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Three-dimensional printing for restoration of the donor face: A new digital technique tested and used in the first facial allotransplantation patient in Finland

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Summary *Background and aims:* Prosthetic mask restoration of the donor face is essential in current facial transplant protocols. The aim was to develop a new three-dimensional (3D) printing (additive manufacturing; AM) process for the production of a donor face mask that fulfilled the requirements for facial restoration after facial harvest.
Materials and methods: A digital image of a single test person's face was obtained in a standardized setting and subjected to three different image processing techniques. These data were used for the 3D modeling and printing of a donor face mask. The process was also tested in a cadaver setting and ultimately used clinically in a donor patient after facial allograft harvest.
Results: and Conclusions: All the three developed and tested techniques enabled the 3D printing of a custom-made face mask in a timely manner that is almost an exact replica of the donor patient's face. This technique was successfully used in a facial allotransplantation donor patient.

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Introduction

Experience in facial allotransplantation is accumulating in several centers worldwide. From 2005, there have been 31 reported facial transplants in seven different countries.[1] These facial transplants have varied from partial to full facial transplants; however, all of them have included a major part of the facial skin and soft tissues. Therefore, in contrast with solid organs, facial procurement leaves a significant visible disfigurement with consequent ethical issues. The approach to facial restoration after facial procurement has varied between different centers internationally and is subject to varying cultural factors. In some cultures, simple coverage of the remnant facial structures with a simple gauze dressing after facial procurement may suffice. However, in other cultures, there is a need for visual restoration after facial procurement. In order to safeguard the dignity of the donor and respect for the family, it is important to restore the facial appearance after procurement. This is particularly the case in "open casket" burials.

In the literature, there is a scarcity of reports on the current available options for donor face mask production. These methods include masks handmade from resin or silicone.[2,3] In short, a mold is obtained from the donor face using alginate, and the mask is prepared using this negative imprint. Next, a replica is prepared from plaster from which a silicone or resin mask is then made, and the mask is finally refined using makeup application. However, the mask is not a perfect copy of the donor's face. There are many steps involved, and the end result relies on the skills of the anaplastologist who should work in close tandem with the facial harvesting team.

Additive manufacturing (AM) aka three-dimensional (3D) printing refers to the technologies used for printing a 3D object and is currently used in various medical applications.[4] The combination of computed tomography (CT) and AM can be applied for the production of medical models for preoperative planning.[5] AM technologies are utilized for anatomic personalization of prosthetic sockets,[6] and additive manufactured implants,[7,8] dental crowns,[9] and denture frameworks[10] have also been successfully used. Our earlier experience with these technologies has comprised various dental and maxillofacial applications.[11–13] Our and other studies have provided validation of the AM concept as a workable solution for various clinical purposes using modern digital technology and obviating the need for a manual working phase.

Here, our aim was to develop and evaluate a new digital process for the manufacturing of a donor face mask for facial restoration using a multidisciplinary setup. We tested three different 3D digital imaging methods for producing a 3D printed donor face mask. Furthermore, this process was investigated in a cadaver setting to evaluate the timing, logistics, and cooperational aspects of the process. This new technique was then used for facial restoration in the first facial allotransplantation donor patient in Finland.

Materials and methods

3D digital imaging method testing

A volunteer provided fully informed consent for the study as a single test person, and digital images of his face were obtained indoors in a standardized setting. These were then manipulated using three different image-processing techniques. These data were used for the 3D modeling and printing of the donor face mask (Table 1).

Two of the methods were based on reconstructing the geometry and colors from photographs (123D, Autodesk Inc., USA and Proface, Planmeca Oy, Finland). The third one used structured light to capture geometry and a monochrome camera with a projector for color channels (red, green, and blue) to capture colors (DAVID-SLS-1 scanning set, DAVID Vision Systems GmbH, Germany).

Data obtained from scanning were then converted to a 3D (Polygon File Format) format using various software (Table 1). Models were repaired, manipulated, and thickened using the 3DataExpert software (3DataExpert 10.0.0.7, DeskArtes Oy, Finland).

The 3D data of the planned mask were then transferred to the AM machine using a ZPrint CAD format. The final physical object was manufactured using a binder jetting method with a full color complement (ZPrinter 450 or 650, 3D Systems Corp, USA).

Cadaver case

The described process was then tested in a cadaver during a facial procurement practice session performed by the Helsinki Facial Allotransplantation team. The face of the deceased was photographed the day before using a Canon Powershot G12 (Canon Inc., Japan) digital camera in normal lighting at the mortuary. The 123D Catch was not used because the licensing agreement only allows the manufacturer to use created 3D models for marketing purposes. Therefore, Agisoft Photoscan (AgiSoft LLC, Russia) was used instead for creating the 3D model from the photographs. The editing and manufacturing were completed as previously described. The face of the cadaver was dissected as planned for the first facial allotransplantation in Finland and included the full face, soft tissues, and Le Fort II type maxilla. The mask was then inserted after dissection and secured with gauze.

Allotransplantation patient

This new donor mask-manufacturing technique was then clinically used in Finland's first facial allotransplantation case. The donor patient was photographed using a standard digital camera soon after the decision for facial procurement was confirmed. The same processing as outlined above was conducted concurrently with the multiple organ and facial allograft harvesting operation. The only difference compared with the cadaver test case was that the donor now had an endotracheal tube and some stains on the skin. These were managed by using standard photo-editing