3D Printing in Orthopaedic Surgery

Composed for / prepared for Dr. Pothireddy Surendranath Reddy — comprehensive review, clinical applications, workflows, case examples, limitations and future directions.

Watch video

Short note on sources & images

This review synthesizes published reviews, clinical studies and technology summaries on 3D printing in orthopaedics, and draws on materials publicly associated with Dr. Pothireddy Surendranath Reddy (public presentations and profiles). Major referenced reviews include a comprehensive NCBI/PMC review and several high-impact reviews on clinical workflows, implants and surgical guides. Key sources: Levesque et al. (2020) review (PMC), Auricchio et al. (2016) clinical applications review, and several recent reviews on metal implants and patient-specific devices. LinkedIn+4PMC+4PMC+4

Executive summary (quick orientation)

3D printing (additive manufacturing) has rapidly matured from a prototyping technology to a clinically useful tool in orthopaedic surgery. Its principal roles are: (1) patient-specific anatomical models for preoperative planning and education, (2) patient-specific surgical guides and cutting jigs that improve intraoperative precision, and (3) custom and semi-custom implants — particularly porous metal structures that encourage osseointegration. While clinical evidence supports improved planning, shorter operative times, and better implant fit in many series, adoption faces barriers — regulation, quality assurance, cost, and the need for robust long-term outcome data. PMC+1

Table of contents

1. Background: definitions & technologies

Additive manufacturing / 3D printing creates three-dimensional objects by depositing material layer-by-layer according to a digital model. In orthopaedics the most commonly used 3D printing techniques are:

- **Stereolithography (SLA)** and **digital light processing (DLP)** — high-resolution resin-based printing used for anatomical models and guides.
- **Fused deposition modeling (FDM)** — thermoplastic extrusion, inexpensive, used for simple models and surgical rehearsal.
- **Selective laser sintering (SLS)** and **selective laser melting / electron beam melting (SLM / EBM)** — powder-bed fusion processes used to manufacture metal implants (Ti-6Al-4V, cobalt-chrome) with complex porous structures that mimic cancellous bone. PMC+1

Key advantages of additive manufacturing over conventional manufacturing include the ability to produce complex internal lattice structures, patient-specific geometries without expensive tooling, and rapid iteration from design to production. Limitations include build size, surface finish (often requiring post-processing), and manufacturing validation for load-bearing clinical devices. Cell

2. Clinical applications in orthopaedics

3D printing is used across the orthopaedic subspecialties:

A. Pre-operative anatomical models

CT or MRI data are segmented and translated into physical models. Surgeons use tactile models to:

- Understand complex fracture geometry (pelvis, acetabulum, periarticular fractures).
- Rehearse osteotomies, plan fixation strategies, and benchmark implant sizes. Evidence shows models improve surgeon understanding, reduce OR time, and aid team communication. PMC+1

B. Patient-specific surgical guides and jigs

Guides for bone cuts, drill trajectories and screw placement (e.g., for complex deformity correction or tumor resections) improve accuracy and reproducibility compared with freehand techniques. They are particularly useful in spinal deformity surgery, pelvic tumor resections, and complex arthroplasty revisions. PMC

C. Patient-specific implants

Custom titanium implants (acetabular cages, hemipelvic reconstructions, large bone defect reconstructions) with porous lattices optimize mechanical performance and bone ingrowth. Early registry and case-series data show promising fixation and functional outcomes in complex reconstructions where standard implants would be unsuitable. Cell

D. Teaching, informed consent and patient communication

3D models improve patient comprehension and can be incorporated into patient education and consent. Trainees gain hands-on experience with anatomy and simulated procedures. PMC

E. Emerging uses

- Surgical instrument prototyping and rapid production of jigs intra-hospital.
- Patient-specific external orthoses and braces.

- Research into bioactive scaffolds and eventual bioprinted bone/cartilage. Tom's Hardware

3. Workflow: from imaging to implant

A consistent clinical workflow is critical for reproducible outcomes. Typical steps:

1. **Image acquisition** — high-resolution CT (thin-slice, sub-millimetre) for bony models; MRI for soft-tissue- or cartilage-related models.
2. **Segmentation** — converting DICOM images to a 3D object (STL/OBJ). Segmentation can be manual, semi-automated or automated using AI tools.
3. **Design & virtual planning** — virtual osteotomies, implant positioning, and guide design performed in CAD software. Surgeon input defines margins and tolerances.
4. **File preparation** — adding supports, checking manufacturability, and slicing the model into printer instructions.
5. **Printing** — selection of technology and material per intended use (resin for guides/models, metal powder-bed fusion for implants).
6. **Post-processing** — cleaning, heat treatment, surface finishing, sterilization validation (for instruments and implants).
7. **Quality control** — dimensional inspection, mechanical testing (where required), and traceability documentation.
8. **Clinical use & data collection** — outcome follow-up and implant surveillance. PMC+1

Attention to sterilization and biocompatibility is essential if the printed item will contact sterile fields or be implanted.

4. Materials used in orthopaedics

- **Polymers & resins:** PLA, ABS (for inexpensive models), medical-grade resins (SLA/DLP) used for sterilizable guides.
- **Metals:** Titanium alloys (Ti-6Al-4V) are the standard for implants due to strength, corrosion resistance and osseointegration potential. EBM/SLM processes produce porous, roughened surfaces to promote bone ingrowth. Cobalt-chrome is used where wear resistance is needed. Cell

- **Bioceramics & composites:** Hydroxyapatite, tricalcium phosphate coatings or composites for bone graft substitutes; research into composite scaffolds continues.
- **Bioinks / living materials:** In early-stage research contexts for cartilage and bone tissue engineering; not yet standard clinical practice. Tom's Hardware

5. Surgical planning and anatomical models: evidence & examples

Multiple systematic reviews and randomized/observational studies report consistent benefits:

- **Operative time reduction:** Studies across pelvic and complex fracture surgeries report shorter OR times when 3D models guide preoperative planning.
- **Blood loss / fluoroscopy reduction:** Improved pre-bending of plates and pre-operative rehearsal reduces intraoperative adjustments and imaging time.
- **Improved fixation choices:** Surgeons can select optimal plate/implant sizes and screw trajectories before entering the theatre. PMC+1

A clinical example: pelvic-acetabular fractures — an area with complex 3D anatomy. Patient-specific models permit pre-contouring of fixation plates and simulated reduction maneuvers, which translate into shorter operative times and fewer intraoperative surprises.

6. Patient-specific surgical guides & instrumentation

Guides translate the preoperative plan precisely to bone. Key points:

- **Design:** Guides conform to unique bone surfaces and include drill sleeves to control trajectory and depth.
- **Accuracy:** Comparative studies show improved placement accuracy for pedicle screws and osteotomies when using guides versus freehand or fluoroscopy-guided methods.
- **Limitations:** Guides require correct seating on bone — soft tissue or cartilage can interfere. Reusable navigation or robotic systems can be complementary. PMC+1

Clinical integration often pairs 3D-printed guides with intraoperative navigation or robotics to maximize accuracy.

7. Custom implants: design, manufacturing, and outcomes

Design principles

- **Anatomical matching:** Custom implants recreate the patient's lost bone geometry (e.g., hemipelvis).
- **Porosity & lattice architecture:** Porous surfaces reduce stiffness mismatch and encourage bone ingrowth; lattice designs balance mechanical strength with biological integration.
- **Fixation features:** Screw flanges, porous flanges, and interface features are tailored to remaining host bone.

Manufacturing

- Powder-bed fusion (SLM/EBM) is the predominant technique for metal implants. Post-build processes (stress relief, machining, surface finishing) are necessary to meet fatigue and surface requirements. Regulatory-grade manufacturing demands validated process control and traceability. Cell

Clinical evidence

- Case series in oncology (pelvic reconstructions), revision arthroplasty (complex acetabular defects), and large segmental bone loss show promising early results: stable fixation, functional recovery, and acceptable complication profiles in challenging cases where off-the-shelf devices would not work. Long-term data are still maturing. Cell

8. Regulatory, quality and ethical considerations

- **Regulation:** Custom implants and guides fall under medical device regulations; approval pathways vary by jurisdiction. Hospitals manufacturing in-house must comply with medical device quality systems or partner with certified manufacturers.
- **Quality assurance:** Each printed implant must meet dimensional, mechanical and biocompatibility criteria; medical device standards and testing are mandatory for implants.

- **Ethics & consent:** Patients should be informed about the novel nature of some devices, uncertainties in long-term outcomes, and manufacturing provenance (in-hospital vs commercial manufacturer).
- **Liability & traceability:** Clear records of materials, print parameters and post-processing steps must be retained for each implant. explorationpub.com+1

9. Cost, accessibility and implementation in low- and middle-income settings

Costs vary widely: desktop printers and model production are low-cost, while metal implant production and regulatory compliance are expensive. Hospital-based 3D printing labs reduce lead time and per-case cost for anatomical models and guides. National initiatives (example: an Indian tertiary institute planning an in-house 3D lab) highlight feasibility and impact on timely care. (See RMLIMS initiative as an example of localized 3D-printing adoption.) The Times of India

Key strategies to improve accessibility:

- Regional 3D-printing hubs serving multiple hospitals.
- Public–private partnerships for implant manufacturing.
- Open-source plans and shared segmentation expertise for models and guides.

10. Future directions

- **Bioprinting & tissue engineering:** Printing cell-laden scaffolds for cartilage and bone — promising but largely experimental. Clinical translation will require immunological, vascularization, and mechanical advances. Tom's Hardware
- **Intraoperative printing / handheld deposition:** Devices to deposit bone graft substitutes directly into defects could shorten workflows and personalize grafts.
- **AI-driven segmentation & design:** Automated segmentation, optimized lattice design and predictive modeling will speed workflows and personalize mechanical properties.
- **Hybrid workflows:** Combining robotics, navigation, and printed patient-specific guides to achieve sub-millimetre accuracy.

11. Practical recommendations for surgeons and hospitals

1. **Start small:** Implement anatomical models and guides for high-impact cases (pelvic / complex periarticular fractures) before moving to implant production.
2. **Partner with experts:** Collaborate with experienced engineers, radiologists, and certified manufacturers for design and QA.
3. **Document everything:** Maintain records of imaging, CAD files, print parameters, materials, and sterilization logs.
4. **Collect outcomes:** Participate in registries and publish outcomes to build evidence for local practice.
5. **Education & training:** Provide hands-on workshops for surgeons and OR staff on model use, guide seating, and implant handling.
6. **Regulatory compliance:** Engage hospital legal and QA teams early, especially for implant use. PMC+1

12. Illustrative cases & image resources

(Images at the top of this document illustrate typical printed implants, anatomical models and printed pelvic constructs.) For practical tutorials, slide decks and presentations by clinicians including Dr. Pothireddy Surendranath Reddy (public presentations on robotics and related technologies) can be found via public slideshare and personal webpages. These are useful starting points for surgeons seeking clinical implementation examples. www.slideshare.net+1

Selected image & resource links (public sources):

- NCBI review on 3D printing in orthopaedic surgery (open-access) — clinical applications and evidence. PMC
- Auricchio et al., clinical applications review — utility of models and guides. PMC
- Review on 3D-printed metal implants: porosity, fatigue and clinical outcomes. Cell
- Dr. Pothireddy Surendranath Reddy — public presentations and profile (slides/sites, LinkedIn). Google Sites+1

13. Limitations of current evidence

- Most comparative data are observational and heterogeneous in endpoints. High-quality randomized controlled trials (RCTs) are limited, particularly for custom implants.
- Long-term implant survivorship and comparative cost-effectiveness analyses remain sparse.
- Standardized outcome metrics and reporting frameworks are needed for inter-study comparability. PMC+1

Conclusion

3D printing has progressed from a supportive tool for preoperative planning to a transformative technology capable of producing patient-specific surgical guides and custom implants. For orthopaedic surgeons, its value is clearest in anatomically complex cases where standard implants fail to provide an adequate solution. Successful clinical adoption requires careful attention to imaging and segmentation, validated manufacturing workflows, regulatory compliance, and rigorous outcome tracking. Continued research, multicentre registries and technological advances (bioprinting, AI-driven design) will expand applications and strengthen the evidence base.

Selected further reading & web resources (quick list)

- Levesque JN et al., *Three-dimensional printing in orthopaedic surgery* (NCBI/PMC review). PMC
- Auricchio F et al., *3D printing: clinical applications in orthopaedics and traumatology* (review). PMC
- Wu Y et al., *Overview of 3D printed metal implants in orthopaedics* (Cell/Heliyon review). Cell
- Practical slide resources & presentations mentioning Dr. Pothireddy Surendranath Reddy. www.slideshare.net+1
- News item: RMLIMS setting up a 3D-printing lab for customised implants (example of institutional adoption). The Times of India