Designing a Virtual Reality Model for Aesthetic Surgery

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Background: Aesthetic surgery deals in large part with the manipulation of soft-tissue structures that are not amenable to visualization by standard technologies. As a result, accurate three-dimensional depictions of relevant surgical anatomy have yet to be developed. This study presents a method for the creation of detailed virtual reality models of anatomy relevant to aesthetic surgery.

Methods: Two-dimensional histologic sections of a cadaver from the National Library of Medicine's Visible Human Project were imported into Alias's Maya, a computer modeling and animation software package. These two-dimensional data were then "stacked" as a series of vertical planes. Relevant anatomy was outlined in cross-section on each two-dimensional section, and the resulting outlines were used to generate three-dimensional representations of the structures in Maya.

Results: A detailed and accurate three-dimensional model of the soft tissues germane to aesthetic surgery was created. This model is optimized for use in surgical animation and can be modified for use in surgical simulators currently being developed.

Conclusions: A model of facial anatomy viewable from any angle in three-dimensional space was developed. The model has applications in medical education and, with future work, could play a role in surgical planning. This study emphasizes the role of three-dimensionalization of the soft tissues of the face in the evolution of aesthetic surgery. (*Plast. Reconstr. Surg.* 116: 893, 2005.)

The key soft-tissue anatomical players in aesthetic surgery of the face exist in three-dimensional relationships difficult to visualize by conventional means. Two-dimensional modalities are necessarily inferior in an analysis of three-dimensional structures, and standard three-dimensional technologies (e.g., three-dimensional computed tomography), although efficacious for skeletal imaging, do not adequately portray facial soft tissues. Three-dimensional surface imaging technologies (e.g., laser scanning) are valuable, but provide images that are only "skin deep." This article presents a method for constructing a three-dimensional virtual reality model of the soft tissues of the face that lie between the skin and bone. The models may prove to be a valuable resource for surgical education, and may eventually play a role in surgical planning.

Materials and Methods

Basic soft-tissue anatomical data were derived from the National Library of Medicine's Visible Human Project (U.S. National Library of Medicine, Bethesda, Md.).[1] The data were in the form of hematoxylin and eosin–stained axial histologic cuts of a female cadaver sectioned

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at 333-μm intervals. These sections were digitized and distributed by the National Library of Medicine. Each image file was cropped to remove frame borders in Adobe's Photoshop 5.5 (Adobe Systems, Inc., San Jose, Calif.). The two-dimensional images were then three-dimensionalized using Alias's Maya 4.0 (Alias Systems Corp., Toronto, Ontario, Canada) according to the following protocol. First, a series of horizontal planes was created with the same height (*x* axis) and width (*y* axis) proportions as the data from the Visible Human Project. These planes were vertically aligned (along the *z* axis) at 1-cm intervals. Two-dimensional sections from the Visible Human Project were selected at intervals of 1 cm and subsequently mapped onto the corresponding planes created in three-dimensional space in Maya (Fig. 1). These planes at 1-cm intervals served as "reference slices" that were used to identify anatomy of interest. As structures to be modeled were identified on these reference slices, increased depth resolution (*z* axis) was often required to define anatomical detail. In such cases, additional planes were created in Maya and corresponding images from the Visible Human Project were imported. Anatomical structures of interest were identified and outlined on these *xy* planes using Maya's EP Curve tool. The EP curves generated from the outlined structures were connected along the *z* axis using Maya's Loft tool. The surfaces thus generated served as primary three-dimensional representations of the soft-tissue anatomy of interest (Fig. 2).

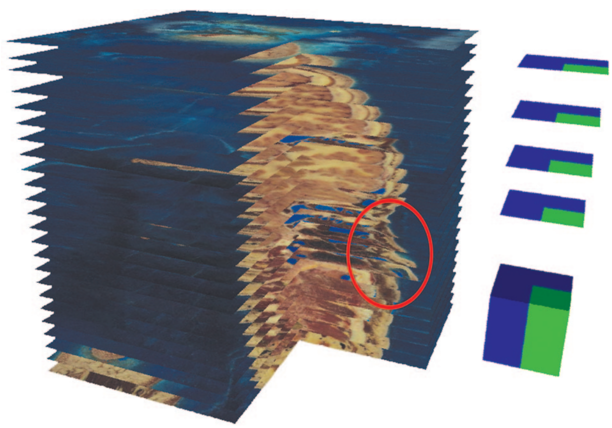

FIG. 1. To showcase the utility of Maya as an environment for viewing the Visible Human Project data, a series of two-dimensional planes, each mapped with a serial section from the Visible Human Project data set, is shown. The planes have been positioned in three-dimensional space with Maya. The blue background represents the compound in which the cadaver was suspended for sectioning. Note that to further emphasize the versatility of this visualization technique, a segment of the stacked slices has been removed. To further orient the viewer, a parasagittal section of the nose is circled in red, and to the right of this stack of Visible Human Project sections, a schematic is shown. A number of individual planes (*left*) are stacked close together to give the appearance of a solid cube from the Visible Human Project. The green portion in the planes and cube on the right represents the segment removed from the stack of Visible Human Project slices at left.

These soft-tissue models were modified to fit a three-dimensional model of a female skull, which had previously been created by the Institute of Reconstructive Plastic Surgery Virtual Surgery Laboratory as an average of several female skull three-dimensional computed tomographic scans.[2,3] These modified secondary soft-tissue models were then manipulated to more clearly demonstrate anatomical relationships in an effort to minimize artifacts inherent in the method just described for translation of a human cadaver into a three-dimensional model. These manipulations were conducted with great care to adhere to anatomical reality, using cadaveric dissection and literature review to ensure faithfulness to reality.[4–11] Our final soft-tissue models, now fit to a skull model, were the result. Some structures (primarily neurovascular) obliterated during sectioning or digitalization of the Visible Human Project data were created de novo in Maya, again guided by cadaveric dissection and literature review. These structures were then superimposed on the soft-tissue and skull models to complete our representation of relevant head and neck anatomy.

A skin model of the young female head was purchased commercially from the Viewpoint Corporation, and the underlying soft-tissue models were manipulated within the limits of normal anatomy to conform to this skin shape. Thus, a model of the female head was created with deep tissues and "matching" overlying skin. Finally, the models were texture-mapped with a combination of photographs enhanced in Adobe Photoshop 7.0 and materials designed in Maya.

RESULTS

A virtual reality model of surgical superficial facial anatomy was created. Included in this model are the superficial musculoaponeurotic system (SMAS), facial musculature, nerves, blood vessels, and fatty tissue most relevant to aesthetic surgery. These structures exist in virtual three-dimensional space such that they

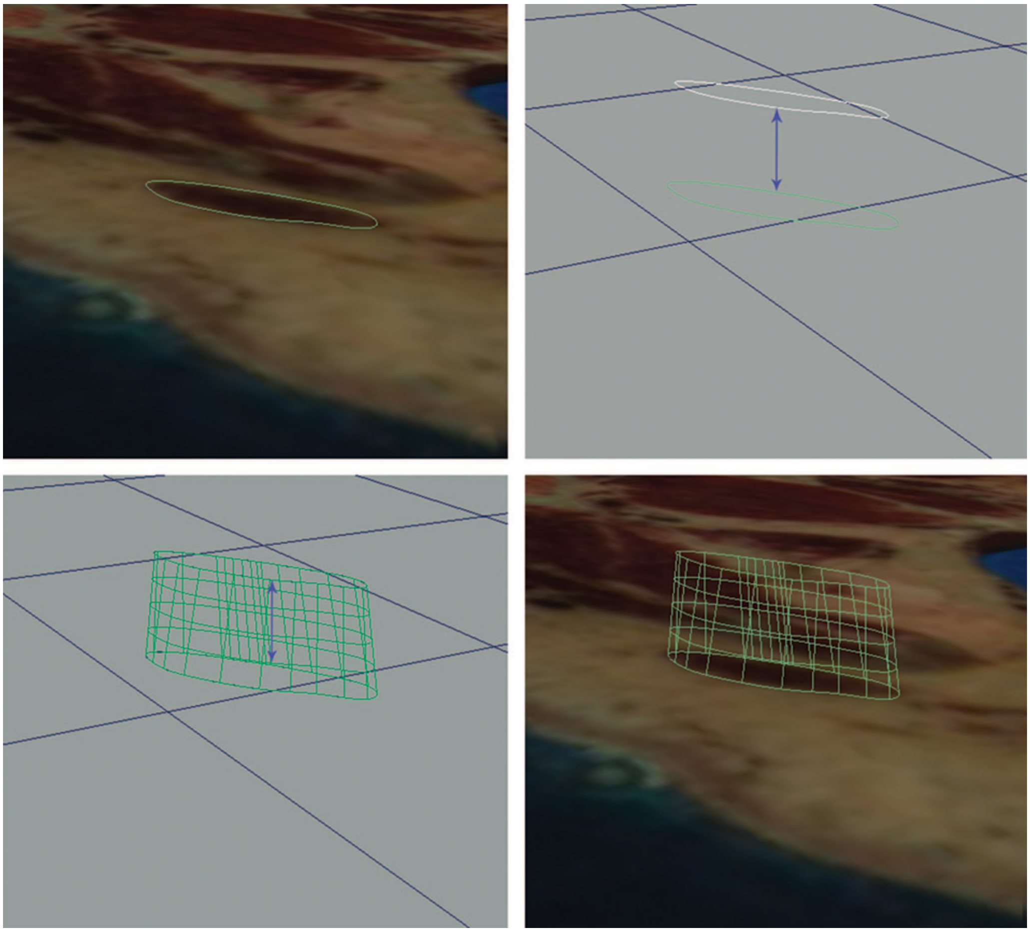

FIG. 2. This image illustrates the modeling process. (*Above, left*) One plane of those stacked in Figure 1 is viewed in isolation, with an EP curve (green) outlining the zygomaticus major muscle in horizontal section. (*Above, right*) Texture maps are removed from this view, highlighting two EP curves (white, representing the zygomaticus major as outlined on a more superior slice; and green, the outline of this muscle as seen on the plane in Fig. 1). The vertical distance between the two curves is emphasized by the *blue arrow*. (*Below, left*) A mesh (green) is created by "lofting" from superficial tracing to inferior tracing. (*Below, right*) The texture map is again visible in this view; the mesh represents the beginnings of the three-dimensional zygomaticus major model.

can be rotated and viewed from any angle. Individual structures can be viewed either in isolation or in relation to one another. Any structure may be highlighted or made completely or partially transparent to aid in the illustration of a specific teaching point. The model can be used for the illustration of any surgical technique or problem involving the depicted facial anatomy (Fig. 3).

By constructing the models with an eye toward minimizing data density while maintaining anatomical detail, we sought to produce three-dimensional meshes that could easily be manipulated or animated in Maya. The resulting models are thus "light," in that they contain relatively few data points for their high level of anatomical detail.

DISCUSSION

Three-dimensional imaging has become an integral part of the practice of craniofacial surgery. Early work by Marsh et al. discusses three-dimensional computed tomography and its use as a method of clarifying the patient's skeletal anatomy.[12,13] Cutting et al. have described applications of three-dimensional computed tomographic scanning to craniofacial surgical planning as they used virtual reality methods to intraoperatively track bone fragment movement to a numerically optimized position.[14]

Three-dimensional imaging is not limited to skeletal anatomy. To name a few examples from a wide selection, Nkenke et al. have used three-dimensional surface imaging for exoph-

FIG. 3. A final rendering of many of the model's components. Note the SMAS (*S*), which has been partially resected for clarity. The portion of the SMAS that is visible is suspended by two hooks. Branches of the facial nerve are visible emerging superior to the cut edge of the SMAS.

thalmometry, Ferrario et al. have applied three-dimensional surface scanning to the analysis of facial morphology in ectodermal dysplasia patients, and Ji et al. have used three-dimensional surface scanning for the assessment of facial tissue expansion.[15–17]

In previous studies, we applied three-dimensional imaging to soft-tissue structures when we designed virtual reality animations to teach cleft palate repair techniques and developed animations that illustrate the biomechanics of eustachian tube dilation as it relates to cleft palate repair.[18–20] The obvious difference between these applications of three-dimensional imaging and those of the skin and bone discussed above is that many of the tissues key to cleft surgery and eustachian tube biomechanics elude scanning by computed tomography and surface digitization modalities alike. As such, we developed a method to partially hand-build three-dimensional models of relevant anatomy as detailed in a previous study. According to this protocol, tracings of histologic sections were made in Adobe Photoshop and essentially stacked using software developed by Dr. Cutting.[20] This technique represents the origin of the system described in the Materials and Methods section of this article for creation of the soft-tissue models in this project.

The models of superficial facial anatomy developed in this project are intended to serve as a three-dimensional atlas of the anatomy germane to aesthetic surgery of the face. Although these models can be viewed from any angle and made selectively transparent to illustrate anatomical relationships difficult to appreciate with other media, their greatest value lies in their suitability for use in various emerging teaching technologies. Examples of these technologies include three-dimensional animations, such as those mentioned above for illustration of cleft repair technique, and three-dimensional surgical simulators, such as that currently being developed by Cutting et al.[18,21] The models are relatively "light" in terms of the number of data points they contain, so it is practical to manipulate them as the need arises in animations, and their polygonal mesh construction renders them compatible with modification for use in surgical simulators.

As mentioned earlier, there are currently no technologies available to directly visualize an individual patient's facial soft-tissue anatomy in three dimensions. Although the system described here is clearly not useful for evaluating a specific patient's anatomy, future applications may allow for the warping of the idealized anatomical models described here to best-fit landmarks of individual patients. For example, if a three-dimensional model of a patient's skin is derived from a laser scan, known relationships between skin landmarks and underlying soft-tissue structures could be used to warp the model of facial soft tissue described here to approximate that of the individual patient. Such technologies could provide clinicians with a reasonable—albeit indirect—depiction of an individual patient's soft-tissue structure. Moreover, because these models are compatible with evolving surgical simulators, and as nascent simulator technology matures, these models represent the basis for the capacity to illustrate planned surgery and to simulate postoperative changes.

CONCLUSIONS

This article presents a three-dimensional computer model of anatomy for aesthetic surgery. The protocol for designing such a model is also discussed. The model illustrates the usefulness of virtual reality in the teaching and practice of aesthetic plastic surgery and can serve as a component of surgical educational and (eventually) planning systems currently being developed.

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