Correlation between structural and color changes in 3D facial images of head and neck cancer patients following reconstructive surgery

J. Lee[1], G. S. Muralidhar[2], A. C. Bovik[1], M. C. Fingeret[3], M. K. Markey[2]
[1] The University of Texas at Austin, Electrical and Computer Engineering, Austin, USA
[2] The University of Texas at Austin, Biomedical Engineering, Austin, USA
[3] The University of Texas MD Anderson Cancer Center, Behavioral Science, Houston, USA

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Purpose

Treatment for head and neck cancer can impair speech and swallowing, and can disfigure the face. Reconstructive surgery can restore some facial function and ameliorate disfigurement, thereby helping patients to psychosocially adjust. However, current surgical reconstruction techniques may not fully restore a patient's pre-cancerous appearance. Therefore, it is important to understand the aspects of disfigurement that persist after surgery, since this could be used to improve the reconstruction process.

Efforts towards developing improved reconstruction approaches would be greatly augmented by suitable disfigurement models. For example, by simulating surgically plausible facial disfigurements that may arise from reconstructive surgery, surgeons might be better able to estimate how the reconstructive process affects the patient's appearance. This would assist the physician in determining which reconstruction options are most appropriate for the patient.

Recently, 3D imaging techniques have been deployed for planning and evaluating reconstructive surgery [1]. Unlike traditional 2D clinical photographs, 3D images preserve the 3D structure of the face in addition to color information. However, the use of 3D imaging for surgical planning has been limited to the analysis of the bony structure of the face. The development of methods for analyzing changes of the soft tissue (an important aspect of facial disfigurement) that would be consequent to different reconstructive options (such as the choice of autologous tissue) remains in a nascent stage of research.

Modeling facial morphology using 3D images has been widely studied in computer graphics (for rendering faces) and in computer vision (for recognizing faces). Beyond this, we believe that 3D face modeling has the potential to be used for simulating surgically plausible facial disfigurements. However, there are many new challenges to be faced in this realm that are not addressed by face rendering or recognition algorithms, such as analyzing and quantifying the changes in the face that can occur as a result of surgery or radiation therapy. These changes can be manifested in both the bony and soft tissues of the face.

To develop a facial disfigurement model that is surgically plausible, it is necessary to understand the relationship between the structural and color components of faces that are disfigured by reconstructive surgery. Thus, we evaluated the relationship between change in the structural and color components of the face of patients suffering from head and neck cancer following reconstructive surgery.

Methods

A total of 24 3D facial images of 12 patients currently undergoing reconstructive surgery on their faces following oncologic surgical treatment were analyzed. For each patient, two sets of 3D images were included: 1) a pre-operative image (*viz.*, prior to any oncologic and reconstructive surgery), and 2) a post-operative image (after initial oncologic and reconstructive surgery). All post-operative images were taken at least 1 month after the oncologic and primary reconstructive surgeries. Fig 1.A and 1.B show the pre- and post-operative 3D images of one of the patients. Each vertex of the 3D image contains structural (xyz coordinates) and color (RGB) information.

To analyze the relationship between changes in the structural and color components of the face due to reconstructive surgery, it was necessary to register the vertices of the pre-operative

and post-operative images of each patient to be located in the same 3D Cartesian space, where the ranges of the x, y, and z axes are [-100 100], [-150 150], and [-130 0] *mm* respectively. To accomplish this, we fixed the tip of each patient's nose as the origin of Cartesian space and manually annotated 29 fiducial points [2] on each 3D image. The list of fiducial points is shown in Fig 1.C. We then applied the Procrustes method [3] without scaling on those fiducial points to confirm the locations of the pre- and post-operative 3D facial image.

Our hypothesis is that changes in the structural components of the face are correlated with the changes in the color components of the face. To evaluate this hypothesis, we first converted the color component in RGB color space to the perceptually uniform CIELab color space. We then obtained histograms of both the structural and color components of the 3D facial image. To construct the structural histogram, the vertices in the space were quantized with cubes having 5 *mm* edges (total 40x60x26 = 62400 bins). To create the color histogram, the colors were quantized into 16x16x16 = 4096 bins. The resulting histograms were scaled to be summed to 1, making them empirical probabilities and so that each patient's data are comparable with the others. The Euclidean distance between the histograms of the pre- and post-operative images were then calculated. The Spearman's rank correlation coefficient was calculated between the Euclidean distance values computed from the structural and color histogram of patient's face.

Results

The observed correlation coefficient (0.594) was statistically significantly different from zero ($p = 0.046$). Changes in the structural components due to reconstruction following surgery are correlated with those in color components (Fig 1.D).

Conclusion

Changes in the structural components of the face due to reconstructive surgery are correlated with changes in the color components of the face. This result suggests that facial models that simultaneously embody models of change in the structural and color components of the face may effectively capture modifications due to oncologic and reconstructive surgery.

References

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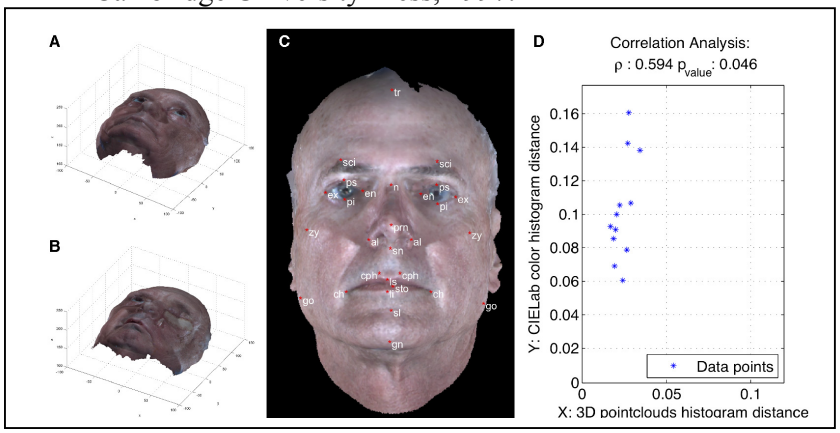

Fig. 1. A and **B** show the pre- and post-operative image of one patient who underwent orbital exenteration followed by the reconstruction using rectus adominis flap. **C** depicts manually located 29 fiducial points. **D** depicts positive correlation between the changes in structural component of the face and those in color component of the face.