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Abstract:
OBJECTIVE. The purpose of this article is to discuss how to convert cross-sectional images into a 3D model and embed them in a Portable Document Format (PDF) file. Four programs are used: OsiriX, MeshLab, Microsoft PowerPoint, and Adobe Acrobat. Step-by-step instructions are provided. CONCLUSION. Embedding 3D radiology models into PDF files is a powerful tool that may be used for clinical, educational, and research purposes. © American Roentgen Ray Society.

Embedding 3D Radiology Models in Portable Document Format

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OBJECTIVE. The purpose of this article is to discuss how to convert cross-sectional images into a 3D model and embed them in a Portable Document Format (PDF) file. Four programs are used: OsiriX, MeshLab, Microsoft PowerPoint, and Adobe Acrobat. Step-by-step instructions are provided.

CONCLUSION. Embedding 3D radiology models into PDF files is a powerful tool that may be used for clinical, educational, and research purposes.

In everyday radiology practice, 3D datasets are acquired for CT, MRI, and occasionally ultrasound. However, radiology publications and presentations generally use 2D images [1]. Since 2008, Adobe Acrobat has offered users the ability to embed 3D models within Portable Document Format (PDF) files, a format that has become the standard of information exchange. This technique has been described in the nonradiology literature [2–4]. The goal of this article is to increase radiologists' awareness of this technique and provide step-by-step instructions to convert DICOM cross-sectional images into surface-shaded 3D models that can be embedded into a PDF document.

Materials and Methods

Four programs are used: OsiriX (version 4.0, 32-bit, open source), MeshLab (version 1.3.0, open source), Microsoft PowerPoint (version 14.1.3), and Adobe Acrobat X Pro (version 10.1.2). The Websites for downloading these programs are listed in Appendix 1. OsiriX (Mac [Apple] only, free [basic version]) is a DICOM viewer that can export 3D models. MeshLab (Mac and PC, free) is a 3D model editing and converting program. Microsoft PowerPoint (Mac and PC) is a presentation program and is used here to create the initial PDF file, although any presentation or word processor program can substitute for this role. Adobe Acrobat X Pro (Mac and PC) is a PDF editing program. Minimum computer requirements for using all of these programs are Mac OS 10.6 or higher with 1 GB of RAM and 1.5 GB of hard-disk space.

The basic instructions are outlined in Appendix 2 and are suitable for Mac users (OsiriX, the DICOM viewer described in this article is limited to that operating system). Removing patient identifying information should be performed at the outset when exporting the DICOM images from the PACS; the process for doing this will vary depending on the PACS vendor. OsiriX cannot directly export a 3D file format compatible with Acrobat nor does it provide any 3D sculpting tools. MeshLab is therefore used as the intermediary program to create an Acrobat-compatible file. MeshLab can also be used for sculpting and refinement of the 3D model, if desired; however, these details are beyond the scope of this article.

Results

A sample PDF file containing embedded 3D models can be downloaded from the last link provided in Appendix 1 and viewed with Adobe Reader (a free downloadable program). A sample screen shot is shown in Figure 1. The minimum time required to complete the steps outlined in Appendix 2 is approximately 10 minutes, determined by creating a 3D model of the skull using standard head CT with 276 images. When a user is first learning these steps or if significant sculpting or filtering is performed with MeshLab, more time may be required. Loading the models in Adobe Reader for viewing takes up to 30 seconds.

A final PDF file with an embedded 3D model ranges in size from less than 1 MB up to several MB, depending on the complexity of the 3D model. Complex shapes, such as airways and tortuous vessels, increase the number of vertices (the geometric "corners" of the 3D model), which can be reduced by sculpting and filtering. As an example of a simple shape,

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0361–803X/12/1996–1342

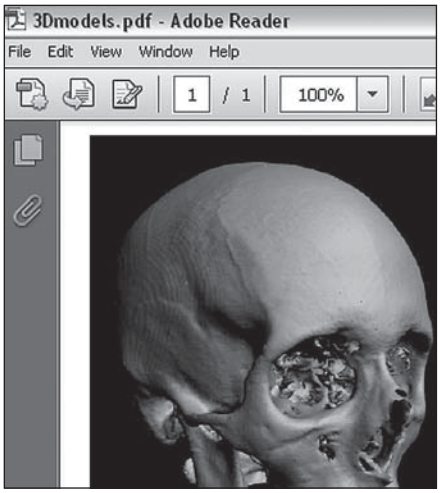

Fig. 1—Adobe Reader screen shot shows Portable Document Format (PDF)-embedded 3D model. Adobe product screen shot reprinted with permission from Adobe Corporation.

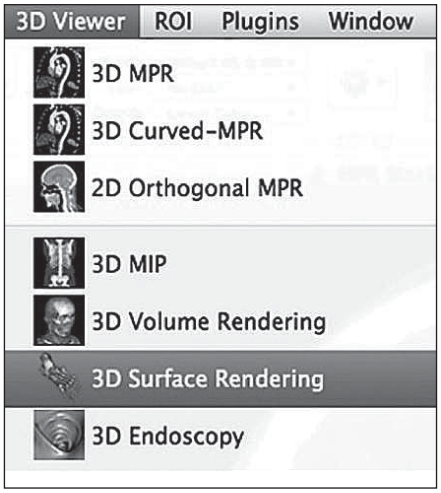

Fig. 2—OsiriX screen shot shows 3D surface rendering.

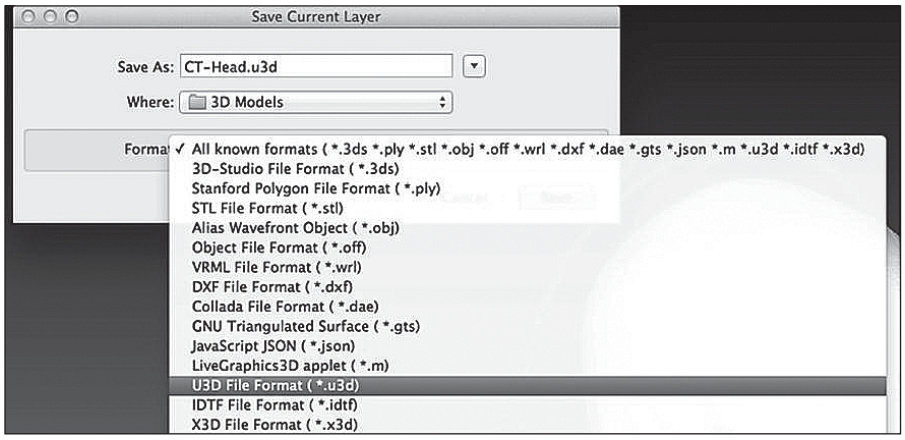

Fig. 3—MeshLab screen shot shows 3D file format.

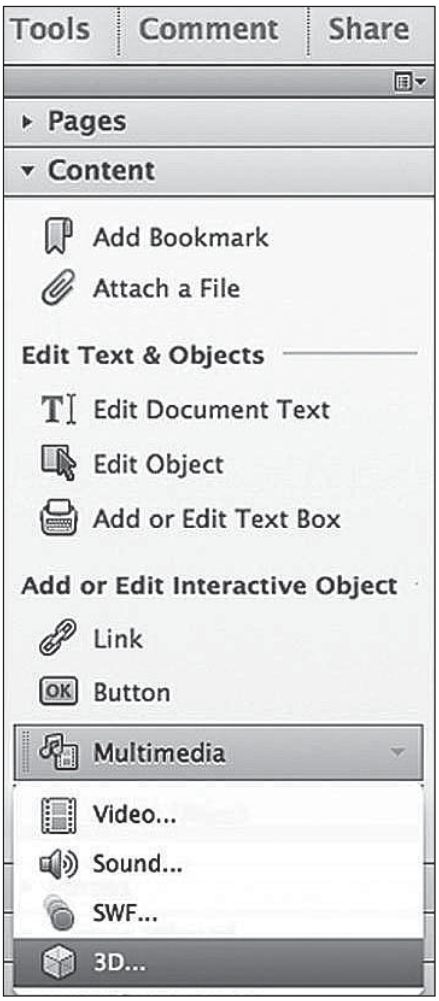

Fig. 4—Adobe Acrobat screen shot shows 3D conversion. Adobe product screen shot reprinted with permission from Adobe Corporation.

a 3D bone model of the pisiform consisting of 1293 vertices requires a 0.14-MB PDF file. In comparison, a 3D airway model of the chest consisting of 1,821,038 vertices requires a 4.4-MB PDF file; however, when this same airway model is sculpted into a coronal thick slab and redundant vertices are filtered out, the vertex count drops to 121,100 and the PDF size to 1.2 MB. Generating visually aesthetic surface-shaded models requires high-contrast interfaces (e.g., air and bone are best) and source data that is thin and unmodified (e.g., no edge-enhancing bone algorithm).

Discussion

We have described a relatively simple and affordable process for embedding a 3D radiology model into a sharable PDF file. The critical first step requires OsiriX, a Mac-only program, to export a 3D file. The basic version of OsiriX is free. Of note, most commercial radiology-specific 3D rendering programs do not have this function.

The greatest limitation of the process described is the number of steps involved. For users not accustomed to these programs, this multistep process may be intimidating. Another limitation of this process is the difficulty in obtaining high-quality surface-shaded models of soft-tissue structures (in which density contrast is not as great as with air and bone). Volume-rendered, as opposed to surface-shaded, 3D models solve this problem; however, at this time we could not identify a means of exporting such a model or embedding it into a PDF file. Lastly, the loading speed of the PDF-embedded 3D models was somewhat slow (up to 30 seconds).

Embedding 3D radiology models into PDF files is a powerful tool that may be used for clinical, educational, and research purposes. With greater consumer demand, other radiology-specific software vendors may also develop 3D export tools. Radiology is a visual profession; this technique may help us produce impressive documents with 3D capabilities.

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APPENDIX 1: Useful Websites

Adobe Acrobat X Pro	www.adobe.com/products/acrobatpro.html
Adobe Reader	get.adobe.com/reader/
Adobe-Supported File Formats	kb2.adobe.com/cps/405/kb405848.html
Microsoft PowerPoint	office.microsoft.com/en-us/powerpoint
MeshLab	Meshlab.sourceforge.net
OsiriX	www.osirix-viewer.com
Sample PDF with Models	radanatomy.com/media/3dmodels.pdf

APPENDIX 2: Instructions for Creating PDF-Embedded 3D Model

Program	Step	Task
OsiriX		Create a 3D file using OsiriX.
	1	File→Import→Import File(s)
	2	Select folder containing DICOM images.
	3	Delete any nonvolumetric images (e.g., scout images).
	4	Double click on images to view.
	5	3D Viewer→3D Surface Rendering (Fig. 2)
	6	Predefined values→Choose CT-Skin, CT-Bone, or CT-Metal (alternatively, pixel value may be defined manually)
	7	Export 3D-SR→Export as VRML (.vrml)
	8	Name file and save to desired location.
MeshLab		Convert the 3D file into an Adobe-compatible format.
	1	File→Import Mesh→Select recently created VRML file.
	(2)	If desired, model may be sculpted at this time. (Sculpting instructions are beyond the scope of this article.)
	3	File→Export Mesh As
	4	Format→U3D File Format (*.u3d) (Fig. 3)
	5	Name file and save to desired location.
Microsoft PowerPoint		Create initial PDF file.
	1	Open or create a PowerPoint presentation. (A single slide with a blank background will suffice.)
	2	File→Save As
	3	Format→PDF
	4	Name file and save to desired location.
Adobe Acrobat		Embed the converted 3D file into the PDF file.
	1	Create PDF→Select recently created PDF file.
	2	Tools→Content→Multimedia→3D (Fig. 4)
	3	Draw rectangle on page where 3D model is to be displayed.
	4	Select recently created U3D file.
	5	File→Save