Editorial

The expanding use of three-dimensional printing in orthopaedic and spine surgery

Albert T. Anastasio[1], Emily M. Peairs[2], Troy Q. Tabarestani[2], Billy I. Kim[2], Samuel B. Adams[1], Robert K. Lark[1]

[1]Department of Orthopaedic Surgery, Duke University, Durham, NC, USA; [2]School of Medicine, Duke University, Durham, NC, USA

Correspondence to: Albert T. Anastasio, MD. Department of Orthopaedic Surgery, Duke University, 200 Trent Drive, Durham, NC 27710, USA. Email: Albert.anastasio@duke.edu.

Comment on: McLaughlin WM, Donnelley CA, Yu K, *et al.* Three-dimensional printing versus freehand surgical techniques in the surgical management of adolescent idiopathic spinal deformity. J Spine Surg 2022;8:234-41.

Submitted Jul 18, 2022. Accepted for publication Aug 16, 2022.

doi: 10.21037/jss-22-63

View this article at: https://dx.doi.org/10.21037/jss-22-63

We read the following manuscript from McLaughlin *et al.* with great interest: "*Three-dimensional printing versus freehand surgical techniques in the surgical management of adolescent idiopathic spinal deformity*" (1). We commend the authors on their careful methodologies, and we find the conclusions from the paper to be interesting with regards to decreased intraoperative blood loss and faster pedicle screw placement from surgical residents with the utilization of three-dimensional (3D) printed guides. At our institution, the use of 3D printing in our surgical practice has expanded over the last decade and is a topic of great excitement within our community. Thus, our intent in this editorial is to briefly review the history and usage of 3D printing in orthopedic surgery in general, and to give some remarks on its usage in spine surgery specifically.

3D printing in orthopedic surgery

The field of 3D printing was introduced by Charles Hull in the 1980s (2). As a simplified explanation, 3D printers utilize computer-based design instructions to build objects from the bottom up, moving in the x-y plane while traveling up the z-axis (3). Since its inception, 3D printing has expanded across various commercial applications, with its medical usage one of recent interest. From polyethylethylketone skull implants to prosthetic ears, 3D printing has expanded the possibilities of precisely tailored interventions geared towards patient-specific applications (4). Within the field of orthopedic surgery, 3D printing has impacted patient care and education in numerous subspecialties, given the limitations of two-dimensional (2D) modalities to provide adequate visualization of some bony abnormalities. 3D printing has revolutionized both pre-operative education and planning as well as intraoperative precision and accuracy.

With regards to pre-operative planning and education, 3D printed anatomic models that mirror patient specific anatomy and pathology can provide a much more comprehensive model and greatly enhance the understanding of a deformity (5). Printed models can be beneficial in building a solid anatomical foundation for trainees. Medical students studying anatomy with 3D technology and 3D printed artificial cadavers have shown to benefit more than when using 2D images and textbooks (6). Similarly, patients show improved understanding when a 3D model is used (7). Residents were surveyed regarding the clinical utility of 3D printed models when planning their approach for a pedicle screw fixation, and, overall, they reported being "very satisfied" with their preparations (8). Additionally, 3D models have crucial applicability in pre-operative planning for complex surgeries. After examining a visual model, 70% of experienced surgeons highly recommended the use of 3D models, while an additional 70% of orthopedic surgeons decided to change their surgical plan after visualizing the model (9). Morgan *et al.* (5) concluded in their systemic review that the use of 3D printing in pre-operative planning for orthopedic trauma reduced operative time, intraoperative blood loss, and fluoroscopy use, thereby reducing radiation exposure to both the patient and operating team. Multiple other studies have corroborated these results, further validating the clinical utility of pre-operative planning with a visual 3D model (10,11).

Intraoperative utilization of 3D printing technology is also becoming commonplace across orthopedics, specifically with regards to patient specific instrumentation (PSI) and custom prosthetics. In both cases, the manufacturer and the surgeon collaborate to design surgical guides or prosthetic implants based off advanced imaging. PSI specifically has been tested in both total knee (TKA) and total hip arthroplasties (THA). While studies have shown mixed results for TKA, Schwarzkopf *et al.* (12) illustrated that PSI could provide significant benefit for THA, as placement of the acetabular cup must be as precise as possible to achieve optimal outcome. PSI can lead to shorter operative times, less blood loss, shorter lengths of stay, and higher patient-reported outcome scores in operative fixation of tibial plateau fractures (13). With regards to 3D printing of prosthetic implants, procedures that were previously too complex for traditional techniques given patient-to-patient variability can now readily be performed (14). Novel talar/tibial protheses, tissue-engineered total disk replacements, and various other anatomic locations can be custom-created to fit a patient's specific needs. For example, a custom total ankle total talus replacement (TATTR) using PSI with built in tunnels for a Brostrom-Gould augmentation is available (15). Additionally, 3D printing technology has revolutionized the design, production, and market for orthotics. Custom ankle-foot and upper extremity orthotics have been linked to higher levels of comfort, function, and satisfaction when compared to baseline generic products (16).

3D printing in spine surgery

Despite the widespread increase in applications of 3D printing across orthopedics, its use in spine surgery has been complicated by difficulty in reproducing full spine models requiring highly specialized and expensive equipment. Moreover, surgeons may be unaware of the applicability of 3D printing to their operations. Broadly, the use of 3D printing in spine surgery can be categorized into three groups: models for pre-operative planning or teaching, templates for procedural accuracy, and custom tools or implants. Posterior spinal fusion for scoliosis is one of the most commonly utilized applications of 3D printed intra-operative templates in spine surgery (17). Insertion of pedicle screws, especially in hemivertebra, severely rotated or small vertebrae, or in short segment fusions, can be exceedingly difficult. There can be a high risk of injury to surrounding nerve roots, major vessels, and the spinal cord. 3D printed templates, custom-designed for each patient to assist in pedicle placement, have increased in popularity in recent years to harness this technology to decrease complications and improve accuracy of pedicle screw placement.

Current pedicle screw placement methods include freehand, the use of a navigation system, and robot-assisted placement. The majority of research compares the efficacy, accuracy, and safety of 3D printed templates to the freehand technique, due to the considerably higher technical and cost investments required for robot-assisted and navigation based techniques (18,19). 3D printed templates generally improve procedural accuracy and placement of screws. Vissarionov *et al.* (17) found that 3D printed templates increased the accuracy of screw placement from 53.8% to 94.4% compared to freehand in the correction of congenital scoliosis. Cao *et al.* (20) found a higher "excellent accuracy" rate, defined as Kawagachi Grade 0, when using 3D templates compared to free-hand. Luo *et al.* (21) conducted a systematic review which found that a significantly higher proportion of screws were placed accurately in the 3D printed guided procedures than in the freehand cohort. Tu *et al.* (22) found similar results, with a significantly higher accuracy of screw placement.

However, the impact of 3D templates surrounding intra-operative blood loss, complication rates, and surgical efficacy is not as clear. While most studies have found comparable surgical outcomes in terms of Cobb angle and kyphosis few studies have evaluated long-term patient follow-up or revision rates (22,23). Some studies showed a decrease in operative time, but this was not consistent; variations may exist based on surgeon cohort, procedure variability, or sample size (20,24). Similarly, other studies reported a decreased operative blood loss or decreased complication rate that was not consistent across the literature (19,25).

While there have been numerous studies illustrating increased accuracy of screw placement with 3D printed guides, the effects of these new tools on safety and outcomes are not fully elucidated. Moreover, utilization of 3D-printed templates in adult patients may differ substantially from usage in pediatric patients (21). Thus, the adult literature cannot be applied writ large to pediatric populations. Furthermore, these technologies require significant costs in the way of technology and materials, as well as increased screw numbers (20). It is reasonable to consider this technology in conjunction with operative complexity, surgeon capabilities, and hospital resources when weighing the costs and benefits of 3D templates in the treatment of congenital scoliosis.

Conclusions

The introduction of 3D printing to the field of orthopedics has revolutionized pre-operative planning capabilities, intra-operative techniques, and widespread availability of patient-specific prosthetic options. Utilization of 3D printing guides for pedicle screw placement is underreported in the literature and is chiefly focused on adult populations. Additional high-quality studies with long-term follow-up are indicated in the pediatric scoliosis literature if the high cost associated with these techniques can be justified with improved patient outcomes.

Acknowledgments

Funding: None.

Footnote

Provenance and Peer Review: This article was commissioned by the editorial office, *Journal of Spine Surgery*. The article did not undergo external peer review.

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://jss.amegroups.com/article/view/10.21037/jss-22-63/coif). SBA reports consultant services for Conventus/Flower, DJO, Exactech, Inc., Orthofix, Inc., Regeneration Technologies, Inc., and Stryker and holds stock or stock options for Medshape. He serves as a board or committee member for the American Orthopaedic Foot and Ankle Society. RKL reports paid consultant services for Nuvasive, and TrackX and unpaid consultant services for Innovations 4 Surgery, and Orthopaedic Innovations. He serves as a board or committee member for the Pediatric Orthopaedic Society of North America and Scoliosis Research Society. He also reports other financial or material support from DePuy and Johnson & Johnson Company. The other authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

References

1. McLaughlin WM, Donnelley CA, Yu K, et al. Three-dimensional printing versus freehand surgical techniques in the surgical management of adolescent idiopathic spinal deformity. J Spine Surg 2022;8:234-41.
2. Schubert C, van Langeveld MC, Donoso LA. Innovations in 3D printing: a 3D overview from optics to organs. Br J Ophthalmol 2014;98:159-61.
3. Kadakia RJ, Wixted CM, Kelly CN, et al. From Patient to Procedure: The Process of Creating a Custom 3D-Printed Medical Device for Foot and Ankle Pathology. Foot Ankle Spec 2021;14:271-80.
4. Jindal S, Manzoor F, Haslam N, et al. 3D printed composite materials for craniofacial implants: current concepts, challenges and future directions. Int J Adv Manuf Technol 2021;112:635-53.
5. Morgan C, Khatri C, Hanna SA, et al. Use of three-dimensional printing in preoperative planning in orthopaedic trauma surgery: A systematic review and meta-analysis. World J Orthop 2020;11:57-67.
6. O'Reilly MK, Reese S, Herlihy T, et al. Fabrication and assessment of 3D printed anatomical models of the lower limb for anatomical teaching and femoral vessel access training in medicine. Anat Sci Educ 2016;9:71-9.
7. Bizzotto N, Sandri A, Regis D, et al. Three-Dimensional Printing of Bone Fractures: A New Tangible Realistic Way for Preoperative Planning and Education. Surg Innov 2015;22:548-51.
8. Kim JW, Lee Y, Seo J, et al. Clinical experience with three-dimensional printing techniques in orthopedic trauma. J Orthop Sci 2018;23:383-8.
9. Kang HJ, Kim BS, Kim SM, et al. Can Preoperative 3D Printing Change Surgeon's Operative Plan for Distal Tibia

Fracture? Biomed Res Int 2019;2019:7059413.
10. Yang L, Shang XW, Fan JN, et al. Application of 3D Printing in the Surgical Planning of Trimalleolar Fracture and Doctor-Patient Communication. Biomed Res Int 2016;2016:2482086.
11. You W, Liu LJ, Chen HX, et al. Application of 3D printing technology on the treatment of complex proximal humeral fractures (Neer3-part and 4-part) in old people. Orthop Traumatol Surg Res 2016;102:897-903.
12. Schwarzkopf R, Schnaser E, Nozaki T, et al. Novel, Patient-Specific Instruments for Acetabular Preparation and Cup Placement. Surg Technol Int 2016;29:309-13.
13. Xie L, Chen C, Zhang Y, et al. Three-dimensional printing assisted ORIF versus conventional ORIF for tibial plateau fractures: A systematic review and meta-analysis. Int J Surg 2018;57:35-44.
14. Banks J. Adding value in additive manufacturing: researchers in the United Kingdom and Europe look to 3D printing for customization. IEEE Pulse 2013;4:22-6.
15. Mu MD, Yang QD, Chen W, et al. Three dimension printing talar prostheses for total replacement in talar necrosis and collapse. Int Orthop 2021;45:2313-21.
16. Graham J, Wang M, Frizzell K, et al. Conventional vs 3-Dimensional Printed Cast Wear Comfort. Hand (N Y) 2020;15:388-92.
17. Vissarionov SV, Kokushin DN, Khusainov NO, et al. Comparing the Treatment of Congenital Spine Deformity Using Freehand Techniques In Vivo and 3D-Printed Templates In Vitro (Prospective-Retrospective Single-Center Analytical Single-Cohort Study). Adv Ther 2020;37:402-19.
18. Du JP, Fan Y, Wu QN, et al. Accuracy of Pedicle Screw Insertion Among 3 Image-Guided Navigation Systems: Systematic Review and Meta-Analysis. World Neurosurg 2018;109:24-30.
19. Lieberman IH, Kisinde S, Hesselbacher S. Robotic-Assisted Pedicle Screw Placement During Spine Surgery. JBJS Essent Surg Tech 2020;10:e0020.
20. Cao J, Zhang X, Liu H, et al. 3D printed templates improve the accuracy and safety of pedicle screw placement in the treatment of pediatric congenital scoliosis. BMC Musculoskelet Disord 2021;22:1014.
21. Luo M, Wang W, Yang N, et al. Does Three-dimensional Printing Plus Pedicle Guider Technology in Severe Congenital Scoliosis Facilitate Accurate and Efficient Pedicle Screw Placement? Clin Orthop Relat Res 2019;477:1904-12.
22. Tu Q, Chen H, Ding HW, et al. Three-Dimensional Printing Technology for Surgical Correction of Congenital Scoliosis Caused by Hemivertebrae. World Neurosurg 2021;149:e969-81.
23. Pan A, Ding H, Hai Y, et al. The Value of Three-Dimensional Printing Spine Model in Severe Spine Deformity Correction Surgery. Global Spine J 2021. [Epub ahead of print]. doi: 10.1177/21925682211008830.
24. Yu C, Ou Y, Xie C, et al. Pedicle screw placement in spinal neurosurgery using a 3D-printed drill guide template: a systematic review and meta-analysis. J Orthop Surg Res 2020;15:1.
25. Thayaparan GK, Owbridge MG, Thompson RG, et al. Designing patient-specific solutions using biomodelling and 3D-printing for revision lumbar spine surgery. Eur Spine J 2019;28:18-24.

Cite this article as: Anastasio AT, Peairs EM, Tabarestani TQ, Kim BI, Adams SB, Lark RK. The expanding use of three-dimensional printing in orthopaedic and spine surgery. J Spine Surg 2022;8(3):300-303. doi: 10.21037/jss-22-63

