scopus, and Google Scholar databases.

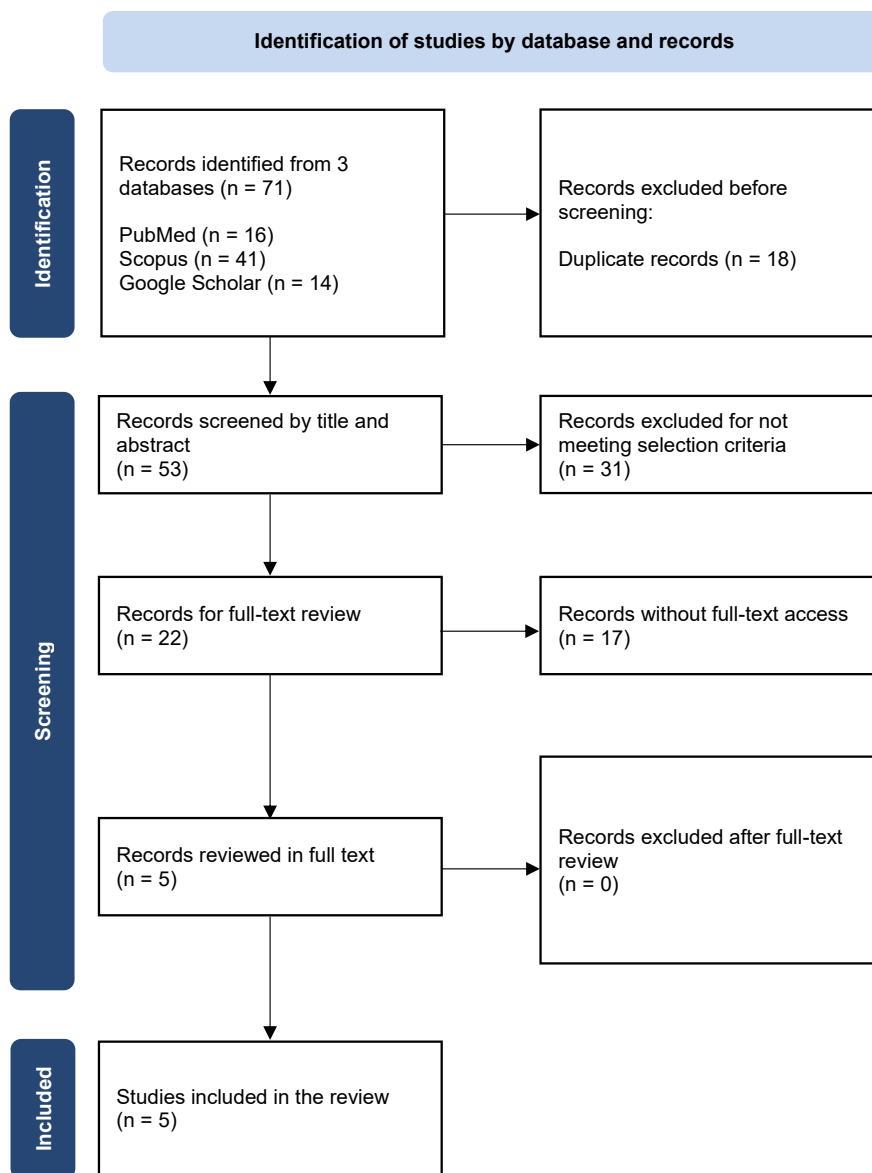
MeSH terms and keywords related to 3D printing and pediatric neurosurgery were used; in addition, Boolean operators such

as AND and OR were applied, adapting the strategy according to each database: ("3D printing" OR "three-dimensional printing" OR "additive manufacturing" OR "rapid prototyping") AND (neurosurgery OR neurosurgical OR "brain surgery" OR "cranial surgery" OR "skull base surgery") AND (pediatric OR paediatric OR child OR children OR infant)).

Studies published between 2016 and 2025 reporting aspects of the use of 3D printing in neurosurgical procedures in pediatric patients under 18 years of age were included. Different study designs were considered, including original experimental or technological development articles, case reports, and case series, without language restriction. Studies addressing both adult and pediatric populations without independent analysis, review studies, and studies whose full text could not be retrieved were excluded.

Records obtained from the selected databases were identified. After removing duplicate records, two reviewers independently assessed the titles and abstracts of the identified articles to determine initial eligibility. Subsequently, full-text access was sought for potentially relevant studies. Articles for which the full text could not be obtained were excluded. Studies with available full-text access underwent full-text evaluation to confirm eligibility. From each included study, information related to preoperative planning, simulation, and training, as well as reconstructive applications using 3D printing, was extracted.

The search yielded a total of 71 studies on January 20, 2026, using the described strategy. Subsequently, 18 duplicate studies were removed. Thus, during the review of 53 studies, 22 potentially relevant studies were identified by title and abstract. Finally, only 5 studies had full-text access available and were included (Figure 1).



**Figure 1.** Flow diagram of the study selection process

The study did not require ethical approval, as it was based exclusively on published literature and did not involve human participants.

## RESULTS

### Preoperative planning using 3D models

3D printing has been used as a tool to improve anatomical understanding and facilitate surgical planning in complex cases.

Facco *et al.* (12) described its use for surgical planning in 4 pediatric patients with complex spinal deformities, including cases of severe scoliosis. The models were generated from computed tomography scans and printed in thermoplastic material. Each model required approximately 5 hours of digital preparation and around 108 hours for printing, with an approximate cost of 180 euros per model. The authors reported that these models allowed improved understanding of the deformed anatomy, facilitated surgical planning, and contributed to more accurate selection of implant size.

Similarly, Sulin *et al.* (13) reported the use of 3D printing for planning a minimally invasive approach in an adolescent with an orbital tumor. Using magnetic resonance imaging, a model of the fronto-orbital region, anterior skull base, globe, and tumor was generated. This model allowed planning of surgical access and guidance of tumor resection. After the intervention, complete tumor resection was achieved, and improvement in visual symptoms was observed, suggesting that 3D modeling may serve as a complementary tool to optimize surgical planning and facilitate intraoperative navigation and visualization.

### Simulation and surgical training

Another relevant application of 3D printing is the development of anatomical models for surgical training and procedure simulation.

London *et al.* (14) developed a 3D-printed model of the pediatric skull base with the aim of evaluating its usefulness as a training tool for endoscopic endonasal procedures. The study included 28 professionals. Participants reported that the model presented an adequate level of anatomical and haptic realism, with scores approaching 7 on a 0–10 scale, assessed through questionnaires. The results indicate that these models may contribute to gaining experience with the anatomical limitations characteristic of the pediatric skull base, especially in contexts where clinical cases are infrequent.

Similarly, Weinstock *et al.* (15) developed a highly realistic simulator for endoscopic third ventriculostomy by combining 3D printing with special effects techniques used in the film industry. The model reproduced internal anatomical structures, vascular pulsations, and cerebrospinal fluid dynamics, allowing repeated practice of the procedure using replaceable components. Validation of the model using questionnaires and structured assessment of technical skills showed high scores for content and face validity, in addition to allowing differentiation of performance between residents and specialists, supporting its usefulness as a surgical training tool.

### Cranial reconstruction using customized implants

3D printing has also been applied in the fabrication of customized implants for repairing cranial defects in pediatric patients.

Sulin *et al.* (16) described the experience of a pediatric neurosurgery center in the use of these technologies to fabricate customized implants intended for closing cranial defects of different etiologies, sizes, and levels of complexity. The authors indicated that its use allows the design of implants adapted to the patient's specific anatomy, which may improve reconstructive precision. They also discussed advantages related to implant customization, as well as limitations associated with technological requirements and the manufacturing process. Among the advantages described are the ability to repair large and complex cranial defects, low risk of infectious complications, high mechanical strength, and applicability in defects of varying bone thickness. Additionally, the authors reported increased technological accessibility, as design software is increasingly intuitive and does not require specialized engineering training. On the other hand, limitations include reduced manufacturing speed, decreased quality and precision when attempting to accelerate the process, and limited use in emergency surgical situations.

## CONCLUSION

The included studies show that 3D printing has multiple applications in the field of pediatric neurosurgery. The main reported uses correspond to surgical planning in anatomically complex cases, simulation and training in neurosurgical procedures, and cranial reconstruction using customized implants.

The results suggest that these technologies may contribute to improving anatomical understanding, optimizing surgical preparation, and strengthening surgical training processes; however, their implementation may be limited by technological requirements, costs, and manufacturing times, especially in contexts requiring urgent interventions.

### Author contributions

AMFC: conceptualization, literature review, writing of the original manuscript draft.

ERYB: literature review, writing, supervision, manuscript review and editing.

### Conflicts of interest

The authors declare no relevant financial or non-financial conflicts of interest.

### Funding

This study did not receive external funding.

### Data availability

The extracted data and the tables prepared for this review are available upon request from the corresponding author.

### Use of artificial intelligence

The artificial intelligence tool ChatGPT (OpenAI) was used to assist with the writing and editing of the manuscript. The final content was reviewed and validated by the authors, who assume full responsibility for its integrity and accuracy. The use of this tool does not constitute authorship.

### Ethical aspects

This review was based exclusively on the analysis of previously published studies and did not involve the collection of primary data or direct interaction with human participants. Therefore, approval by an Institutional Research Ethics Committee was not required.

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