A REVIEW ON: 3D Printing in Spine Surgery

[1]Shivi Tripathi, [2]Dr. Ashish Manoria, [3]Dr. Pankaj Agrawal

[1]ME Scholar at Mechanical Department SATI Vidisha , MP , India , [2]Professor at Mechanical department , SATI Vidisha, MP, India , [3]Head of Department at Mechanical department SATI Vidisha MP , India.

Abstract : : Additive manufacturing is rapidly appearing technology which is being successfully implemented in various fields like medical fields , automobile industries , aerospace industries and so on. In this paper I am giving the review of use of 3d printing in medical field and the specific goal of this paper is to understand the steps involved in 3d printing of any model . Additive manufacturing technology is a bottom up manufacturing approach that prints objects in a layer fashion means one layer at a time from three dimensional model . This process can freely couturier the shape and local material properties because as the material is deposited in small quantity at a time . The best part of this technology is that a single instrument can print wide range of shapes as well as change of design is simple and it involves reprogramming but not retooling . The main advantage is designs can be emailed acrossed the globe and printed locally. In this paper I am focusing on the use of 3d printing in spine surgery and its benfits during complicated spine surgeries .

***IndexTerms* - - scanning, MRI Imaging, 3d printing machine, printing material**

I. INTRODUCTION

The implantation of spinal instrumentation remains a challenging and critical aspect of spine surgery. The advent and advancement of additive manufacturing technology over the last 30 years has shown promise in aiding surgeons with insertion of spinal instrumentation. Three-dimensional (3D) printing has also gained popularity in the development of novel spinal implants. This new technology could be used to develop personalized implant guides or other patient-specific implantable spinal instrumentation. Conventional surgical instruments and drill guides are designed to be used many hundreds of times on a variety of patients for multiple procedures. These guides are designed to be durable and simple. The method and skill in which these tools are used however depend wholly on the surgeon and his/her training and experience. Placing pedicle screws by anatomy and feel requires significant skill but the least ancillary equipment. Inserting these screws in the cervical spine or in the setting of complex deformities may increase the risk to neurovascular structures. Placing screws by Carm fluoroscopy aids the surgeon in visualizing the anatomy that might not be seen with surgical exposure alone. Intraoperative fluoroscopy does increase the radiation to the patient as well as the surgeon, additive over their career. X-ray imaging is not always fail-safe especially in cases of lateral imaging which can be difficult in the cervical-thoracic junction and in patients with a challenging body habitus. Surgeons can therefore benefit from techniques that do not rely on X-ray imaging intraoperatively. Computerized tomographyeguided navigation has gained popularity over the last several years in an attempt to alleviate some of these concerns. It is largely an accurate, albeit expensive, option. The downsides include the reliance on static patient positioning, the high start-up cost of the equipment. This technology is not new, but it was previously very expensive to purchase printers and required extensive training to master. Increased interest outside of medicine has driven costs down. Software used with this equipment has also improved in capability and user interface. This has resulted in increased access for nonengineers and hobbyists, some of whom happened to be surgeons. 3D printing technology allows for creation of patient-specific implants and implant guides. These can be printed on an as-needed basis to fit patientspecific anatomy. Off-the-shelf implants can use 3D printing to generate specific surface coatings. These implants could also be printed as needed to cut down on inventory demands. 3D printing of patientspecific drill guides, implants, and surface coatings have already been created throughout the world with a few centers outside of the United States currently leading the way. Even with this new progress, additive manufacturing for use in the operating theater is still in its infancy.

PATIENT-SPECIFIC IMPLANT GUIDES

This section will include the design and manufacturing of patient-specific spinal implant guides. We will also include instructions in text and tables to help guide surgeons, should they desire to 3D print their own surgical guides. The topic of 3D-printed implant guides will be divided into four sections:

1.1 Patient-specific implant guides for the cervical spine
1.2 Patient-specific implant guides for the thoracic spine
1.3 Patient-specific implant guides for the lumbar spine
1.4 Future direction of patient-specific implant guides

3D-printed devices include implants that aid in spinal fixation and instruments that facilitate the surgical procedure. Creating the 3D models of the spine necessary for these designs requires a skill set not possessed by most surgeons. As the technology has improved, many of the more technical coding-like processes have been eliminated to make a more user-friendly experience. This will likely continue to improve as software companies compete, and interest grows. Patient-specific drill guides of varying design have been demonstrated to be effective throughout the spine. These guides are currently being produced by bot device companies and spine surgeons. Sugawara et al. and Kaneyama et al. have investigated several areas of the spine for the implementation of their process. They noted that the thoracic spine frequently presents its own unique problems associated with instrumentation. Dysplastic pedicles, deformity, and other alterations in anatomy can present challenging operations that require long operating times and an increased risk for misplaced spinal instrumentation. Dysplastic pedicles that appear too small on imaging for conventional screw fixation techniques are typically either skipped or fixed with alternative devices such as sublaminar fixation systems. Deformity that could benefit from guidance can also be present in the cervical and lumbar spine. Surgical computerized navigation has been used with some success to address this problem and does allow the surgeon the ability to visualize the start point and angle of screw insertion based on preoperative or intraoperative CT scan. Although this is helpful, it is based on an image that could be rendered inaccurate. If the patient is shifted or if the surgeon pressed down on the patient while probing the pedicle, the navigation accuracy may be affected. Every technique requires the surgeon to use multiple sources of information to assess the safety of inserting instrumentation. Patient-specific screw guide templates (SGTs) can be used as another tool to help mitigate risk inthis process. These guides can be designed and printed either by the surgeon/hospital facility or by the industry. At least one company (Medacta) already offers this commercially.

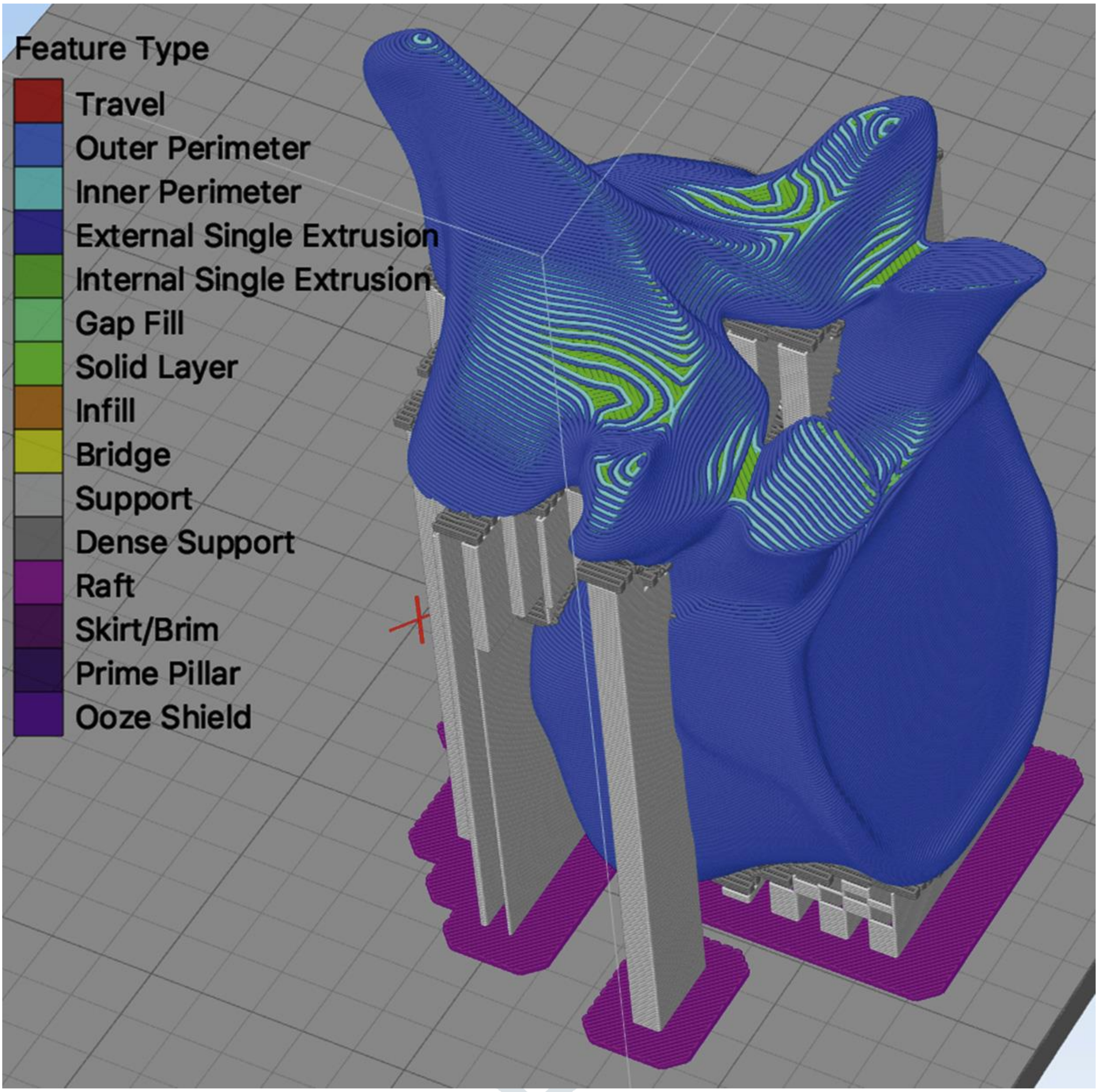
1 Several surgeons have also performed this,and many have published small case series. The processes vary by surgeon and institution, but the general process remains constant, and the early results are promising. For the surgeon to begin the process, a preoperative CT scan of the affected area is loaded into multiplanar software. This is typically loaded as a Digital Imaging and Communications in Medicine (DICOM) file which is the standard medical imaging file type in the United States. That file will then be converted to a stereolithography file by the software.

Stereolithography files were originally designed for computer-aided design (CAD) software and are now a standard file format for 3D printing. Once converted to a stereolithography file, the surgeon has the ability.

This Table Gives Detailed Instructions for Creating and Printing a Pedicle Screw Drill Guide From a Patient's CT Scan in DICOM Format. This Same Technique Could be Adapted to Placing Screws Anywhere in the Spine

Download image	Images can be imported from DICOM files directly from most hospital/clinic image-viewing programs or from outside CTs. These files can be uploaded without conversion into many software programs designed to read images.
Configure image	My preferred software is Osirix (freeware on Mac, 3DSlicer is a similar program for PC). This "slicer" software allows for reading any type of imaging. Through this software the CT can be reformatted to show structures within a given Hounsfield range. In this case the software is configured to include only cortical bone (the surgeon can decide to include cancellous bone as well). This creates a new CT scan with all desired bone converted to white for 3D rendering, whereas all other structures are converted to black and deleted. The model created here resembles the anatomy of the bone but contains ridges or plateaus limited by the thickness of the CT slices
Export new image	This image is again exported as a stereolithography file.
Clean up new image	I open this file in Blender (Mac/PC). Blender is another free program that helps to modify 3D files. Some of this editing can be done in Osirix or 3D slicer, but finer work is done at this stage. These 3D images are essentially made up of many thousands of triangles and a few complex polygons. To make these images more printable, Blender can convert all these into triangles. It can then "smooth" the image by converting each triangle into multiple triangles. One must keep in mind that the more smoothing might result in more esthetic but less accurate models.
Create drill guide	The patient-specific drill guide then needs to be created from this model. This is most easily done in 3D slicer but can be performed in many programs. First this model is saved (File 1). The painting tool can be used to add material directly behind the lamina in areas where the drill guide should exist. Small tubes of material (hollow cylinders) are then added to the model to be centered through the pedicle. This new file is then saved under a new name (File 2). Finally the original file (File 1) is then opened in the same working space. The software allows the user to convert any object into a void. This essentially gives the surgeon an eraser in the shape of the vertebrae body. This is lined up over File 2 such that it eliminates all of the original body while leaving the extra material drawn

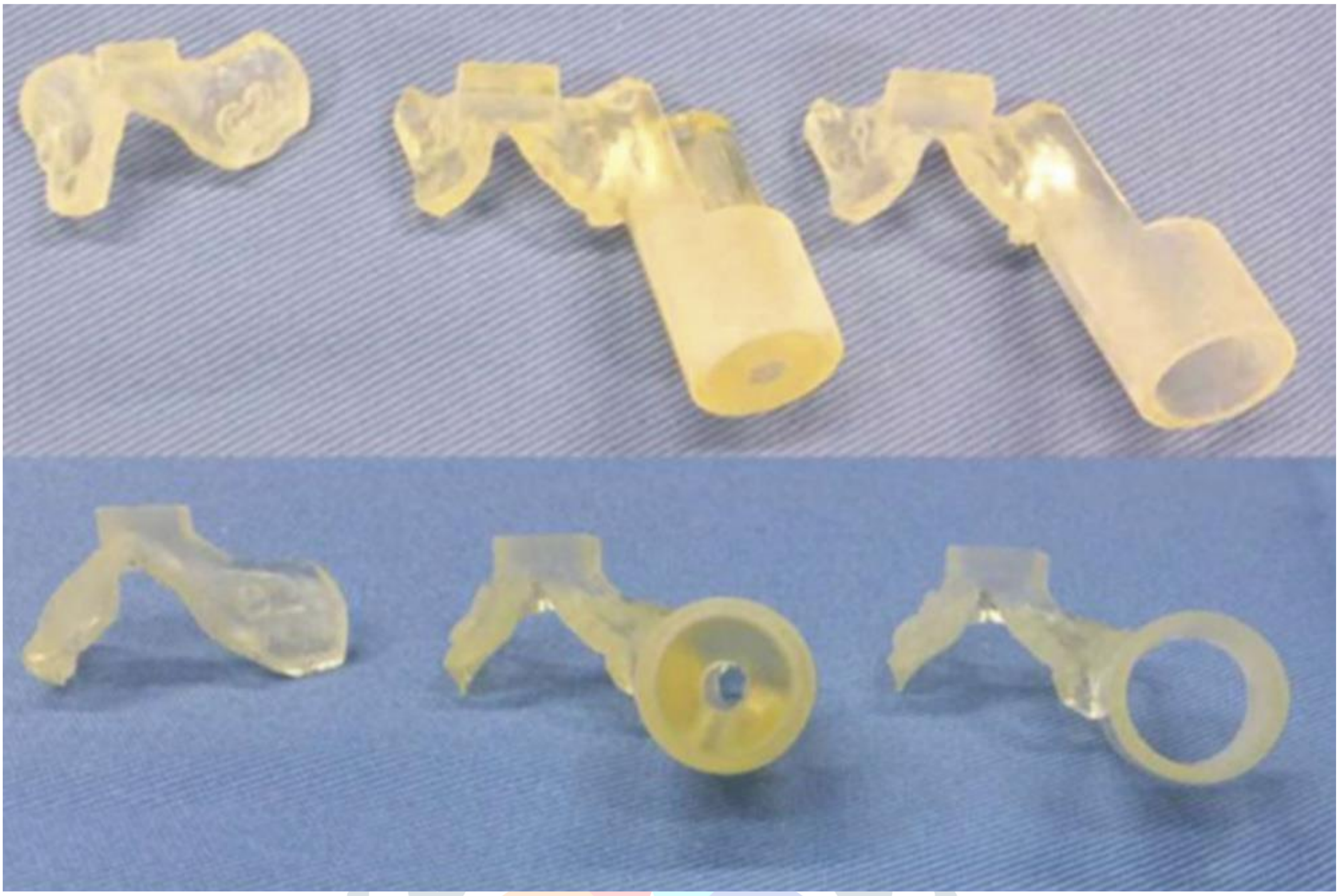
	behind the lamina and the tubes sticking out of this material directed toward the pedicles. This file is then saved (File 3). It is very important not to perform any smoothing of this guide after fitting it to the vertebral body digitaly .
Export new image	This image is again exported as a stereolithography file.
Prepare for printing	I use Simplify3D for print preparation. This program is not free ($150) but offers many tools that free programs do not. There are, however, many popular free alternatives such as Repetier or Cura that work well. These programs allow for scaling and orienting of the object over the digital build plate. These programs determine appropriate locations for support material (scaffolding) and allow for helpful structures such as rafts and ooze shields. Rafts help to prevent warping, and ooze shields prevent extra plastic from being extruded when printing with two different plastics. The density of the model and precision of the nozzle can also be tailored at this point. The nozzles and build plate temperatures can also be tailored. When completed, one can preview the print process in the software before exporting to the printer. This allows for circumventing problems without wasting plastic or time .
Export to printer	The file can then be saved on an SD card (via an SD card adapter or built-in port) and inserted into the printer. The computer can alternatively be connected directly to the printer. Once the print is initiated, the printer will run on its own until it is finished. Some printers move the build plate down away from the extruders a fraction of a millimeter at a time. Other printers raise the extruders up after each level is completed.



This is a digital image created by "Simplify3D" software. The varying colors demonstrate different print processes. The support material (light gray, dark gray) and raft (purple) facilitate the printing process and are removed from the model after print completion. Image created is taken by the reference papers

1.1 Cervical Spine

Instrumentation of the cervical spine can be fraught with potential complication. The anatomy is smaller than that of other regions of the spine, and neurovascular structures are closer to common and ideal screw trajectories. Lateral mass screws are commonly used in the cervical spine to lessen the risk of injury compared to pedicle screws. Unfortunately, lateral mass screws have only half the pull-out strength of cervical pedicle screws.4 Kaneyama attempted a three-step technique to guide cervical pedicle screw placement in C-2. Sugawara originally described this technique for thoracic pedicle screws2 . In this study his team successfully placed 26 pedicle screws, 12 pars screws, 6 laminar screws, and 4 C1eC2 transarticular screws. Ninetyeight percent (47/48) of the screws were found to have been placed with acceptable parameters.5 Sugawara then studied C1eC2 fixation with the same SGT guide process. This time they placed C1 lateral mass screws and C2 pedicle or laminar screws. Their 24 C1 lateral mass screws, 20 C2 pedicle screws, and 4 C2 laminar screws were all placed without any cortical breaches.6 This technique allowed for precise screw placement without necessitating exposure of the C2



1.2 Thoracic Spine

There are currently fewer published studies involving SGTs of the thoracic spine. In their original article demonstrating the three-guide technique, Sugawara et al. chose to focus on the thoracic spine. They were able to successfully place all thoracic pedicle screw (58 in total) within the pedicular borders.2 There are studies that show freehand pedicle screw placement in the thoracic spine to have breach rates of 25% e43%. The in-out-in technique, although better than no screw, is associated with w23% decrease in pedicle screw pull-out strength.8 Not only were these guided pedicle screws within the pedicle but on postoperative imaging they were found to have screw tips that deviated from their planned course by a mean of 0.89 mm. The authors were also able to reduce their operative time and radiation exposure compared to their prior technique.

1.3 Lumbar Spine

The anatomy of the lumbar spine typically allows for a larger margin of error due to pedicular size. The application of drill template technology for traditional lumbar screw placement is debatable for more straight-forward procedures. The added time preoperatively might not result in increased screw placement precision in these cases. This process does require substantial operative planning, and current rates of pedicle breaches in the lumbar spine have been reported as low as 6%. However, there are atypical screw placement options that might benefit from patient-specific guidance.

One such option is the transpedicular transdiscal (TPTD) screw trajectory for three column fusions first introduced by Emery et al. In this technique it is essential to keep the screws within the pedicle so that they only cross into the more cranial vertebral body after they enter the caudal vertebral body. When performed correctly, this allows the surgeon to approach the spine posteriorly, protect the neural elements, and instrument between the vertebral bodies. This technique was also shown to produce a fusion construct 1.6e1.8x stiffer than a traditional pedicle For this study secondary data has been collected. From the website of KSE the monthly stock prices for the sample firms are obtaiscrew construct . They also found this construct to have no difference in stiffness compared to posterior instrumentation with interbody fixation. The technical demands of this procedure as well as the use of a computerized navigation system, which comes with equipment costs and extra radiation for the patient, preclude many from adopting this technique. The ability to eliminate the need for navigation while still accurately and precisely placing these TPTD screws could lead to stiffer constructs with less expense .

1.4 Future Direction

Patient-specific SGTs provide a cost-effective alternative for precisely placing posterior spinal instrumentation. Although the advantages are largely positive, there are drawbacks to this new technology. Perhaps the largest of these is the surgical exposure requirement. For the guides to fit properly, all muscle must be removed from the lamina under the SGTs. Minimally invasive surgery including mini incision techniques and tubular retractor system would not be compatible with this technique currently. The time needed to produce the guides is also a limiting factor. The three-guide system took the authors an average of 3 days to produce. This limits their availability for trauma patients.2,5,6,11 There are many positive aspects of this budding technology. Small-scale printing can be quite economical. 3D printers with reasonable accuracy are available now starting around $400. The spine models themselves are also quite affordable to produce. One can print an entire cervical model, a set of C2eC6 SGTs for testing on the spine model, and a set of C2eC6 SGTs for the patient for a total of w$100. A 10-level thoracic spine fusion costs w$250 to template and test. In relation to the cost of the surgery these modeling costs are negligible. Avoiding only one revision surgery due to superior screw placement could pay for hundreds of cases to be performed with SGTs. These could also be printed by industry for the surgeons . As with many technologies, small increases in usability could result in dramatically increased adoption in the near future.

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