6 Use of 3D Print Technology for Training on Craniosynostosis Surgeries: A Novel Approach

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Introduction

Neurosurgery entails understanding some of the most complex anatomic structures in human body, and also the consequences of minor technical errors in assimilating and working through this complex anatomy can be devastating.[1] It excludes the possibility of learning on the patient for those training in this field. Thus, neurosurgery is one of the surgical branches with very long learning curves for the residents. However, with the growth in technology, it is now possible to decrease the learning curve without putting patients' lives at risk. Anatomical models for different diseases may prove to be very helpful in delineating the microsurgical anatomy and relations with surrounding structures in detail, not otherwise possible. If such a model into a complete simulator can be radiographically scanned and allows pre- and postoperative imaging to evaluate the outcome of the surgery, it would be of great benefit to the young neurosurgeons. The recent advances in the three-dimensional (3D) printing technology have made it possible to accomplish this goal. It has been shown that assimilation of surgical techniques is greatly enhanced by laboratory training using such simulations in all the surgical fields.[2,3]

Three-Dimensional Printing in Neurosurgery

As the name suggests, it means that a 3D object is made by deposition of additional layers of requisite material over the underlying structure successively.[4] It is a method of additive manufacturing (AM) that involves construction of 3D structures from the designs created in computer, thus called as *computer-aided designs* (CADs).[5,6] It has grown tremendously since its initial introduction in 1980. With the elimination of all intermediate stages such as procurement of tools, supply, and production lines, etc., it provides for a time and cost-effective way to turn concepts into physical reality. Several different methods have been devised for the same. All the methods primarily involve use of materials that can be modified in selective areas of specific layers. One of such methods is the *fused deposition modeling* (FDM)[7] that uses the property of thermoplasticity. Three-dimensional models are made with substances that change their hardness in response to heat exposure. With slight changes in the composition, the level of hardness can be controlled and a model with desired variability in hardness and texture can be made. *Selective laser sintering* (SLS)[8] is also an AM technique in which laser is used to sinter powdered substance such that the final solid structure created is same as the 3D model intended. Another method is *stereolithography* (SLA)[9] that includes use of ultraviolet (UV) light to solidify a photopolymer resin by drawing a programmed shape successively in each layer to make a complete 3D object. In the past few years, there have been several innovations that have decreased the cost while increasing the accuracy and the range of objects that can be 3D printed. With such innovations, it has now become possible to use this technology in medicine, ranging from making patient-tailored implant to development of simulation models that can be used to train medical students and surgical residents.

A paradigm shift in the way neurosurgical skills are imparted with the help of such 3D models being routinely used with a resultant decrease in the learning curve can be expected in the very near future. In this regard, the authors would like to share their experience of using SLA models for training and planning of craniosynostosis surgeries at our institute.

With the advent and advances in the 3D printing technology, the authors have recently started using SLA models. The advance from a virtual simulation to a physical simulation is a huge step forward as their experience suggests. Physical models render the detailed simulation of the anatomical complexities of certain cases possible. Their experience suggests that a "mixed simulator" approach including both the virtual and physical simulators proves to be even better than physical alone. The authors have used these virtual and physical models created for surgical planning for the training purposed of residents and fellows. **Fig. 6.1** shows a 3D STL model used for training at the authors' institute.

It was observed that a mixed simulation combines the desired results of both the physical and virtual simulations enhancing

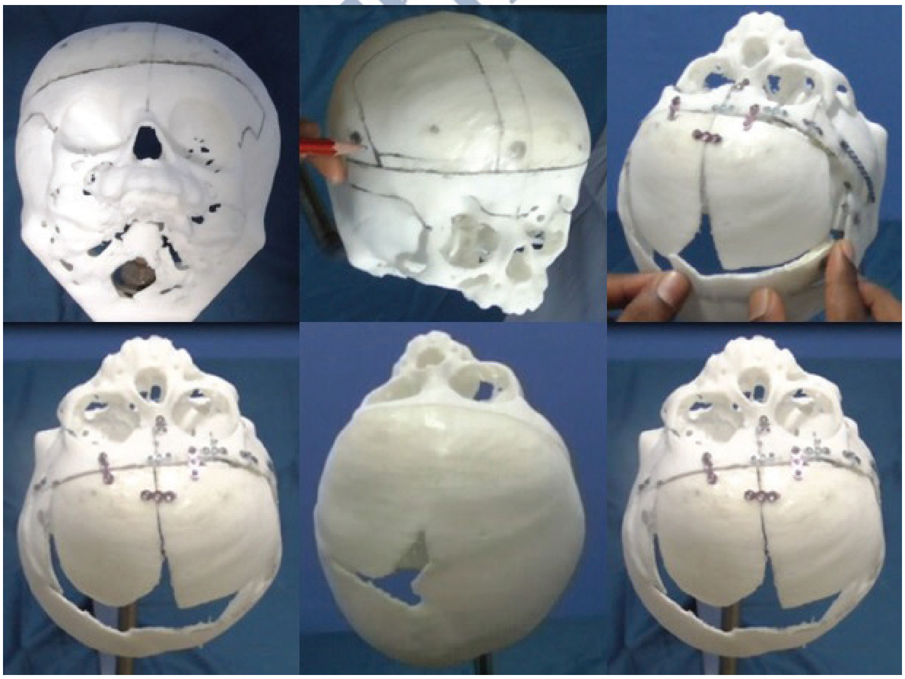

Fig. 6.1 Three-dimensional printed (rapid prototyping stereolithography) craniosynostosis model used for training.

the skill acquisition with minimal risk to real patients. It helped our residents learn the aspects of surgeries that could not be practiced on nonpathologic animal models such as the key practical techniques of deformity correction and restoration of intracranial volume.

Discussion

Neurosurgery seems to be the branch of medicine that stands to benefit the most from 3D printing. Its benefits in neurosurgery are manifold. Neurosurgery involves in-depth understanding of the 3D anatomy of normal and abnormal neural structures with no scope of any mistake. Presently various radiologic imaging modalities are used for the same.[10] However, they provide only two-dimensional (2D) representations of the 3D reality.[11] However, with the recent advances in 3D printing, 3D models can be made using the volumetric data from these imaging modalities in much shorter time and lesser cost than previously possible. These physical models can be used for not only surgical planning but also for education and training purposes. Surgical simulations can be created from these models that will provide opportunities to residents to practice their surgical skills without any attendant risks associated with learning on the patient. The ongoing innovations have made it possible to not only create just the 3D model of different neurosurgical diseases but also replicate the different types of tissue texture and hardness, which provide tactile feedback in addition to visual. This leads to a simulation that is very close to reality that can be used for training and for evaluating the skill of residents before they are allowed to perform surgery on patients.[12] Such models have already come in use for training in several neurosurgical disciplines. Skull models with vessels and aneurysm have been made for practicing aneurysm clipping.[13,14] Similarly tumor simulators have also been developed, which simulate even the varying consistencies and densities of different tumor tissues and the normal brain tissue.[15,16] Spinal models have also been developed with the same purpose.[17] Use of all such models has been shown in several studies to improve the level of understanding of the trainees and to decrease the time taken to reach a particular level of proficiency. Apart from training, another advantage of using such simulators is to assess the trainees regarding their level of skills. Once their use becomes common, practice guidelines may be laid down to determine the readiness of residents for real surgery.

Three-Dimensional Printing for Craniosynostosis

It is very difficult to train the young neurosurgeons in surgeries for craniosynostosis. The extensiveness of surgery and complications such as blood loss precludes direct training on the patient.[18] Also, variables such as the postoperative intracranial volume attained have significant effect on the long-term outcome as it allows for the normal growth of the brain with time. Thus it is extremely essential to train the residents well in all these nuances of this surgery, before they perform the surgery in a real patient. However, unlike other neurosurgical disciplines, such models are still very rare for craniosynostosis due to inability to take into account all the complexities in the simulations.

Presently, training for craniosynostosis surgery involves use of animal models and human cadaveric specimen. However, there are several limitations of using these methods. A lot many aspects of the surgery remain unrepresented in these models. The most commonly used model, at present, cadaveric sheep cranium can be used to understand these limitations.[19] Most importantly, the sheep cranium does not present with the primary pathology that needs to be surgically corrected and the trainees are being trained for. Thus the training leaves out the most important part, that is, dealing with the pathology in question practically during surgery. Also, the cadaveric tissue has a tactile feedback that is very different from the living human tissue robbing the trainees of a very important surgical cue of touch. In cadaveric skulls, the most important complication of extensive bleeding is not encountered. Thus, the trainees are not able to learn to deal with this complication during such training. With logistic problems in performing postoperative scans and ethical issues, surrounding use of animals for training purposes the list of limitations is long.

Three-dimensional models can prove to be very useful in eliminating nearly all of these limitations. These models are made using CAD made in turn from the volumetric data acquisition from the imaging software for radiologic investigations such as computed tomography (CT) or magnetic resonance imaging (MRI). Thus, the model made resembles the pathologic entity exactly as present in the real patient. The application of the surgical principles for correction of the pathology can thus be practiced in entirety in such models. With the possibility of imitating the texture and thus the tactile feedback of different tissues ranging from skin to the brain, it has the potential to revolutionize the training of the residents. Structures such as superior sagittal sinus and ventricles can also be incorporated in the models, making it possible that complications such as sinus injury and resultant bleeding are also encountered and their solutions practiced hands on. All the steps of surgery starting from positioning to skin incision to corrective surgery and the final closure can thus be practiced on such 3D model simulators with almost perfect resemblance to the real situation without any possible harm to a real patient. By virtue of the specific material used, some of the models also permit pre- and postoperative radiologic evaluation that helps assess the efficacy of surgery performed and the adequacy of the intracranial volume obtained. Coelho et al[20] in collaboration with a Brazilian company Pro Delphus have developed such a simulator, using a thermoplastic material that with minor variations in composition can mimic tissues with different textures ranging from skin to skull as shown in **Fig. 6.2**.

This model also has structure resembling sinuses that may help in the training of management of intraoperative complications such as bleeding. Further development of such models including more features to increase the similarity with the real surgery can be expected soon with greater advancement of 3D printing technology.

Conclusion

Considering the long learning curve and possible harm to the patient in the traditional training method of supervised learning on a real patient, surgical simulation models present an attractive alternative with all the

Fig. 6.2 Three-dimensional model for craniosynostosis. (Reproduced with permission from Coelho et al[20] by FDM 3D printing.)

benefits and none of the risks. Use of such simulators can drastically reduce learning curve and contribute to faster skill transfer to the young neurosurgeons in making. It is needless to say that in future it will be imperative for all the institutes to use such simulation models to improve the training while decreasing the learning curve for the young neurosurgeons.

References

1. Chan S, Conti F, Salisbury K, Blevins NH. Virtual reality simulation in neurosurgery: technologies and evolution. Neurosurgery 2013;72(Suppl 1):154–164
2. Aboud E, Al-Mefty O, Yaşargil MG. New laboratory model for neurosurgical training that simulates live surgery. J Neurosurg 2002;97(6):1367–1372
3. Hicdonmez T, Parsak T, Cobanoglu S. Simulation of surgery for craniosynostosis: a training model in a fresh cadaveric sheep cranium. Technical note. J Neurosurg 2006;105(2, Suppl):150–152
4. Liew Y, Beveridge E, Demetriades AK, Hughes MA. 3D printing of patient-specific anatomy: a tool to improve patient consent and enhance imaging interpretation by trainees. Br J Neurosurg 2015;29(5):712–714
5. Bártolo PJ, Gibson I. History of stereolithographic processes. In: Bártolo PJ, ed. Stereolithography. Boston, MA: Springer US; 2011:37–56
6. Lipson H, Kurman M. Fabricated: the new world of 3D printing. Indianapolis, IN: Indiana; 2013
7. Taufik M, Jain PK. A study of build edge profile for prediction of surface roughness in fused deposition modeling. J Manuf Sci Eng 2016;138:061002
8. Selective Laser Sintering. Birth of an Industry—Department of Mechanical Engineering. http://www.me.utexas.edu/news/news/selective-laser-sintering-birth-of-an-industry#ch4. Accessed August 2, 2017
9. Hull CW. Apparatus for production of three-dimensional objects by stereolithography; 1986
10. Klein GT, Lu Y, Wang MY. 3D printing and neurosurgery—ready for prime time? World Neurosurg 2013;80(3-4):233–235
11. Xu W-H, Liu J, Li M-L, Sun ZY, Chen J, Wu JH. 3D printing of intracranial artery stenosis based on the source images of magnetic resonance angiograph. Ann Transl Med 2014;2(8):74
12. Tai BL, Rooney D, Stephenson F, et al. Development of a 3D-printed external ventricular drain placement simulator: technical note. J Neurosurg 2015;123(4):1070–1076
13. Mashiko T, Otani K, Kawano R, et al. Development of three-dimensional hollow elastic model for cerebral aneurysm clipping simulation enabling rapid and low cost prototyping. World Neurosurg 2015;83(3):351–361
14. Mashiko T, Konno T, Kaneko N, Watanabe E. Training in brain retraction using a self-made three-dimensional model. World Neurosurg 2015;84(2):585–590
15. Waran V, Narayanan V, Karuppiah R, Owen SL, Aziz T. Utility of multimaterial 3D printers in creating models with pathological entities to enhance the training experience of neurosurgeons. J Neurosurg 2014;120(2):489–492
16. Waran V, Narayanan V, Karuppiah R, et al. Injecting realism in surgical training-initial simulation experience with custom 3D models. J Surg Educ 2014;71(2):193–197
17. Bova FJ, Rajon DA, Friedman WA, et al. Mixed-reality simulation for neurosurgical procedures. Neurosurgery 2013;73(Suppl 1):138–145
18. Steinbok P, Heran N, Hicdonmez T, Cochrane DD, Price A. Minimizing blood transfusions in the surgical correction of coronal and metopic craniosynostosis. Childs Nerv Syst 2004;20(7):445–452
19. Grist EPM. Transmissible spongiform encephalopathy risk assessment: the UK experience. Risk Anal 2005;25(3):519–532
20. Coelho G, Warf B, Lyra M, Zanon N. Anatomical pediatric model for craniosynostosis surgical training. Childs Nerv Syst 2014;30(12):2009–2014