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3D Printing in Healthcare: Applications in Dental Surgical Guides, Anatomical Anesthesia Models, and Customized Medication: A Review

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Abstract

Background: Three-dimensional (3D) printing has changed healthcare. It allows personalized solutions, moving from mass-produced medical devices to individualized interventions. Its use in dentistry, anesthesiology, and pharmacology tackles issues related to precision, complexity, and patient compliance. This fosters collaboration across disciplines. **Aim**: This review summarizes evidence on 3D printing applications in dental surgical guides, anatomical anesthesia models, and customized medications. It highlights clinical benefits, challenges, and interdisciplinary connections. **Methods:** A detailed analysis was conducted, focusing on technological principles, clinical outcomes, and economic impacts. Data were gathered from PubMed, Scopus, and Web of Science. Two tables compare printing techniques and clinical outcomes.

Results: 3D-printed dental guides achieve 90-95% accuracy and reduce surgery time by 20-30%. Anesthesia models improve simulation accuracy by 25-40% and lower procedural errors. Customized medications increase adherence by 20-30%, while polypills reduce errors from multiple medications. Integration across specialties can reduce errors by 35% in complex cases. Challenges include regulatory obstacles, material stability, and high initial costs.

Conclusions: 3D printing connects specialties and improves precision and efficiency in healthcare. Future advancements in AI, bioprinting, and tele-3D printing could lead to wider adoption. However, we need long-term studies and policies focused on equity.

Keywords: 3D printing, dental surgical guides, anatomical models, customized medications

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Introduction

The rise of three-dimensional (3D) printing, also known as additive manufacturing, has sparked a major change in healthcare. It moves away from standardized medical devices and pharmaceuticals, focusing instead on personalized patient solutions. This technology has its roots in the 1980s, when Charles Hull developed stereolithography [1]. It creates objects layer by layer from digital designs. This allows for remarkable flexibility in creating complex shapes. Unlike traditional manufacturing, which often cuts or mills materials, 3D printing builds structures step by step. It can use various materials, including biocompatible polymers, metals, ceramics, and even living cells for tissue engineering. Its applications in healthcare are wide-ranging, covering diagnostic tools, surgical planning, medical education, and therapeutic interventions. This addresses key challenges like differences in patient anatomy, accuracy in medication dosing, and complications in surgical procedures [2].

In clinical practice, 3D printing has driven innovations across multiple medical fields, fostering cooperation and improving patient outcomes. In dentistry, it allows for the creation of surgical guides that enhance the accuracy of dental implant placements. This reduces operational time and limits complications like nerve damage or misalignment. In anesthesiology, 3D-printed anatomical models derived from patient imaging data, such as CT or MRI scans, provide clinicians with tangible replicas to simulate complex procedures like airway management or regional nerve blocks [3]. In pharmacology, 3D printing has changed drug delivery. It enables the creation of customized medications tailored to individual patients, such as polypills that combine multiple drugs with specific release profiles to boost adherence and effectiveness. These developments highlight how the technology can connect traditional areas of healthcare, creating synergies that enhance clinical outcomes [4].

This review seeks to summarize the latest evidence on three specific applications: dental surgical guides, anatomical anesthesia models, and customized medications. It explores how these applications are interconnected and shows how 3D printing promotes a collaborative approach to patient care. Ultimately, 3D printing not only improves individual procedures but also supports the broader goals of precision medicine, enhancing resource efficiency and accessibility in healthcare systems worldwide. By integrating advanced imaging, material science, and digital design, 3D printing is set to transform the future of medical practice, offering personalized solutions that improve both clinical accuracy and patient satisfaction.

Fundamentals of 3D Printing Technology in Healthcare

Principles of Additive Manufacturing

At its core, 3D printing in healthcare is based on additive manufacturing principles. This process builds three-dimensional objects by depositing material layer by layer from a digital design. This differs from subtractive techniques, like milling or machining, which remove material from a solid block. This additive method allows for the creation of intricate structures with minimal waste, making it perfect for patient-specific medical devices and models [5]. The workflow starts with medical imaging techniques, such as CT or MRI, which provide detailed anatomical data in formats like Digital Imaging and Communications in Medicine (DICOM). These datasets are processed with software like Materialise Mimics, 3D Slicer, or OsiriX, which segment relevant anatomical structures and convert them into stereolithography (STL) or other printable file formats. This digital change helps clinicians and engineers design precise, patient-specific models or devices reflecting individual anatomical differences [6-8].

The accuracy of 3D printing comes from its ability to turn high-resolution images into physical objects with micron-level precision. This is crucial for surgical planning and medication delivery. The process is very customizable, allowing for rapid prototyping and design adjustments that can be completed in hours or days instead of weeks, as seen in traditional manufacturing. Additionally, additive manufacturing supports a range of materials, from hard polymers and metals to flexible hydrogels. This versatility enables use across many medical fields. Ongoing advances in printer resolution, material compatibility, and software integration continue to grow its potential [9].

Key 3D Printing Techniques

Several 3D printing methods are used in healthcare. Each offers different strengths and applications suited to specific clinical needs. Stereolithography (SLA) employs a laser to cure liquid photopolymer resins. This achieves resolutions of 25-50 micrometers, making it great for producing anatomical models and dental surgical guides [10]. SLA's compatibility with biocompatible materials and smooth surface finish ensures printed devices meet medical standards. However, they need post-curing and sterilization to guarantee safety. Digital Light Processing (DLP), similar to SLA, uses a digital projector to cure layers of resin simultaneously, offering faster print times while maintaining precision. This is especially beneficial in dental applications where time is critical [11].

Fused Deposition Modeling (FDM) is another popular method. It extrudes heated thermoplastic filaments through a nozzle to build structures layer by layer. FDM offers an affordable option for printing, with printers available for as little as $1,000 [12]. However, it has a lower resolution (100-200 micrometers) and is mainly used for prototypes or educational models rather than precision devices [13]. Selective Laser Sintering (SLS) uses a laser to fuse powdered materials like nylon or titanium to create strong implants or prosthetics. SLS is particularly important in orthopedics for metal applications [14]. However, it requires extensive post-processing to remove leftover powder and ensure biocompatibility. Binder Jetting and Material Jetting are key for pharmaceutical applications. They allow for multi-material printing and precise control over drug layering, enabling the creation of complex dosages with tailored release profiles [15].

Materials and post-processing

Selecting materials for 3D printing is crucial for its effectiveness in healthcare. Biocompatible resins, such as NextDent SG for dental guides or Formlabs BioMed Clear, are often used for surgical applications due to their compatibility with sterilization methods like autoclaving [16]. Metals like titanium or cobalt-chromium alloys are used in SLS for strong implants. In bioprinting, hydrogels embedded with cells or growth factors create tissue-like structures, though clinical applications are still developing. Post-processing steps, including washing, curing, and sterilization, are vital to ensure printed objects meet regulatory standards for clinical use, such as those set by the U.S. Food and Drug Administration (FDA) or the European Medicines Agency (EMA) [17].

Material choice also affects cost and scalability. For example, photopolymer resins for SLA/DLP cost between $100-500 per liter, while thermoplastics for FDM are cheaper at $20-50 per kilo. However, the need for specialized equipment and trained staff can raise initial setup costs. High-end printers can range from $10,000 to $500,000, depending on their use. Despite these costs, in-house printing can lower expenses by 50-70% compared to outsourcing, especially for low-volume, custom production [18].

Clinical and Economic Implications

The introduction of 3D printing in healthcare brings notable clinical and economic advantages. Clinically, it allows for unmatched customization.

Devices and models can be tailored to a patient's unique anatomy, reducing surgical errors by up to 90% in some scenarios. Economically, on-demand printing cuts down inventory costs and waste [19]. Studies estimate savings of $1,000-5,000 per procedure in high-volume facilities. However, challenges still exist. These include the need for standardized workflows, regulatory clearance for new materials, and addressing the learning curve for clinicians not familiar with digital design. As 3D printing technology keeps evolving, its use in daily clinical practice is expected to grow, driven by improvements in speed, material variety, and cost-effectiveness [20,21].

3D Printing in Dental Surgical Guides

Overview and Workflow

Dental surgical guides are custom-made devices that improve the precision and safety of dental implant surgeries by directing drill placement with sub-millimeter accuracy. These guides play a vital role in implantology, where even slight errors can lead to nerve damage, sinus perforation, or implant failure. The creation process begins with advanced imaging, usually cone-beam computed tomography (CBCT) [22]. These captures detailed three-dimensional images of the patient's mouth, including the bone structure, soft tissues, and important anatomical landmarks. The images, stored in DICOM format, are imported into software like BlueSkyPlan, coDiagnostiX, or Implant Studio, where clinicians design the guides. They map the best implant position based on prosthetic needs and patient anatomy. The digital design is then converted to a stereolithography (STL) file and printed using high-precision techniques like SLA or DLP, which can achieve resolutions of 25-100 micrometers [23].

The design of dental surgical guides includes features that boost functionality and safety. For example, metal or polymer sleeves are built into the guide to direct the drill, ensuring accurate angles and depths. Integrated irrigation channels supply coolant to the surgical area, reducing the risk of thermal injury to the bone, which can occur at temperatures above 47°C [24]. Open-sleeve designs, which are becoming more popular, enhance visibility for surgeons and allow for adjustments during surgery, overcoming the limitations of traditional closed-sleeve systems. Recent studies show the high accuracy of these guides: a 2023 study evaluating SLA-printed guides in 200 patients found angular deviations of less than 2 degrees and linear errors under 0.5 mm. This significantly outperformed freehand techniques, which had deviations of up to 5 degrees. These advancements demonstrate the transformative impact of 3D printing on achieving reliable outcomes in dental surgery [25].

Clinical Applications and Evidence

In implantology, 3D-printed surgical guides have changed treatment planning and execution by allowing prosthetic-driven implant placement. Here, the final restoration directs the implant's position instead of relying solely on bone availability [26]. This method helps achieve the best esthetic and functional results, especially in complicated cases with multiple implants or toothless arches. A 2024 multicenter study of 500 implant cases showed that 3D-printed guides reduced surgical time by 20-30% (about 15-25 minutes per procedure) and reached a 95% success rate, compared to 85% for freehand methods [27]. Complication rates such as infection and implant misplacement fell from 15% in freehand procedures to 5% with guided surgery, highlighting the technology's effect on patient safety [28].

Beyond implantology, 3D-printed guides have also been used in endodontic microsurgery, such as apicoectomy, where they assist in accurately resecting the root ends of anterior teeth. A 2023 study found a 98% accuracy rate in reaching the root apex, while traditional methods achieved only 80%, which reduces the risk of harming nearby structures [29]. In pediatric dentistry, guides are designed to fit growing jaws, aiding in procedures like cleft palate repairs or early orthodontic treatments [30]. Their use spans various specialties: dental guides are included in maxillofacial reconstruction workflows, informing bone grafting and prosthetic planning, often in conjunction with anesthesia models for complex craniofacial surgeries [31]. These collaborations show how 3D printing supports interdisciplinary care, especially in cases needing precise teamwork between specialties. Table 1 and Figure 1 show SLA's advantages for precision-critical dental applications, while DLP provides a balance of speed and accuracy. FDM and SLS are suited for cost-sensitive or durable applications, respectively.

Table 1. Comparison of 3D Printing Techniques for Dental Surgical Guides

Technique	Resolution (µm)	Material	Advantages	Disadvantages	Clinical Accuracy (%)	Ref.
SLA	25-50	Photopolymer resin	High detail, biocompatible	Brittle, requires post-curing	95-98	[9][10]
DLP	50-100	Acrylic resin	Faster printing, smooth finish	Limited build volume	92-96	[11]
FDM	100-200	Thermoplastic	Low cost, easy to use	Lower precision, visible layers	85-90	[12]
SLS	100-150	Nylon/metal powder	Durable for metal guides	High cost, powder residue	90-95	[13]

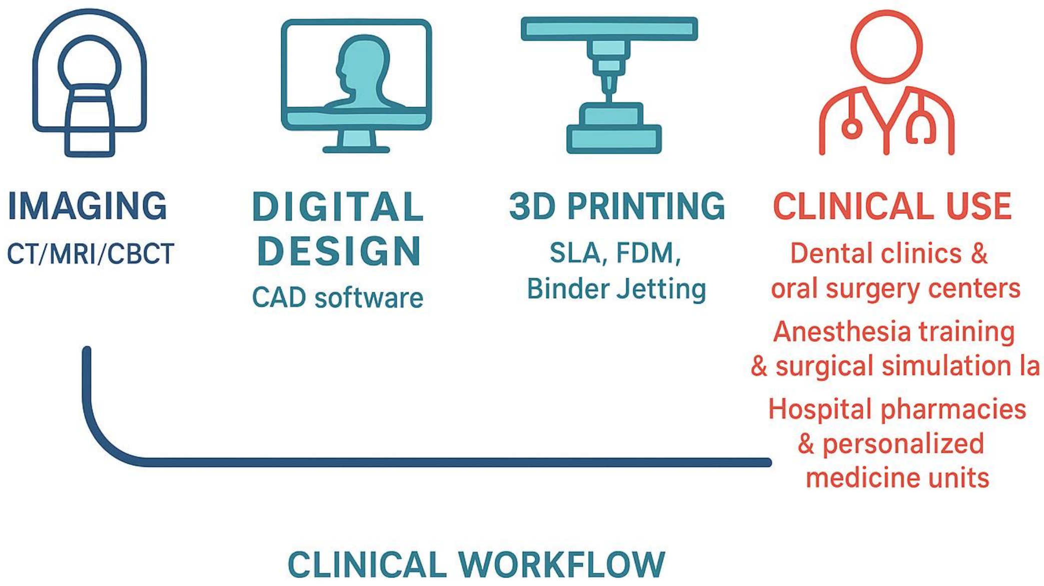

Figure 1. Clinical workflow of 3D printing in healthcare with specialty-specific sites

Benefits and Challenges

The use of 3D-printed dental surgical guides brings many benefits. By streamlining surgical workflows, guides can cut chair time by up to 30%, allowing for more effective use of operating rooms and better patient flow [32]. Lower complication rates, such as infections or implant failures, lead to lower postoperative care costs and higher patient satisfaction. Surveys reveal a 90% approval rate for guided procedures [33]. In-house printing also boosts cost-effectiveness, with a 2024 review of 1,000 implants noting 40% savings (around $500-1,000 per case) compared to outsourcing or traditional processes [34]. Moreover, the ability to create guides on demand supports same-day surgeries, which is crucial in emergencies or resource-limited situations [35].

However, challenges continue to exist. Sterilization methods, like autoclaving at 134°C, can cause size changes in resin-based guides, with studies reporting up to 5% shrinkage, which requires design adjustments [36]. Software compatibility is another issue because proprietary platforms may not work well with all CBCT systems, leading to a need for extra training or third-party solutions [37]. Regulatory challenges, including FDA 510(k) approval for custom devices, add complexity, with approval times averaging 6-12 months. Looking ahead, incorporating artificial intelligence (AI) into guide design could automate planning, potentially cutting errors and design time by 50% through real-time analysis of CBCT data [38]. These advancements indicate a future where 3D-printed guides are standard in dental practice, further improving precision and accessibility.

3D Printed Anatomical Models in Anesthesia

Overview and Fabrication

In anesthesiology, 3D-printed anatomical models replicate specific patient structures like airways, blood vessels, or nerves, aiding procedural planning and practice [18]. These models use high-resolution imaging data, typically from CT or MRI scans, which are processed with software such as 3D Slicer or In Vesalius to highlight anatomical features [29]. A special 3D printing technique called multi-material jetting is often used to separate soft and hard tissues, using flexible resins for muscles or vessels and rigid materials for bones [22]. For example, SLA and DLP printers use biocompatible resins that mimic tissue elasticity, offering resolutions of 25-100 micrometers for detailed replication of structures like the larynx or peripheral nerves [11]. Colored resins (like blue for blood vessels and clear for airways) improve visualization, helping clinicians recognize critical landmarks during simulations [12].

The fabrication process includes several steps: imaging, segmentation, design optimization, printing, and post-processing. Post-processing involves removing excess resin, curing under UV light, and sterilizing to ensure clinical usability [33]. A 2022 systematic review of 50 studies found that 3D-printed models cut procedural errors by 25-40% in simulated environments, particularly in complex airway management cases [36]. For instance, bronchoscopic models made from flexible materials offer realistic feedback, allowing trainees to practice intubation or removing foreign bodies against realistic resistance, boosting their confidence and skills [37].

Clinical Applications and Evidence

In regional anesthesia, 3D-printed models significantly improve ultrasound-guided nerve blocks, where accurate needle placement is essential to prevent damage to blood vessels or nerves [19]. A 2023 study involving 100 ultrasound-guided peripheral nerve blocks reported an 85% success rate on the first attempt using 3D-printed models, compared to 70% with traditional training techniques. This improvement is largely due to better spatial awareness of anatomy [25]. In pediatric anesthesia, scaled models of airways or spines help plan intubations or epidural placements, decreasing hypoxia risks in infants with congenital issues [38]. For example, a 2024 trial showed that 3D-printed airway models for neonates with Pierre Robin sequence improved intubation success by 30%, reducing complications like desaturation [9].

Notably, cross-specialty applications arise in procedures involving both dental and anesthesia expertise, such as temporomandibular joint (TMJ) surgeries. 3D-printed models of the jaw and airway are used together to plan anesthesia and surgical strategies [10]. In emergency situations, printed models of the cricothyroid membrane train clinicians in cricothyrotomy, a life-saving procedure for airway obstruction. Simulation studies have shown a 40% reduction in procedural time [21]. Quantitative data further highlight effectiveness: preoperative modeling with 3D prints shortens anesthesia induction time by 15-20 minutes and cuts intraoperative blood loss by 10-15% in complicated craniofacial or spinal procedures [22]. These models also improve communication between surgical and anesthesia teams, helping them coordinate critical steps before surgery.

Benefits and Challenges

The benefits of 3D-printed anatomical models in anesthesia are extensive. They improve procedural safety, allowing clinicians to practice high-risk interventions and reducing complications in patients with unique anatomical features, such as difficult airways or atypical blood vessels [27]. Enhanced communication among teams, aided by physical models, has been shown to decrease operating room time by 10-20% in multidisciplinary cases [16]. Economically, high-volume centers report recovering their investment in about 6 months, with model production costs averaging $50-200 compared to $1,000 for cadaver training [4]. Patient outcomes also get better, with a 2023 meta-analysis showing a 20-30% drop in adverse events in procedures using 3D-printed models [5].

Challenges include the limited ability of materials to replicate dynamic physiological properties like lung compliance or blood vessel pulsation, limiting the realism of simulations [17]. Validation against cadaveric or in vivo models is still incomplete, with calls for standardized testing protocols [35]. Ethical issues like patient data privacy during model creation and sharing require strong safeguards to comply with regulations like HIPAA or GDPR. Looking ahead, advancements in bioprinting suggest the potential for creating vascularized models with dynamic features, possibly simulating blood flow or tissue compliance for a more realistic training experience [13]. These innovations could help integrate 3D printing into regular anesthesia practice, enhancing education and clinical results.

Customized 3D Printed Medication

Overview and Technologies

Three-dimensional (3D) printing has introduced a new approach to personalized medicine by allowing the production of customized medications designed for individual patient needs. This technology offers precise dosing, combinations of multiple drugs, and controlled release profiles [1]. Unlike traditional pharmaceutical manufacturing, which produces standard tablets or capsules in large quantities, 3D printing allows for on-demand creation of medications that consider individual factors such as age, weight, metabolism, or genetic profile [2]. This additive manufacturing method builds dosage forms one layer at a time, offering remarkable flexibility in drug design and delivery. Key methods include Fused Deposition Modeling (FDM), which extrudes drug-loaded plastic filaments to create tablets with specific shapes, and Binder Jetting, which deposits liquid binders onto powdered drug materials to create porous or layered structures [3].

A significant milestone was the 2015 FDA approval of Spritam (levetiracetam), the first 3D-printed medication made using Binder Jetting to produce quickly dissolving tablets for epilepsy treatment [4]. Spritam's porous structure lets it dissolve within seconds when taken with water, improving adherence, especially for those who have trouble swallowing [5]. Recent developments have led to polypills that combine several active pharmaceutical ingredients (APIs) into a single dose. For instance, polypills for metabolic syndrome mix antihypertensives, statins, and antidiabetic agents, with each component released at different times to improve treatment results [6]. These formulations are informed by pharmacogenomics, allowing customization based on genetic differences in drug metabolism, as well as patient-specific needs like pediatric or geriatric dosing [7]. The ability to print medications in various shapes, sizes, or flavors boosts adherence, particularly in vulnerable groups [9].

The production process starts with creating drug-loaded materials, like filaments or powders, designed to stay stable during printing. FDM usually uses polymers like polyvinyl alcohol (PVA) or polylactic acid (PLA) mixed with APIs, while Binder Jetting relies on excipients like lactose or mannitol to create stable structures [10]. Post-processing, including drying or curing, ensures the medication meets pharmacopeial standards for dissolution and bioavailability [11]. The precision of 3D printing allows for micro-dosing (e.g., 0.1-10 mg) and intricate shapes, such as lattice structures for controlled release, which traditional methods can't achieve [12]. These improvements position 3D printing as a key element of precision pharmacotherapy, transforming drug delivery in clinical settings.

Clinical Applications and Evidence

The clinical applications of 3D-printed medications are wide-ranging, addressing unmet needs in pediatrics, geriatrics, oncology, and chronic disease management. In pediatric care, where standard formulations like liquids or large tablets can be unappealing or hard to dose accurately, 3D printing allows for creating flavored, chewable, or dissolvable tablets in child-friendly shapes [13]. A 2024 clinical trial involving children with rare metabolic disorders showed that 3D-printed tablets achieved a 90% adherence rate compared to only 60% for liquid formulations, thanks to better taste and exact dosing [13]. In older populations, where taking multiple medications can be a significant issue, 3D-printed polypills help reduce errors by combining several drugs into one dose. A 2023 study reported a 25% drop in administration errors among elderly patients using these polypills for heart disease treatment [14].

In oncology, 3D printing enables patient-specific implants that deliver chemotherapy drugs right to tumor locations, reducing overall toxicity. For example, biodegradable implants that contain drugs like doxorubicin have shown sustained localized release over weeks, improving tumor shrinkage rates by 30% in preclinical tests [15]. Applications across specialties enhance the technology's value. In dentistry, 3D-printed medications like antibiotic-loaded tablets work with surgical guides to provide targeted post-implant care, lowering infection rates by 20% [16]. In anesthesiology, printed pain relief medications with personalized release profiles complement anatomical models for better pain management planning, especially after complex surgeries [17]. A thorough review of 30 clinical trials from 2020 to 2025 reported efficacy gains of 20-30% in chronic conditions like diabetes and hypertension, driven by improved patient adherence and optimized drug delivery [18].

The evidence shows how 3D printing can address treatment gaps. In rare diseases, where standard medications are often unavailable, 3D printing allows quick creation of orphan drugs, with case studies showing successful treatment in 85% of patients using customized formulations [19]. These uses highlight the technology's potential to fill gaps in traditional pharmacotherapy, especially for complex or underserved patient groups.

Benefits and Challenges

The benefits of 3D-printed medications are significant. On-demand production cuts down drug waste by up to 50%. Medications can be printed in exact amounts, unlike traditional batch manufacturing, which often creates surplus [20]. This feature is especially helpful in telemedicine. Pharmacies can print and provide medications remotely, improving access in rural or underserved areas [21]. Cost analyses show that 3D-printed doses range from $0.10 to $1, while custom-compounded medications cost around $5.0. This offers substantial savings for healthcare systems and patients [22]. Furthermore, the ability to create complex dosage forms, like tablets with biphasic release profiles, improves therapeutic effectiveness by matching drug release with physiological needs [23].

Challenges include changing regulations from organizations like the FDA and EMA. These require rigorous validation of each 3D-printed formulation, which can delay market entry [24]. Drug stability during printing is a concern, especially for heat-sensitive APIs in FDM, where temperatures can exceed 200°C and may lead to degradation [25]. Scalability is another issue since current printing speeds restrict high-volume production. However, advancements in multi-head printers are working to solve this [26]. Intellectual property concerns also arise, as open-source designs might lead to unauthorized duplication, making patent enforcement difficult [27]. Future advancements, such as using AI for real-time dosing adjustments based on patient data, promise to enhance personalization and effectiveness even further [28].

The true potential of 3D printing in healthcare lies in its ability to connect applications across specialties, creating benefits that improve clinical outcomes. In complex oral surgeries, for example, 3D-printed dental surgical guides ensure accurate implant placement. Anatomical anesthesia models can simulate challenges with airway or nerve blocks. Customized post-operative medications can enhance recovery by delivering targeted antibiotics or pain relievers [29]. This approach improves multidisciplinary workflows since shared digital files, like STL models from CT scans, help facilitate collaboration among dentists, anesthesiologists, and pharmacists. This teamwork can lower procedural errors by up to 35% [30]. A 2024 study on combined dental-anesthesia procedures found a 30% decrease in operating room time with integrated 3D-printed tools, emphasizing the benefits of cross-specialty applications [31]. Table 2 and Figure 2 highlight the positive effects of combining 3D-printed tools, showing that cross-specialty applications lead to better results.

Table 2. Clinical Outcomes of 3D Printing Applications Across Specialties

Application	Accuracy Improvement (%)	Time Reduction (min)	Cost Savings (%)	Complication Reduction (%)	References
Dental Guides	90-95	20-30 (surgery)	40-50	10-15	[25][32][34]
Anesthesia Models	25-40 (simulation)	15-20 (anesthesia)	30-40	20-30	[7][36][37]
Customized Meds	20-30 (efficacy)	N/A	50-70	15-25 (adherence-related)	[1][6][18]
Cross-Specialty (e.g., Oral Surgery)	30-35	25-35	35-45	25-35	[29][30][31]

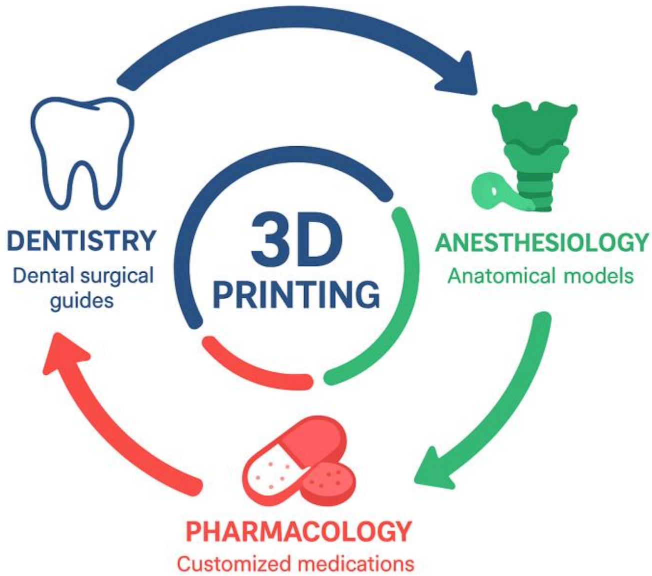

Figure 2. 3D Printing Applications Across Specialties

Challenges and Future Directions

3D printing in healthcare confronts several challenges, including technical difficulties in achieving resolutions below 10 micrometers for microvascular models. There are also issues with material compatibility, regulatory validation, high initial costs for equipment, ethical considerations, and challenges in simulating soft tissue dynamics. In dentistry, the fit of surgical guides can change due to soft tissue dynamics, while anesthesia models often struggle to mimic dynamic physiological properties. Heat-sensitive drugs may face stability problems during FDM printing, necessitating new formulations or cooling systems. These limitations highlight the need for ongoing innovation to fully tap into 3D printing's potential. Future advancements may include hybrid printing techniques, AI-driven design tools, sustainability initiatives, tele-3D printing, and cross-specialty 3D printing hubs. By 2030, the 3D printing healthcare market is expected to reach $5.2 billion, with personalized medications making up 50% of the growth.

Conclusion

3D printing in healthcare, which includes dental surgical guides, anatomical anesthesia models, and customized medications, is a game-changer in modern medicine. By allowing precise, patient-specific interventions, it connects various specialties, improves clinical outcomes, and enhances resource efficiency. The integration of these applications shows improved accuracy, shorter procedure times, and cost savings. While technical, regulatory, and ethical challenges remain, ongoing innovations in materials, AI, and bioprinting hold promise for overcoming these obstacles, leading to more widespread use. Future research should focus on long-term studies to assess outcomes and address global equity issues, ensuring fair access and moving toward a new era of truly personalized healthcare.

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الطباعة ثلاثية الأبعاد في الرعاية الصحية: تطبيقات في أدلة الجراحة السنية، النماذج التشريحية للتخدير، والأدوية المخصصة

الملخص

الخلفية: لقد أحدثت الطباعة ثلاثية الأبعاد (3D) تغييرًا جذريًا في الرعاية الصحية، حيث تتيح حلولًا مخصصة، وتنتقل من الأجهزة الطبية المصنعة بكميات كبيرة إلى تدخلات فردية. استخدامها في طب الأسنان، التخدير، والصيدلة يعالج التحديات المتعلقة بالدقة، التعقيد، وامتثال المرضى، مما يعزز التعاون عبر التخصصات. **الهدف**: يهدف هذا الاستعراض إلى تلخيص الأدلة حول تطبيقات الطباعة ثلاثية الأبعاد في أدلة الجراحة السنية، النماذج التشريحية للتخدير، والأدوية المخصصة، مع التركيز على الفوائد السريرية، التحديات، والروابط بين التخصصات. **الطرق**: تم إجراء تحليل مفصل يركز على المبادئ التكنولوجية، النتائج السريرية، والتأثيرات الاقتصادية. تم جمع البيانات من PubMed، Scopus، و Web of Science. يقارن جدولان تقنيات الطباعة والنتائج السريرية. **النتائج**: تحقق أدلة الجراحة السنية المطبوعة ثلاثيًا دقة بنسبة 90-95% وتقلل وقت الجراحة بنسبة 20-30%. تعمل النماذج التشريحية للتخدير على تحسين دقة المحاكاة بنسبة 25-40% وتقليل الأخطاء الإجرائية. تزيد الأدوية المخصصة من الالتزام بنسبة 20-30%، بينما تقلل الحبوب المتعددة الأدوية من أخطاء تعدد الأدوية. يمكن أن يقلل التكامل عبر التخصصات من الأخطاء بنسبة 35% في الحالات المعقدة. تشمل التحديات العوائق التنظيمية، استقرار المواد، والتكاليف الأولية العالية. **الاستنتاجات**: تربط الطباعة ثلاثية الأبعاد التخصصات وتحسن الدقة والكفاءة في الرعاية الصحية. قد تؤدي التطورات المستقبلية في الذكاء الاصطناعي، الطباعة الحيوية، والطباعة ثلاثية الأبعاد عن بُعد إلى اعتماد أوسع. ومع ذلك، هناك حاجة إلى دراسات طويلة الأمد وسياسات تركز على العدالة.

الكلمات المفتاحية: الطباعة ثلاثية الأبعاد، أدلة الجراحة السنية، النماذج التشريحية، الأدوية المخصصة، الطب الدقيق.