

CAD-CAM generated ear cast by means of a laser scanner and rapid prototyping machine

Leonardo Ciocca, DDS, PhD,^a and Roberto Scotti, MD, DDS^b
Alma Mater Studiorum University of Bologna, Bologna, Italy

Sculpting a wax ear cast for use when making a definitive prosthesis for a patient who has had auricle ablative surgery, is challenging. It requires a skilled anaplastologist along with complex instrumentation able to perform facial laser scans and reproduce anatomic details. The aim of this article is to present a technique to create a cast by laser scanning a stone cast of the existing ear. A 3D laser scanner develops an integrated 3D digital image of the unaffected ear, which is copied and then mirrored. A rapid prototyping machine collects the necessary data to manufacture the definitive resin ear. This procedure is time and cost effective only if the technology is free of charge. (J Prosthet Dent 2004;92:591-5.)

The surgical ablative treatment of maxillofacial cancer may cause facial disfigurement and consequently psychologic disturbances. The involvement of facial organs often causes great difficulties in terms of social relationships and economic consequences.¹ Patients may be restored using modern microvascular flaps, but some patients may not receive such surgery because of age or general medical condition. In such circumstances, a facial prosthesis could serve as a viable definitive alternative.²

When sculpting a wax ear cast, an anaplastologist faces the challenge of reproducing correct anatomic morphology. Furthermore, this type of rehabilitation often represents an additional cost for patients. Recent studies³⁻⁷ have focused on computer-assisted rapid prototyping machines to sculpture facial prostheses. Several techniques have been reported to fabricate a mirror-image wax cast for maxillofacial prostheses,^{4,8,9} however, these techniques are costly and may require more time than manual fabrication. Nusinov and Gay⁸ used a vertical camera capable of reproducing 3-dimensional objects to transfer parallel lines to casts for positioning. Mankovich et al⁹ presented a technique for fabricating a prosthetic scalp using a computerized tomography (CT) scanner. Runte et al⁶ investigated the use of an optical impression technique, based on a 3-dimensional optical data acquisition system, to circumvent impression problems when fabricating a facial prosthesis. Furthermore, the technical equipment and high cost represented problems in these clinical procedures.

Other studies have focused on the materials used to make impressions by optimizing the definitive cast and minimizing soft tissue distortion,^{10,11} whereas Cheah et al^{12,13} presented a manufacturing approach to achieve automated fabrication of spatially and anatomically accurate extraoral prostheses using the computer-aided design-computer-aided manufacturing (CAD-CAM)

technique. In the first part of the present article, the authors outline a protocol for the fabrication of a prosthesis replica which includes a laser scan of the face and the rapid prototyping of the prosthesis. The authors developed a method to eliminate the use of conventional impressions and the necessity to depend on the artistic skills of an anaplastologist. In the second part, the authors present the design and production steps of negative molds used in the definitive prosthesis using CAD, rapid prototyping, and rapid tooling techniques. This article describes a technique to rapidly create a wax cast by laser scanning a plaster cast of the existing ear.

TECHNIQUE

Data acquisition

1. Randomly position a cast of the existing ear on a platform with colored pins (Ballpin; Buffetti, Milan, Italy) (diameter 2.5 mm) around it. (Fig. 1, A)
2. Use a laser scanner (Minolta VIVID 900; Minolta, Osaka, Japan) connected to a personal computer (Asus, Pentium 4 /2.8, 1 GB Ram, HD 80 GB) to acquire the 3D spatial coordinates using software (Polygon Editing Tool v1.03; Minolta). Make the first measurement after positioning the stone cast in front of the laser scanner. (Fig. 1, B)
3. Place the cast of the ear in 8 random positions (Fig. 2) to obtain 8 laser measurements of the surface from different angles to detect all undercuts.
4. Record these patterns with the software (Polygon Editing Tool v1.03) of the laser scanner.
5. Represent the surface by 8 clouds (the entire number of the 3D points representing a volume surface) of 50,000 points, each with 3D point coordinates.
6. Adjust these digitalized surfaces as explained in steps 7 to 14 of this technique, then merge them to combine the 3D clouds of points, using software (Inus Rapidform 2004 CAD v2004; INUS Techn, Seoul, Korea) to locate the same 3D points in each digital image. Overlap the center of each colored spherical pin with the corresponding pin in the

^aClinical Assistant Professor of Maxillofacial Prosthesis, Section of Oral and Maxillofacial Rehabilitation, Department of Oral Science.

^bDean and Professor of Prosthodontics, Section of Oral and Maxillofacial Rehabilitation, Department of Oral Science.



Fig. 1. **A,** Colored pins for repositioning diverse angled images. **B,** Minolta Vivid 900 laser scanner.

other diverse angled image scans and integrate all measurements (Fig. 3).

Data elaboration

7. Use the “Register 2 Shells” function for the recombination and alignment of the pairs of scans through 3D translations.



Fig. 2. Eight random positions of laser scanner.

8. Use the “Register Fine” function to permit the entire surface to be recombined by using an automatic algorithm.
9. Use the “Merge Mesh” function to blend the different surfaces into 1 virtual model and to construct a surface with the 3D values of each corresponding point of the different scans.
10. Use the “Clean Abnormal Face” function to eliminate surface abnormalities of the previously elaborated shell.
11. Use the “Smooth” function to smooth the surface of the image.
12. Use the “Remesh” command to allow for the organization of the triangulated mesh of the points.
13. Use the “Decimate” function to reduce the magnitude of the computerized file.
14. Use the “Fill Holes” function to automatically or manually eliminate surface gaps that remain after data elaboration.
15. Develop an STL-integrated 3D digital file with the software, using the “Export as STL file” function.
16. Copy and mirror the existing surface (Fig. 4) using the “Divide/Mirror” tool to permit visualization of the defective ear as it appeared before ablative surgery.

CAD-CAM technology and rapid prototyping procedure

17. Process the STL file using the computer system (Z Printer 310; Z Corp, Burlington, Mass) to manufacture the definitive acrylic ear cast in a single step. By using the Z Printer 310 machine, provide a layer of sealant (Z Corp Sealant; Z Corp) with a layer of resin powder (Z Corp Powder; Z Corp) and develop the entire volume through layer-by-layer manufacturing.
18. Allow 60 minutes for the acrylic resin to polymerize.
19. Extract the cast from the powder and then infiltrate the surface of the manufactured ear with cyanoacry-

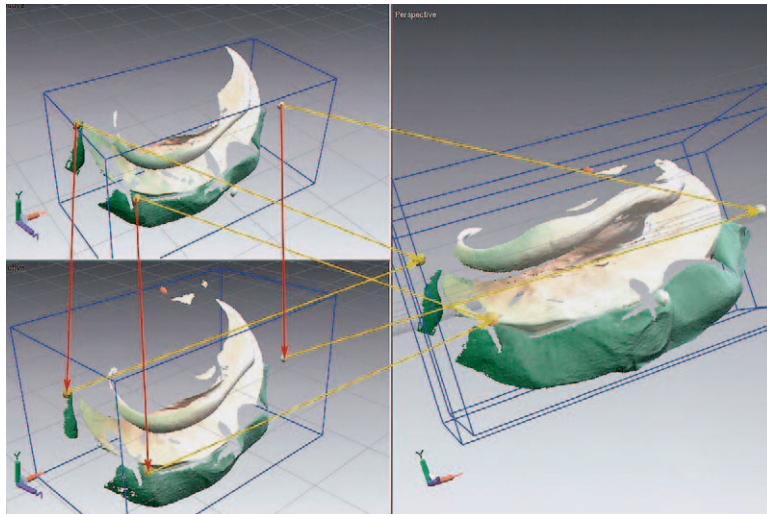


Fig. 3. Reproduction of overlapping process.

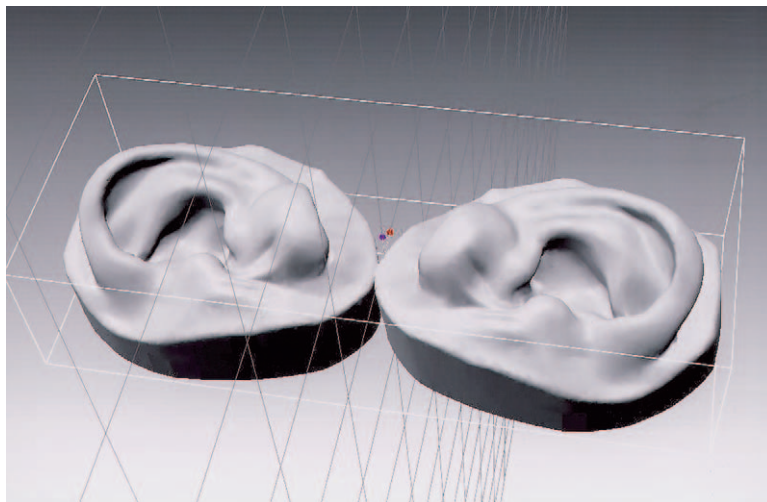


Fig. 4. Digitalized image is copied and mirrored.

late (496; Loctite Italia, Brughiero, Italy) to further harden the acrylic resin ear (Fig. 5).

Prosthesis production

20. Use a vinyl polysiloxane material (Zetalabor Platinum; Zhermack, Badia Polesine, Italy) to transform the acrylic resin cast into a wax ear.
21. Make a mold with the silicone, leaving an opening in the mold all around the base of the prototyped ear.
22. Split the vinyl polysiloxane mold during the removal of the resin cast and recombine it using the cyanoacrylate before pouring the mold with the wax (Tenatex; Associated Dental Products, Imadent, Turin, Italy).
23. Once the wax hardens, separate the 2 parts of the mold and extract the wax cast from the silicone mold.
24. Adapt the margins of the mirrored section to the post surgical face asymmetries. The mirror projection of the corresponding surface will not initially fit in the resection cavity (Fig. 6).
25. Perform conventional processing procedures as described by Beumer et al¹⁴ to obtain the definitive prosthesis (Fig. 7).
26. Use a spectrophotometer to determine the intrinsic color of the ear (SpectroShade Office; MHT, Verona, Italy)
27. Apply extrinsic colors (Extrinsic; Factor II, Lakeside, Ariz), and use acetoxysilicone adhesive (A-564; Factor II) to seal the coloration onto the silicone.

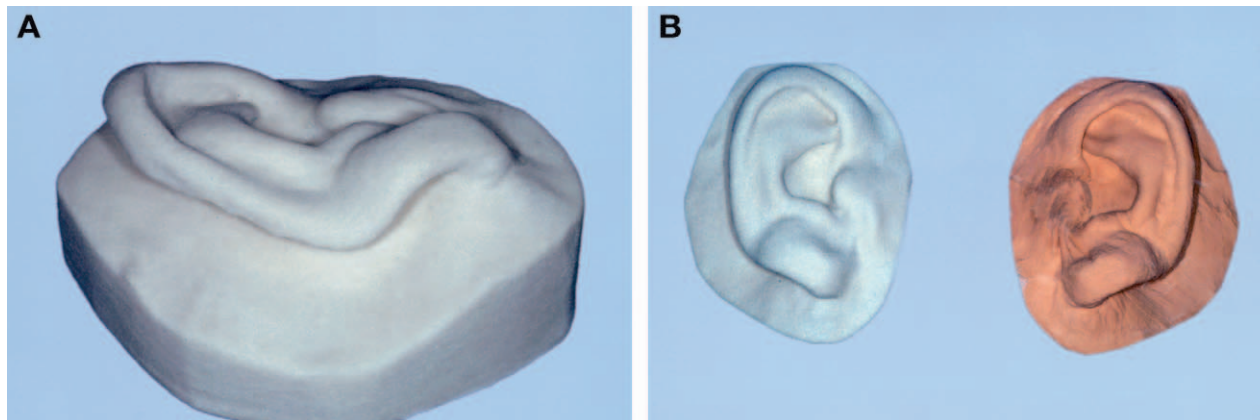


Fig. 5. A, Rapid prototyping in acrylic of undercuts. B, Frontal view of acrylic final result (on left).



Fig. 6. Initial trial of wax ear obtained through silicone duplication on patient.



Fig. 7. Definitive result.

DISCUSSION

Several research protocols have proposed technical computer-assisted solutions, however, this article describes a simple, inexpensive, and repeatable method of obtaining a definitive wax cast of a maxillofacial prosthesis. Using a pin system around the ear cast prior to duplication, 8 laser measurements of the surface from new angles allow for the detection of all undercuts. Each colored sphere at the top of the pin permits the detection the center point from every angle it is observed and subsequently the recombination of the different angled images which overlap with the corresponding colored pin center of the other diverse image scans (Fig. 3). The software blends the different surfaces of the ear into 1 virtual 3D model using the sphere around the cast, whose perimeters and centers may be easily detected and overlapped with the corresponding one in the other images of the different scans. Other recent studies^{7,12} have proposed scanning methods which used custom-made laser scanners or expensive rapid prototyping devices. This tech-

nique requires only a conventional laser scanner and a commercial 3D printer.

This technique is also faster and less expensive than the work of an anaplastologist which is done by hand. However, it should be noted that the authors had use of equipment at the Architectural Department of the Engineering Department at the University of Bologna, Italy, free of charge. The equipment needed is similar to that used for the rapid prototyping process in architectural modeling. If access to such a computerized system is available, the only cost is the powder and the sealant of the 3D printer. Using this equipment, the procedure takes no more than 8 hours, the majority of which is spent on data elaboration.

This technique, used for computer-generated facial prosthesis construction, has several advantages. The laser scanner and the rapid prototyping machine used for reproducing a mirrored cast of an existing ear with this technique are commonly available. Data acquisition and elaboration is less time consuming and expensive than with previously described methods or fabricating the wax prosthesis manually. Surface data may be corrected

and adapted to more accurately reconstruct the prosthesis. The definitive resin cast may be saved in a maxillofacial prosthetic computerized library and reproduced when the prosthesis requires repair or duplication.

A disadvantage of this clinical procedure is the lack of detailed color information. The use of a spectrophotometer is necessary to obtain precise color matching.¹⁵ If clinicians do not have a specialized, cost-free laboratory at their disposal, the price of the recommended technical equipment may be a disadvantage.

Future developments might include a color map of the definitive prosthesis by means of a spectrophotometer-assisted color calibration of the surface. The integration of the 2 systems, color and volume, would be required. Moreover, future developments may include details of the undercuts and the adaptation of the acrylic resin cast to the resection margins. In addition, the system for the fabrication of a maxillofacial prosthesis might be used as a presurgical template for the craniofacial implant positioning diagnosis by means of a CT scan.

SUMMARY

This article describes a technique for making maxillofacial prostheses using CAD-CAM technology and a rapid prototyping machine. A laser scanner was used to develop an integrated 3D digital image of the existing ear of a patient subjected to auricle ablative surgery. The image was mirrored and used to manufacture the solid ear cast by means of a rapid prototyping machine. This procedure is time and cost effective if the technology is available free of charge. Subsequently, the definitive prosthesis was obtained through conventional procedures.

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