3D Printed Models Application Intraining of Endoscopically Navigated Maxillary Sinus Floor Augmentation Procedure

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Abstract: ***Aim**: Printing three - dimensional (3D) simulation models to be used for training in trocar – guided endoscopic technique navigating maxillary sinus floor augmentation procedure. **Materials and methods**: Based on 20 preoperative CBCT images (10 of male and 10 of female patients), using a Standard Tessellation Language (STL) file, to print 20 3D simulation models using a 3D printer with Fused Deposition Modeling (FDM) printing principle. **Results**: The 3D printing algorithm presented by us can be useful for the production of FDM 3D simulation models based on CBCT images, as accessible teaching materials with detailed reproduction of the anatomical features of the maxillary sinus, the materialized visualization of the surgical field serves as a simulator to enhance manual skills and provides an opportunity to find the most accurate approach in the preoperative preparation. **Conclusion**: FDM 3D printing is a reliable, fast, accessible and low – cost option to create detailed anatomical simulation models for use in the training of undergraduate, postgraduate and PhD students, although the production of the models requires interdisciplinary skills.*

Keywords: 3d printed models, maxillary sinus, trocar - guided endoscopy, CBCT, digital modeling

1. Introduction

Hammad et. al. (10) in a systematic literature review examined the application of 3Dprinting in surgical practice. The authors found that the application of the technology is increasing as it allows the rapid conversion of anatomical images into physical objects that are used in three main areas - anatomical models, surgical instruments, implants and prostheses. The costs associated with implementing the technology and the time required for printing are important factors to consider before its widespread use. In the near future, this is an exciting and interesting technology with the capacity to radically change medicine and revolutionize modern surgery.

The 3D printing is an "additive manufacturing" process, which means new material is added to the surface of an existing material to build a physical 3D model. An initial digital model of the patient's anatomy obtained from a CT, CBCT or MRI is typically used to create a 3D printed anatomical model, and a new digital model is custom created from the start. There are three commonly used methods for 3D printing - FDM, SLS, SLA.

Fused Deposition Modelling (FDM) - layers are created by depositing a thermally softened polymer using a computer controlled extrusion nozzle. This technique is used in most economical consumer printers, but also finds application in medicine.

Selective laser sintering (SLS) - a powder layer of a different material such as polymer or metal is used. The powder is applied and a focused energy source (laser or electronic beam) solidifies the applied material. Once the hardening of the current layer is complete, a new layer of fresh powder is added and the process is repeated.

Stereo lithography (SLA) uses an optical light energy source to scan over a tub of light - curable resin, hardening specific areas of the liquid surface. The floor of the liquid container is gradually lowered, which increases the depth of the material as the pattern grows and successive layers of resin harden on top of each other (2, 6, 7, 8).

In 1986, Charles Hull introduced the first 3D printing technology, and the industry developed many different manufacturing technologies that were applied in different fields. In 1986, Hull patented Stereolithography (SLA) and built and developed a 3D printing system. In 1990, Scott Crump received a patent for fused deposition modeling (FDM). Since then, 3D printing has been increasingly advancing (11).

Kamio et. al. . (4) stated that with the increasing use of 3D models in dentistry, oral surgery, and implantology, they expect FDM 3D printers to play a significant role in this process.

2. Materials and methods

To perform the study, we selected 20 preoperative CBCT images of patients who underwent bilateral sinus floor elevation with a lateral approach and measured the height of the available subantral bone in the areas submitted to the augmentation maxillary sinus floor elevation procedure between 2 - 4 mm. The preoperative CBCT images selected to produce the 3D models were of 10 male and 10 female patients.

Using the CBCT image processing software "Planmeca Romexis", an image is generated from which an STL file is output. The "Planmeca Romexis" software allows producing a higher quality STL file by selecting the resolution and the visualization of the object to be exported, also selecting the directory to export and naming the file. We visualize the generated STL files using the software program "Autodesk Meshmixer", in order to further process the image - cleaning from artifacts. When processing the images in the program they automatically acquire *mix. extension. The prepared images that we want to print need to be displayed again in STL format.

The prepared STL files of the 3D models were printed using the "Visions3Dprinter" of the manufacturer 3Dfactories. The working principle of this printer is FDM (Fused Deposition Modeling) - the model is built by applying a melted material (PLA - filament) through an extruder (nozzle) heated to 200º, which is part of an extrusion head that moves horizontally ("X" and "Y" axis), layer by layer along a defined path on a movable in the vertical direction ("Z" axis to 150 mm) table with dimensions 150 x 150 mm. The material the printer works with is a thermoplastic polymer - polylactic acid (PLA). The material is a filament with a diameter of 1, 75 mm wrapped on a roll. The extruder of the printer has a diameter of 0, 3 mm, the maximum printing speed is 80 mm/s, there is a built - in LED lighting that allows the printing process to be monitored. The printer works with a software program to prepare for printing models - "3Dfactories - Repetier - Host V1.0.6"

The ready STL files are prepared for printing using "3Dfactories - Repetier - Host V1.0.6", and for all 20 models the same individual printing parameters are set to meet the needs of our task - model build quality - 0.08 mm (High quality), type of adhesion of the model to the table - Raft and model maintenance by touching the table. The printing speed and the printing speed of the outer perimeter of the printed model is the same - 38mm/s - slow type. Fill speed is 45mm/s and density is 60%. After setting the parameters in this way, the STL files are subjected to slicing with CuraEngine. After the slicing is completed, the software program visualizes the future 3D simulation model by predicting the printing time, the total number of layers, the total number of rows to be applied layer by layer and the required amount of filament in mm (Figure1).

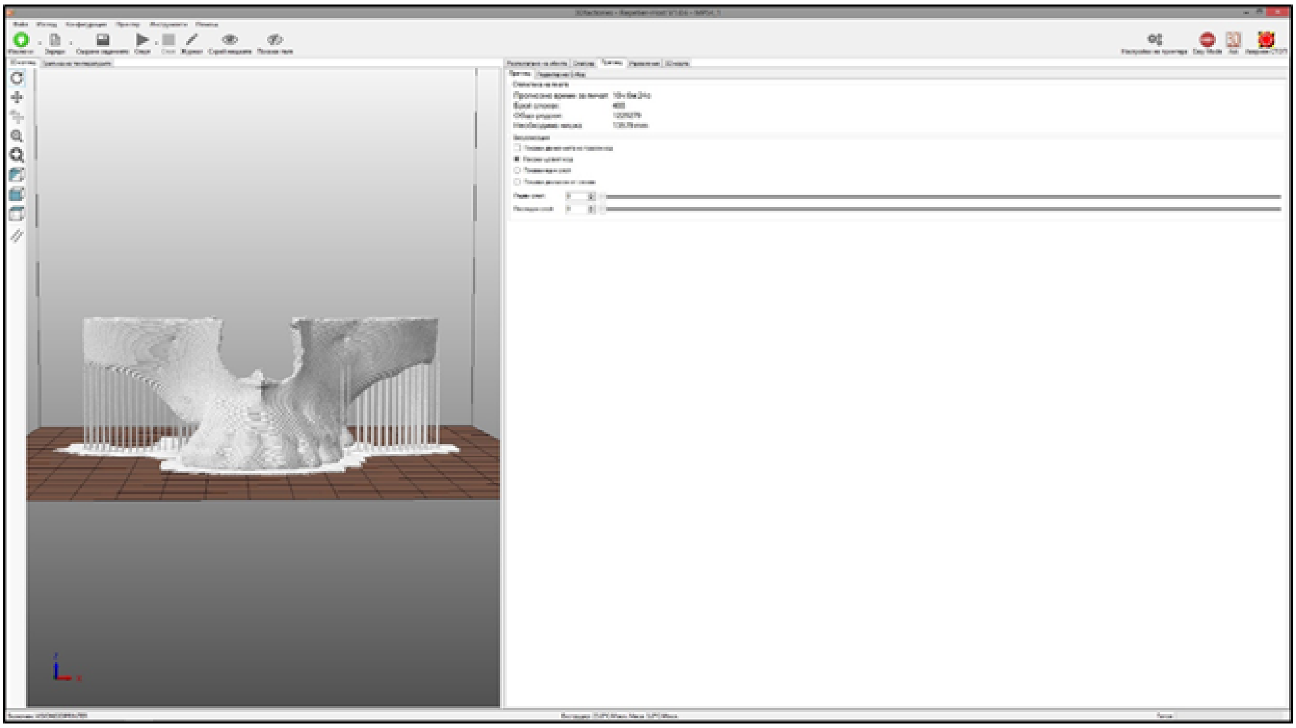

Figure 1

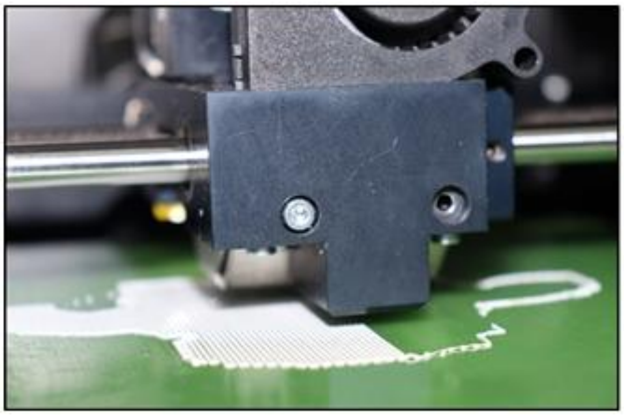

Figure 2

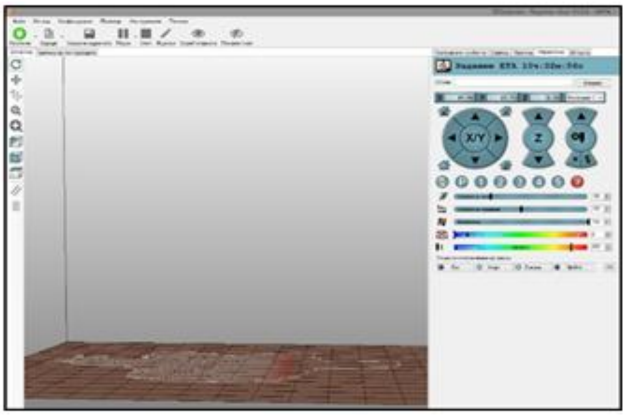

Figure 3

Before printing the 3D stimulation model we set the individual print values of the 3D printer, which are: print speed and filament feed speed (filament) - 100, running cooling function - fan and extruder heating to 200 º. After the extruder reaches the temperature of 200 º, the printing is started. During printing of the 3D simulation models, there is a visualization of the extruder head itself moving in the layer application order preset by CuraEngine. This allows the printing to be monitored and, if an error occurs, stopped for debugging (Figures 2 and 3).

Once the 3D simulation models have completed the printing process, they are carefully detached from the printer table. The models are subjected to cleaning from the support elements. The 3D simulation models are scaled 1: 1 relative to the patients (Figure 4).

Figure 4

3. Results

We obtained 20 3D CBCT - based simulation models of patients. The resulting 20 models reproduced in detail the specific individual maxillary and maxillary sinus anatomy as well as bone density. The anterior wall of each maxillary sinus, 40 in total, was trained for endoscopic access via a trocar with an outer diameter of 5 mm (Figure 5), and three holes were created on the anterior wall of each maxillary sinus, medial, central and distal, with a distance of 8 mm between the centers of each of the three holes (Figure 6). A total of 120 openings were created, which trained us and increased our manual technique for trocar handling in a simulated environment before proceeding to clinical performance.

4. Discussion

Pashkova et. al. (9) in a clinical case of implant placement, reported the use of a 3D CBCT - based printed model of the patient, which helps to pre - visualize the surgical field, thereby improving preoperative preparation and selection of the most accurate approach in treatment planning.

Georgantza et. al. (3) in a report discussed the basic principles and applications of 3D printed models based on CBCT data of patients for training in dental implantology. The authors stated that there are 3 main applications of 3D printed models in dental implantology training - for better illustration in teaching anatomical structures, treatment planning and preoperative practice, and with simulation applications. They conclude that 3D printed models based on CBCT data of patients have great potential for implantology education, for better understanding and planning of surgical manipulations.

Tuce et. al. (12) explored the possibility of simulating a maxillary sinus floor lifting procedure on 3D printed models based on CBCT data of patients. The study resulted in the augmentation of the maxillary sinus floor and the placement of an implant on the 3D printed model, which served as a simulator of the operative field to train the operator's practical skills. The authors conclude that the 3D printed models could serve as simulation materials for training, and in dental practice for treatment planning.

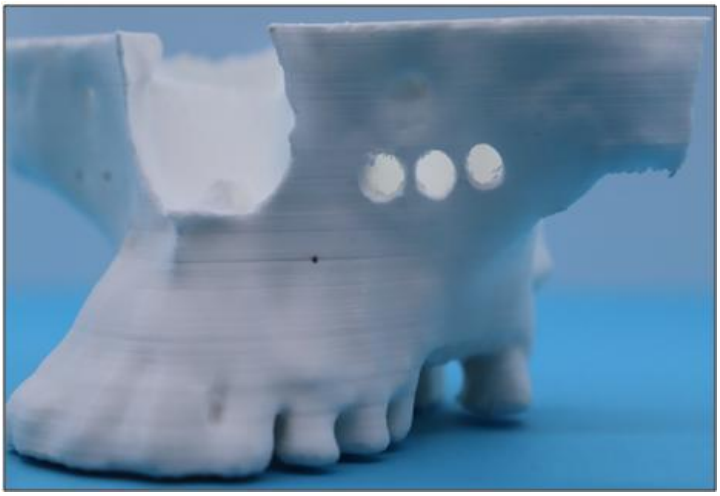

Figure 5

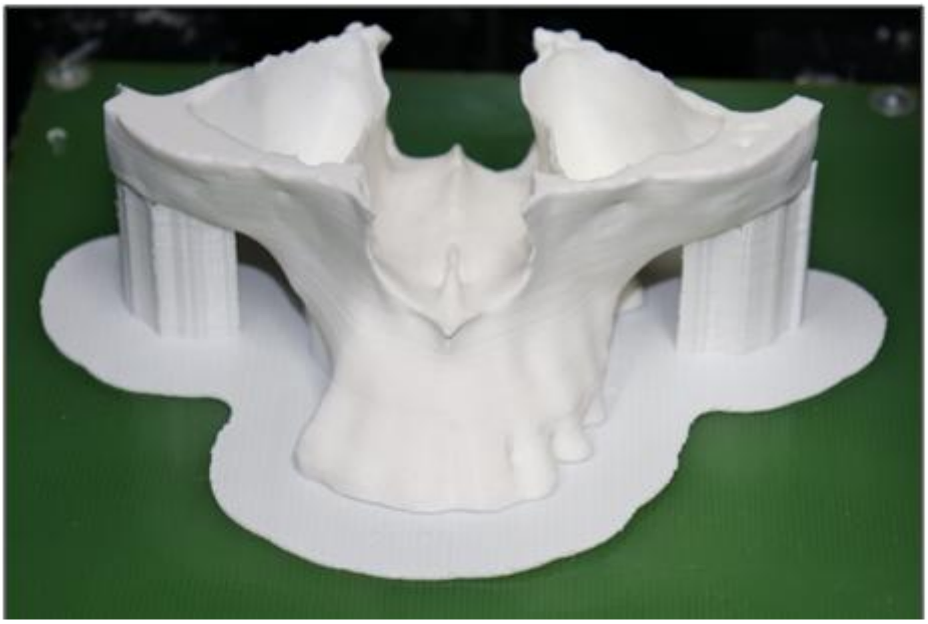

Figure 6

Araneda et. al. (1) conducted a study to present a strategy for morphological analysis of the maxillary sinus using 3D printed models, based on CBCT data of patients.24 patients were included. A total of 48 models were produced. The authors concluded that 3D printed models provide a new approach to understand the exact anatomical characteristics of the maxillary sinus, compared to its evaluation on a two – dimensional screen.3D printed maxillary sinus models are a suitable method for preoperative analysis and training.

Meglioli et. al. (5) in a systematic literature review aimed to evaluate the use of 3D printed bone models for training, simulation and/or intervention planning in oral and maxillofacial surgery. As a result, theyfoundthat3D printed bone models are mainly used as training or simulation models in bone reconstruction. FDM 3D printers showed satisfactory results for creating training models.

With our study, we confirm that FDM 3D printed simulation models based on CBCT images reproduce anatomical features in detail and serve as a simulator of the surgical field to train the operator's manual skills, the materialized visualization of the surgical field provides an opportunity to find the most accurate approach in the preoperative preparation of a clinical case. Our presented 3D printing algorithm can be useful for the production of accessible training materials.

5. Conclusion

The progress in digital modelling and 3D printing enables FDM 3D printed simulation models based on CBCT images to be a reliable, fast, accessible and in expensive option for creating detailed anatomical simulation models to be more widely used in the education of undergraduate, postgraduate and PhD students, in order to understand the anatomy of certain objects through their visualization, illustrate specific surgical techniques, and to serve as a physical training object to increase manual skills. We hope that the advantages of FDM 3D printing will gain wider application, both in dental education and clinical practice, as it provides a good visualization of the surgical field, which helps to find the optimal treatment approach in the preoperative preparation, although the production of the models requires interdisciplinary skills.

References

[1] Araneda N, Parra M, González - Arriagada WA, Del Sol M, Haidar ZS, Olate S. Morphological analysis of the human maxillary sinus using three - dimensional printing. Contemp Clin Dent 2019; 10: 294 - 8.
[2] Fedorovich NE, Alblas J, Hennink WE, Oner FC, Dhert WJ. Organ printing: the future of bone regeneration? Trends Biotechnol.2011 Dec; 29 (12): 601 - 6.
[3] Georgantza, Aikaterini&Pellech, Thomas & Suzuki, Takanori&Chaar, Edgard& Cho, Sang - Choon&Froum, Stuart &Loomer, Peter. (2015). Utilizing 3D Models for Dental Implant Education.
[4] Kamio, Takashi & Hayashi, Kamichika&Onda, Takeshi &Takaki, Takashi & Shibahara, Takahiko &Yakushiji, Takashi &Shibui, Takeo & Kato, Hiroshi. (2018). Utilizing a low - cost desktop 3D printer to develop a “one - stop 3D printing lab” for oral and maxillofacial surgery and dentistry fields.3D Printing in Medicine.4.10.1186/s41205 - 018 - 0028 - 5.
[5] Meglioli M, Naveau A, Macaluso GM, Catros S.3D printed bone models in oral and cranio - maxillofacial surgery: a systematic review.3D Print Med.2020 Oct 20; 6 (1): 30. doi: 10.1186/s41205 - 020 - 00082 - 5. Erratum in: 3D Print Med.2020 Dec 2; 6 (1): 36. PMID: 33079298; PMCID: PMC7574578.
[6] Mironov V, Kasyanov V, Markwald RR. Organ printing: from bioprinter to organ biofabrication line. CurrOpinBiotechnol.2011 Oct; 22 (5): 667 - 73.
[7] Mironov V. Printing technology to produce living tissue. Expert Opin Biol Ther.2003 Aug; 3 (5): 701 - 4. doi: 10.1517/14712598.3.5.701. PMID: 12880370.
[8] Orlando G, Wood KJ, De Coppi P, Baptista PM, Binder KW, Bitar KN, Breuer C, Burnett L, Christ G, Farney A, Figliuzzi M, Holmes JH 4th, Koch K,

Macchiarini P, Mirmalek Sani SH, Opara E, Remuzzi A, Rogers J, Saul JM, Seliktar D, Shapira - Schweitzer K, Smith T, Solomon D, Van Dyke M, Yoo JJ, Zhang Y, Atala A, Stratta RJ, Soker S. Regenerative medicine as applied to general surgery. Ann Surg.2012 May; 255 (5): 867 - 80.

[9] Pashkova, Tatiana &Hotchandani, Arshin& Georgantza, Aikaterini& Suzuki, Takanori& Cho, Sang - Choon& Yu, Yung. (2020). Surgical and Restorative Aid of 3D Printed Models for Implant Placement: A Case Presentation.

[10] Q, Hammad & Malik, Hons &Darwood, Alastair &Shaunak, Shalin&Kulatilake, Priyantha& El - Hilly, Abdulrahman &Mulki, Omar &Baskaradas, Aroon&Mrcs,. (2015). Three - dimensional printing in surgery: A review of current surgical applications. Journal of Surgical Research.199.10.1016/j. jss.2015.06.051.

[11] Tian Y, Chen C, Xu X, Wang J, Hou X, Li K, Lu X, Shi H, Lee ES, Jiang HB. A Review of 3D Printing in Dentistry: Technologies, Affecting Factors, and Applications. Scanning.2021 Jul 17; 2021: 9950131

[12] Tuce, Robert &Arjoca, Stelian&Neagu, Monica &Neagu, Adrian. (2019). The use of 3D - printed surgical guides and models for sinus lift surgery planning and education. Journal of 3D Printing in Medicine.3.10.2217/3dp - 2019 - 0014.

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