

Extending Application of Computer-aided Manufacturing for Development of Microtia Grade III Prosthesis - A Case Study

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Abstract

Contributions of various engineering fundamentals in collaboration with medical science for making human life better are increasing exponentially in recent times. In this work, a collaborative team of professionals from engineering as well as medicine has jointly developed a prosthesis for microtia grade III using fundamentals of computer-aided manufacturing at a very affordable cost as well as within a considerably short duration. A young girl has a deficiency related to microtia grade III in her left ear. To develop a prosthesis related to her left ear, a quick-setting gypsum replica of her right ear has been initially developed. This gypsum mold is usually scanned using a CT scan to create 3D model for further processing by medical practitioners. This technique usually increases the cost of scanning. Here, a 3D structured light scanning technique is employed to create a 3D model from gypsum mold. The proposed technique has provided results with accuracy comparable with the CT scan at a very affordable cost. The three-dimensional model of the right ear was then mirrored to create a model of the left ear using a solid modeling tool. The mirrored three-dimensional model was then transformed into a format suitable for 3D printing. The 3D model of the right ear was then created using Fused Deposition Modeling based on 3D printing and implanted followed by minor processing. Here, collaborative efforts of engineering with medicine increase the possibility of the development of prostheses related to microtia grade III within a very affordable cost and time frame.

Keywords

Microtia, Computer-aided manufacturing, Human prosthesis, Three-dimensional printing

Introduction

In the field of medical science, 3D data image acquiring information technology like Computed Tomography (CT), Magnetic Resonance Imaging (MRI) but all techniques are costly solutions for general people. In the recent last decade, 3D scanning techniques (Structured light scanning and laser light scanning) enhanced the quality of image acquiring techniques at low cost. A 2D image is easy to capture but the image can't capture all the details regarding the depth of the object. The current 3D Scanning technique resolves the issue of depth measurement. This technique is very much used for industrial purposes. In recent last few years, it is used in medical science as a cost-effective solution. We propose a 3D reconstruction technique for an image acquired and product development for human prosthesis development. Industrial 3D structured light scanner develops correct 360° three dimensional models for further image processing

and three-dimensional printing process. Application of digital 3D scanning, 3D modeling, 3D printing and computer-aided engineering in medical science are emerging tools. Developing and learning 3D anatomy helps during surgery. In recent years, this technology has started to be of global use in the medical science field. Diagnostic techniques like CT, MRI, and X-rays are mostly used for internal biological structure identification. On the other side, 3D scanning opens the direct image acquisition of three-dimensional data of the outer anatomical surface without using CT and MRI scan technology.

Background Information

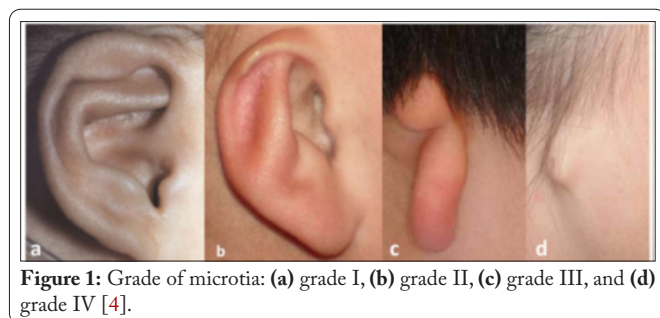
Craniofacial microsomia (CFM) diseases mainly affect the 5th and 6th month of child development during pregnancy. This disease is mainly the anatomical region of child development [1]. Those people who have CFM normally have ear abnormalities in one or both ears. Microtia is identified as the underdevelopment of one or both ears externally. The abnormality of the external ear of a child is known as microtia. A global survey occurred in 2011 and found every 2.06 child from 10,000 children has microtia [2]. The disfigurement is one of the primes focuses of body shape, size, the orientation of external ear [3] that instead of dissolute of ear auricle. There are four types of defects occur on the external ear, the defect is identified as microtia severity grade I to IV. In grade I the size of the ears are a bit small and identify the physical defect. (Figure 1a). In grade II, the size of the ear is one-half or two-thirds of the original size. (Figure 1b), grade III type of microtia is the most frequent defect and it is identified by a “peanut” shape of the external ear (Figure 1c), last in grade IV type of microtia, it is generally identified as anotia, here external ear absolutely missing (Figure 1d) [4].

Generally, microtia defects are found in 80% of people, also they are lost their hearing ability [5]. Primarily study on Microtia/anotia was mostly found in children with speech and language delay [6], also trouble occurs during human-to-human communication [7]. A survey comes to occur with some surprising result on microtia malformation and absolute missing/some physical disorder in the aesthetic aspect of the external ear, there are some negative psychological effects on the patient mind and lack of self-confidence, almost 52% of people compromising the quality of life due to microtia disorder [8]. The main target of doctors is to use prostheses and surgical processes to regenerate and reshape the ear disfigurement, so patients get confidence in life and improve leaving quality [9]. There are mainly three-techniques to resolve microtia: (a) Using fix Osseo integrated implant technique using silicon ear prostheses (b) restoration of auricular with synthetic material

implant, and (c) restoration of auricular with autologous tissue [10]. The patient, who is not going with surgery and want to take less risk of bacterial infection [3], follow silicone artificial ear, which involves medical skin adhesive but the prosthetic way for medical treatment is not a permanent solution for the patient [11]. The method for the development of ear prosthesis is vulcanizing; the process is allowed at room temperature, which involves different mechanical characteristic testing like tensile, hardness, etc. [12]. Medical technicians have gone through the vulcanizing process for ear prostheses is development, which gives a proper ear impression of the existing ear for mirroring the new prosthesis [4]. In the above listed all the methods have several challenges: time consuming, required more skilled doctors and paramedical staff for carving. To overcome such a constraint, doctors and paramedical staff had followed Computer-Aided Design/Manufacturing, 3D Scanning, and 3D Printing (Additive Manufacturing) technology. In the literature on human prosthesis development, the listed steps are as follows [13-15].

- (1) Data collection from 3D Scanning (Structured scanning and laser scanning), CT scan, or other photogrammetry technique.
- (2) 3D modeling of the human prosthesis using CAD tools (i.e., by using 3D modeling software).
- (3) Import 3D modeling data into 3D printer for mold manufacturing.
- (4) Refilling of the mold to achieve silicon base ear prosthesis.
- (5) Data collection of the patient for 3D Scanning.
- (6) Scan the 3D model and generate a 3D modeling database from the patient database.
- (7) 3D print (Additive Manufacturing) human prosthesis by using simulation in the 3D printing software.

From the doctor’s point of view, simulation is a very useful tool for medical clinical to identify detail and its evaluation for a case like an abnormality and prosthesis developing. Simulation using CAD/CAM tool it is very easy to reproduce patient’s anatomy, such as 3D replica and allowed doctors to plan the interventional with apex level accuracy and low risk during surgery. In this way before surgery, the surgeon can learn and develop their strategy for operating on a patient. It is great to work for a physician to identify and observe the co-relation with planning and familiarize himself with anatomy and create mental maps inside the operation theater. With this regard, 3D modeling, printing, and scanning all are very priority parameters for learning, simulation, and fabrication of 3D printing during surgery. During the last decades, all the technology has been widely used in the medical science field, and it gives revolutionizing results in the betterment of human life. Three main steps involved in the simulation and fabrication of the prosthesis. Image distinguishing methods and 3D Scanning methods [16] are very much used to capture the anatomy image of a body part. So, the 3D Scanning technique opens the direct data acquisition of the 3D outer anatomical surface at a low cost [17]. In the medical science field, many scientific studies report the use of the 3D scanner to collect anatomical data for the construction of orthotists and prosthetists [18].



In this work, the patient's anatomical 3D Scanning data will be collected by using Industrial 3D Structured Light Scanner and imported into solid modelling software. Then the data is processed by eliminating artefacts, filling holes, etc. and creating 3D models in STL format, to be 3D printed directly in plastic material (e.g., ABS). Additive manufacturing creates a new opportunity for biomedical engineers and doctors for the production of the 3D model by using the fused deposition modeling technique, where deposition of material is layer by layer from CAD-based 3D model. 3D printing has lost of advantages compared with traditional silicon base molds development technique, like reduction in time and cost, scale down the waste of material, also one of the best positive points is creating most complex shape in easy of way and strong use for facilitating patient life [19, 22].

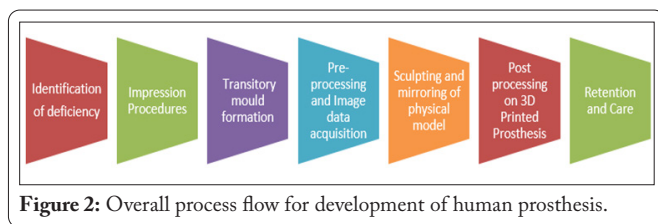


Figure 2: Overall process flow for development of human prosthesis.

Clinical Reports

The study was performed jointly with professionals from mechanical engineering and medical science. A study goes with a 14-year-old girl, who presented with left-sided microtia of grade III type. A joint decision was taken by the researcher in the present case to avoid any surgery and less bacterial infection patient go with CAD/CAM and Additive Manufacturing technique for improving the aesthetical view.

Computer-Aided Methodology for Auricular Prosthesis Development

Identification of deficiency

During medical practices of Dr. Deepika came up with a 14-year-old girl who has microtia of grade III shown in figure 3 deficiency on left ear by birth. Parents of the patient do not go with any surgical procedure on-ear due to limitation of financial problem. After several discussions the way was selected is going with CAD/CAM and Additive Manufacturing tool with low cost and effective solution with minimum medical treatment on the body.

Impression procedure

Examination of patient's deficiency on left ear with scar formation and rudimentary tissue was found, and contralateral ear was normal [20, 21] before impression development shown in figure 4, need to take the dimension of a normal ear. There are mainly three directions of dimension for covering the full ear, first from the junction of the helix, second from the middle of the tragus, and last at the junction of the ear lobe with a side of the head. The same marking is performed on the defective side for proper mirroring. During the development of mold for normal ear, the external auditory canal was blocked by surgical cotton for protecting from imparting of foreign particles in



Figure 3: Microtia grade III level deficiency of the left ear of the patient.

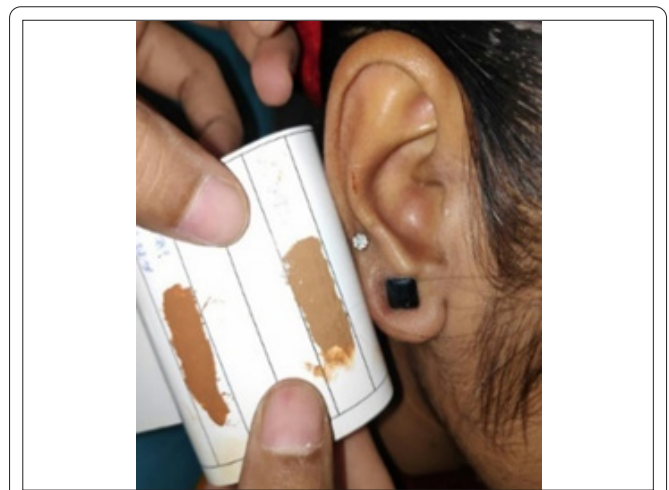


Figure 4: Impression procedure.

the auditory canal.

Transitory mold formation

Using quick-setting gypsum plaster of pairs show in figure 5 for physical impression of normal ear and also give

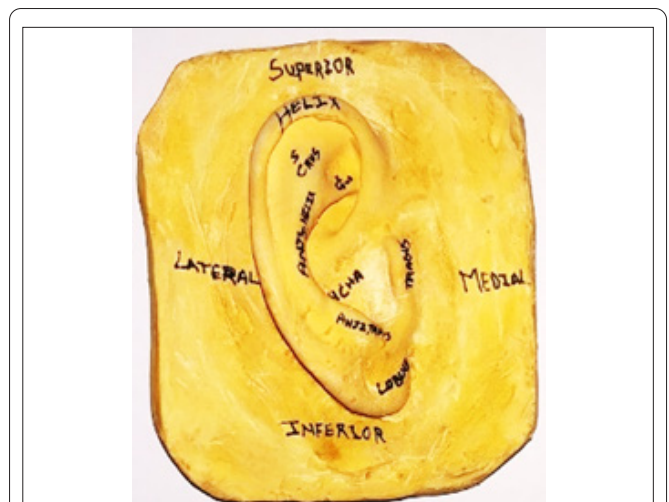


Figure 5: Quick-setting gypsum right side ear model.

quick resulting in the terms of good quality of mold making of a normal ear.

Pre-processing and image data acquisition

Prosthesis is a lifelong appearance for the patient, so it is very important for good quality output of work during pre-processing and needs to take utmost care during generating of digital data from the physical model. After the development of quick-setting gypsum plaster of pairs model from the normal ear, it is very important to convert the same data into digital form. For the conversation of data in digital form here, we are using structured-light 3D scanner technology (hardware setup shown in figure 6 and figure 7) for converting physical model into digital data which is used for 3D printing. Figure 8 shows scanning of gypsum right side ear model with high accuracy and precision.

Sculpting and mirroring of physical model

Process flow from 3D scanning to 3D printing shown in figure 8, where mirroring and conversation of physical model into digital data and need some image process on digital data like cleaning, alignment of all image and shape fusion of all images. Image data acquisition and image mirroring are playing a major role in the development of 3D printed human prosthesis.

Post-processing on 3D printed prosthesis

Identify process flow of using Reversing Engineering, Rapid Prototyping, and Additive Manufacturing, we can obtain imaging data acquisition by using 3D scanner and generate 3D scanned image of quick-setting gypsum base right ear of the patient and after need to rendering available image from software. Mirror the same image using any 3D modeling software and execute stereolithography (STL) file. After we go through 3D printing of the mirror ear shown in figure 9.

Retention and care

With utmost care during fixing a 3D printed prosthesis, after 3D printing, it was fixed on left side ear on girl show in figure 10.

Conclusion

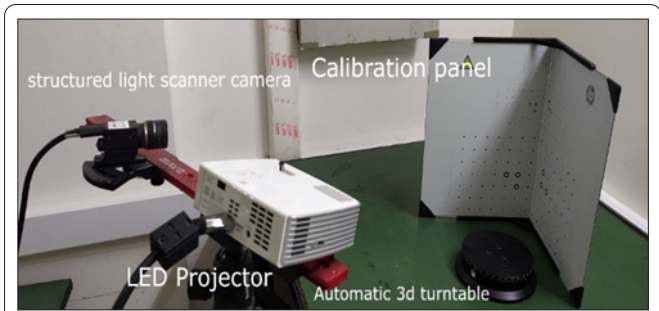


Figure 6: 3D scanner hardware setup.

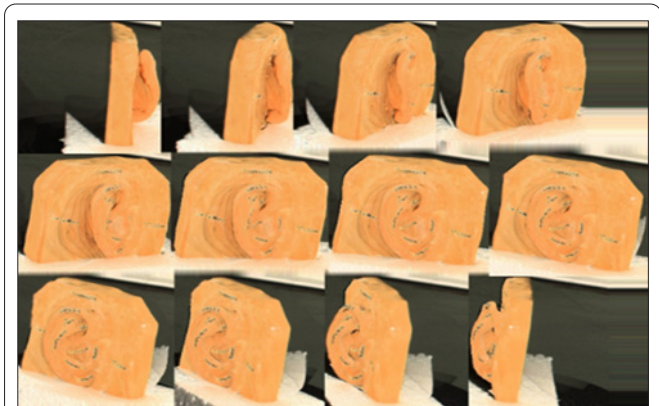


Figure 7: Clock the round 3D scanning of quick-setting gypsum model using turntable.

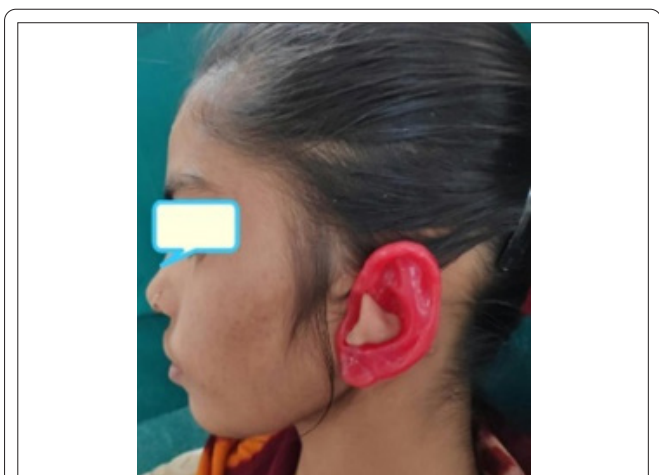


Figure 9: Post-processing on 3D printed prosthesis.

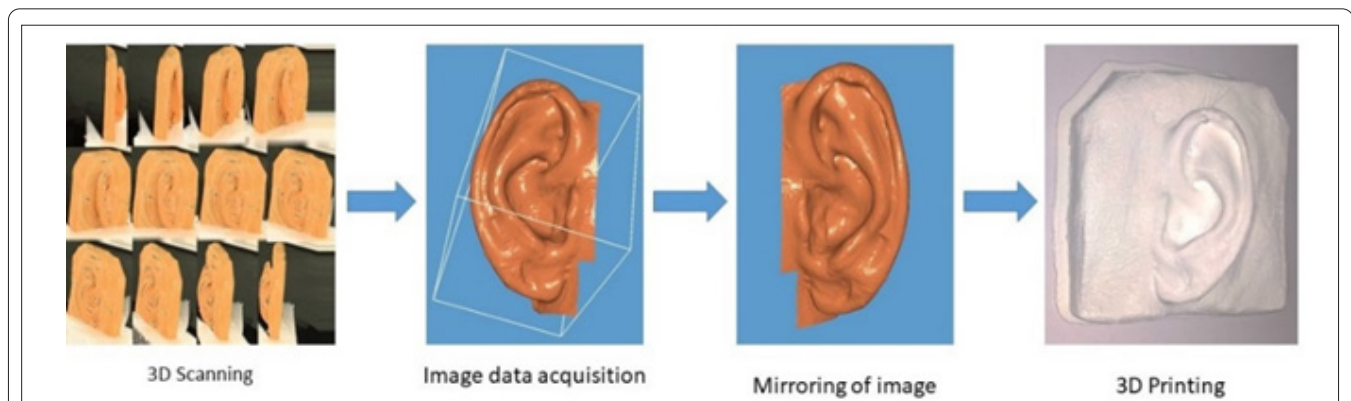


Figure 8: Steps involve from 3D scanning to 3D printing.

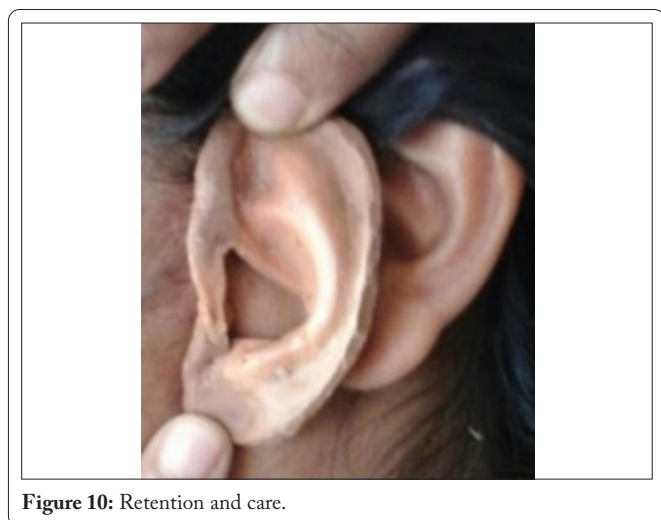


Figure 10: Retention and care.

Although, challenging work was accepted and completing the task by the team of engineering and medical professionals was excellent and new work for all team members. This work is describing the development of a left ear prosthesis for a 14-year-old girl, who is suffering deficiency related to microtia grade III in her left ear. The overall time is taken to completing all the steps within one month, starting from identification of deficiency to implement. In this case study advanced technology like 3D scanning and 3D printing is used for quick and efficient output. It is a quite smooth process for the development of human prostheses by using advanced CAD/CAM technology which gives cost-effective prosthesis.

Acknowledgements

None.

Conflict of Interest

The authors declare no competing interests that are relevant to the content of this article.

Credit Author Statement

Jignesh D. Jani: Development of 3D scanning and 3D Printing model; Siddharth Jhala: Biological aspect of work; Deepika Mor: Development of gypsum mold of right ear; Amit V. Sata: Guidance and Supervision. All the authors read and approved the manuscript.

References

1. Heike CL, Luquetti DV, Hing AV. 2014. Craniofacial Microsomia Overview—RETIRED CHAPTER, FOR HISTORICAL REFERENCE ONLY. In: GeneReviews®. University of Washington, Seattle.
2. Luquetti DV, Leoncini E, Mastroiacovo P. 2011. Microtia-anotia: a global review of prevalence rates. *Birth Defects Res A Clin Mol Teratol* 91(9): 813-822. <https://doi.org/10.1002/bdra.20836>
3. Ross MT, Cruz R, Hutchinson C, Arnott WL, Woodruff MA, et al. 2018. Aesthetic reconstruction of microtia: a review of current techniques and new 3D printing approaches. *Virtual Phys Prototyp* 13(2): 117-130. <https://doi.org/10.1080/17452759.2018.1430246>
4. Mussi E, Furferi R, Volpe Y, Facchini F, McGreevy KS, et al. 2019. Ear reconstruction simulation: from handcrafting to 3D printing. *Bioengineering* 6(1): 14. <https://doi.org/10.3390/bioengineering6010014>
5. Llano-Rivas I, del Castillo V, Reyes R, Carnevale A. 1999. Microtia: a clinical and genetic study at the National Institute of Pediatrics in Mexico City. *Arch Med Res* 30(2): 120-124. [https://doi.org/10.1016/s0188-0128\(98\)00023-2](https://doi.org/10.1016/s0188-0128(98)00023-2)
6. Billings KR, Qureshi H, Gouveia C, Ittner C, Hoff SR. 2016. Management of hearing loss and the normal ear in cases of unilateral microtia with aural atresia. *Laryngoscope* 126(6): 1470-1474. <https://doi.org/10.1002/lary.25530>
7. Zhu P, Chen S. 2016. Clinical outcomes following ear reconstruction with adjuvant 3D template model. *Acta Otolaryngol* 136(12): 1236-1241. <https://doi.org/10.1080/00016489.2016.1206967>
8. Horlock N, Vögelin E, Bradbury ET, Grobbelaar AO, Gault DT. 2005. Psychosocial outcome of patients after ear reconstruction: a retrospective study of 62 patients. *Ann Plast Surg* 54(5): 517-524. <https://doi.org/10.1097/01.sap.0000155284.96308.32>
9. Soukup B, Mashhadi SA, Bulstrode NW. 2012. Health-related quality-of-life assessment and surgical outcomes for auricular reconstruction using autologous costal cartilage. *Plast Reconstr Surg* 129(3): 632-640. <https://doi.org/10.1097/PRS.0b013e3182402ca7>
10. Baluch N, Nagata S, Park C, Wilkes GH, Reinisch J, et al. 2014. Auricular reconstruction for microtia: a review of available methods. *Plast Surg* 22(1): 39-43.
11. Federspil PA. 2018. Auricular prostheses in microtia. *Facial Plast Surg Clin North Am* 26(1): 97-104. <https://doi.org/10.1016/j.fsc.2017.09.007>
12. Artioli BO, Kunkel ME, Mestanza SN. 2019. Feasibility Study of a Methodology using Additive Manufacture to Produce Silicone Ear Prostheses. In Lhotska L, Sukupova L, Lacković I, Ibbott GS (eds) World Congress on Medical Physics and Biomedical Engineering. Springer, Singapore, Vol. 3, pp 211-215.
13. Subburaj K, Nair C, Rajesh S, Meshram SM, Ravi B. 2007. Rapid development of auricular prosthesis using CAD and rapid prototyping technologies. *Int J Oral Maxillofac Surg* 36(10): 938-943. <https://doi.org/10.1016/j.ijom.2007.07.013>
14. Ciocca L, Mingucci R, Gassino G, Scotti R. 2007. CAD/CAM ear model and virtual construction of the mold. *J Prosthet Dent* 98(5): 339-343. [https://doi.org/10.1016/S0022-3913\(07\)60116-4](https://doi.org/10.1016/S0022-3913(07)60116-4)
15. Yadav S, Narayan AI, Choudhry A, Balakrishnan D. 2017. CAD/CAM-assisted auricular prosthesis fabrication for a quick, precise, and more retentive outcome: a clinical report. *J Prosthodont* 26(7): 616-621. <https://doi.org/10.1111/jopr.12589>
16. Im DD, Paskhover B, Staffenberg DA, Jarrahy R. 2013. Current management of microtia: a national survey. *Aesthetic Plast Surg* 37: 402-408. <https://doi.org/10.1007/s00266-012-0008-x>
17. Furferi R, Governi L, Uccheddu F, Volpe Y. 2017. A RGB-D based Instant Body-Scanning Solution for Compact Box Installation. In Eynard B, Nigrelli V, Oliveri S, Peris-Fajarnes G, Rizzuti S. (eds) Advances on Mechanics, Design Engineering and Manufacturing: Proceedings of the International Joint Conference on Mechanics, Design Engineering & Advanced Manufacturing. Springer, Cham, pp 819-828.
18. Baronio G, Harran S, Signoroni A. 2016. A critical analysis of a hand orthosis reverse engineering and 3D printing process. *Appl Bionics Biomech* 2016: 8347478. <https://doi.org/10.1155/2016/8347478>
19. Liaw CY, Guvendiren M. 2017. Current and emerging applications of 3D printing in medicine. *Biofabrication*, 9(2): 024102. <https://doi.org/10.1088/1758-5090/aa7279>
20. Kaur M, Kaura SM, Sharma A, Showkat R. 2020. Restoration of microtia by prosthetic method: a case report. *Eur J Med Health Sci* 2(4). <https://doi.org/10.24018/ejmed.2020.2.4.408>
21. Watson J, Hatamleh MM. 2014. Complete integration of technology for improved reproduction of auricular prostheses. *J Prosthet Dent* 111(5): 430-436. <https://doi.org/10.1016/j.prosdent.2013.07.018>
22. Cruz RL, Ross MT, Skewes J, Allenby MC, Powell SK, et al. 2020. An advanced prosthetic manufacturing framework for economic personalised ear prostheses. *Sci Rep* 10(1): 11453. <https://doi.org/10.1038/s41598-020-67945-z>