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## MEDICAL EDUCATION

# **The Virtual Anatomy Practical:** A Stereoscopic 3D Interactive Multimedia Computer Examination Program

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Continuing advances in computer visualization and interface technologies have enabled development of ''virtual reality'' programs that allow users to perceive and to interact with objects in artificial three-dimensional environments. Such technologies were used to create an image database and program for administering a practical examination in human gross anatomy. Stereoscopic image pairs of prepared laboratory dissections were digitized from multiple views of the thorax, abdomen, pelvic region, and upper and lower extremities. For each view, the stereo pairs were interlaced into a single, field-sequential stereoscopic picture using an image processing program. The resulting color-corrected, interlaced image files were organized in a database stored on a large-capacity hard disk. Selected views were provided with structural identification pointers and letters (A and B). For each view, appropriate two-part examination questions were spoken by a human narrator, digitally recorded, and saved as universal audio format files on the archival hard disk. Images and digital narration were organized in an interactive multimedia program created with a high-level multimedia authoring system. At run-time, 24-bit color 3D images were displayed on a large-screen computer monitor and observed through liquid crystal shutter goggles. A 90-second interval timer and tone were provided to give student users a time limit for each question comparable to that of a conventional practical examination. Users could control the program and select regional ''subexams'' using a mouse and cursor to point-and-click on screen-level control words (''buttons''). Clin. Anat. 11:89–94, 1998. 

**Key words: virtual reality; instructional computing; human gross anatomy; medical education; multimedia**

## INTRODUCTION

In a previous *Clinical Anatomy* article (Trelease, 1996), we reported on the development of an interactive, stereoscopic 3D, multimedia "virtual anatomy" program for studying the human skull. *3D Explorer—The Skull* made use of some of the computer display and interface technologies that have made "virtual reality" (VR) a promising methodology for biomedical instruction and for surgical procedure simulation (Frisbie, 1993; Kaltenborn and Rienhoff, 1993; Satava, 1993, 1995; Thalmann and Thalmann, 1994).

Although current "high end" VR systems allow users to perceive and to interact with simulated objects in artificial three-dimensional (3D) environments, object realism tends to be very low, limiting the usefulness of the technology in representing anatomical structures. Generating realistic stereoscopic (binocular) 3D scenes and objects while allowing a user free movement within 3D space is very computationally intensive, typically requiring ultrahigh-speed computers (e.g., "supergraphics" workstations) to display relatively primitive, nonphoto-realistic, polygon-based model structures. Our virtual anatomy methodology takes an alternative approach by using the current generation of high-speed personal computer hardware and pre-processed stereographic 3D digital "photographs" of human anatomical specimens presented by interactive multimedia programs with mouse-based ("point-and-click") user interfaces.

This article reports on the acquisition and processing of photo-realistic stereoscopic 3D images, narrative audio sampling, design of the user interface, and functional characteristics for a new virtual anatomy

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multimedia computer program for administering a practical examination in medical gross anatomy.

## MATERIALS AND METHODS

All specimens were recently prepared whole cadaver dissections from the medical gross anatomy laboratory at UCLA School of Medicine. Obscuring fat and connective tissue were removed from the dissections by the author, and each specimen was arranged for the best image composition and framing. Illumination was a combination of daylight, indirect fluorescent, and photographic tungsten spot lighting, inasmuch as specimens were imaged in situ in the student dissection laboratory. The dissection tables and artificial lighting were positioned to reduce undesirable shadows and overexposure.

The general image acquisition and processing technology was similar to that described in the previous article (Trelease, 1996) with some differences relating to the need for acquiring images of preserved specimens within the dissection laboratory. To allow image digitization to be portable for access to all cadaver tanks, the Hi-8 camcorder (Nikon VN 960) was attached to a custom-built, swing-arm camera mount affixed to a mobile equipment cart. The mount allowed the focal points (aim) at different camera positions to converge at the pivot axis. To keep the perceived position of the stereo images deep to the plane of the monitor viewing screen, all images were acquired with the swing-arm axis positioned in front of the specimen. Left and right eye perspective image pairs were acquired for multiple full screen and close-up (macro) views of multiple views of dissection preparations of the thorax, abdomen, pelvic region, and upper and lower extremities from 20 different cadavers. Typically, at least two views, wide-angle and close-up, were digitized for each preparation/location, and >200 images were acquired. Multiple views allowed selection of the best-appearing 3D presentation for each specimen/question when the right and left images were merged into an interlaced single stereogram.

Digitization, subsequent image processing, program development, and presentation were performed on Amiga 2000 and 3000 computer systems with six or more megabytes random access memory (minimum configuration for all functions). All images were acquired at maximum overscan video image resolution ($736 \times 482$ pixels and 24-bit color for photo-realistic images on a standard 14 inch monitor) using a DCTV slow-scan video digitizer (Progressive Image Technology, Rancho Cordova, CA) connected to the Amiga parallel port. Original stereo image pairs were saved on a large-capacity hard disk in a bit-mapped file format easily converted to formats displayable on Macintoshes, MS-DOS/Windows PCs, or Unix workstations. For each view, stereo pairs were color-corrected with an image processing program (Art Department Professional [ADPro]; ASDG, Madison, WI) to compensate for the aforementioned different balances of natural and artificial lighting at different dissection stations. Left and right images were interlaced into a single, field-sequential Amiga IFF format stereoscopic picture (left eye perspective, odd video scanlines; right eye perspective, even scanlines) using ADPro. Stereo pair separations (angular displacement in the horizontal plane) were controlled in order to keep the resulting perceived 3D images close to the plane of the monitor screen.

Selected images were copied, and the duplicates were labeled with structure pointers and large-case text (letters A and B) according to a pre-edited list of examination questions (see Fig. 1 for a stereophotographic rendering of one of these examination images). All scripted examination questions, consisting of two subparts, were narrated by a reader in a separate laboratory and recorded as monaural 8-bit digital sound samples at 22 kilohertz using a DSS-8 digitizer and Digital Sound Studio (DSS) software. The samples received additional signal processing in DSS and were stored on the archival hard disk as universal format (AIFF) digital sound files. The resulting interlaced 3D image and digital sound files were organized in an interactive multimedia stereoscopic display program created with the same high-level authoring system (CanDo, INOVAtronics, Dallas, TX) used for *3D Explorer—The Skull* (Trelease, 1996). The new program was designed to simulate a conventional gross anatomy practical midterm examination and included an interval timer allowing 90 seconds to respond to each two-part question. For each image, the respective digitized speech questions were played back twice—once just after image display started and once 40 seconds later. At the end of each 90-second interval, a digital tone sounded prior to the program advancing to the next question. Questions were arranged in four groups of 10 each by region, and interactive menu screens were programmed to allow student users to select regional subexaminations for the thorax, abdomen, and upper and lower extremities. The program was named *3D Explorer—The Virtual Practical.*

As shown in Figure 2, images were displayed on a large-screen computer monitor and observed through liquid crystal shutter goggles (Haitex, Sega, and Nintendo) that could be worn over eyeglasses. These goggles were designed to alternate briefly occluding one eye while the other eye's image was displayed on

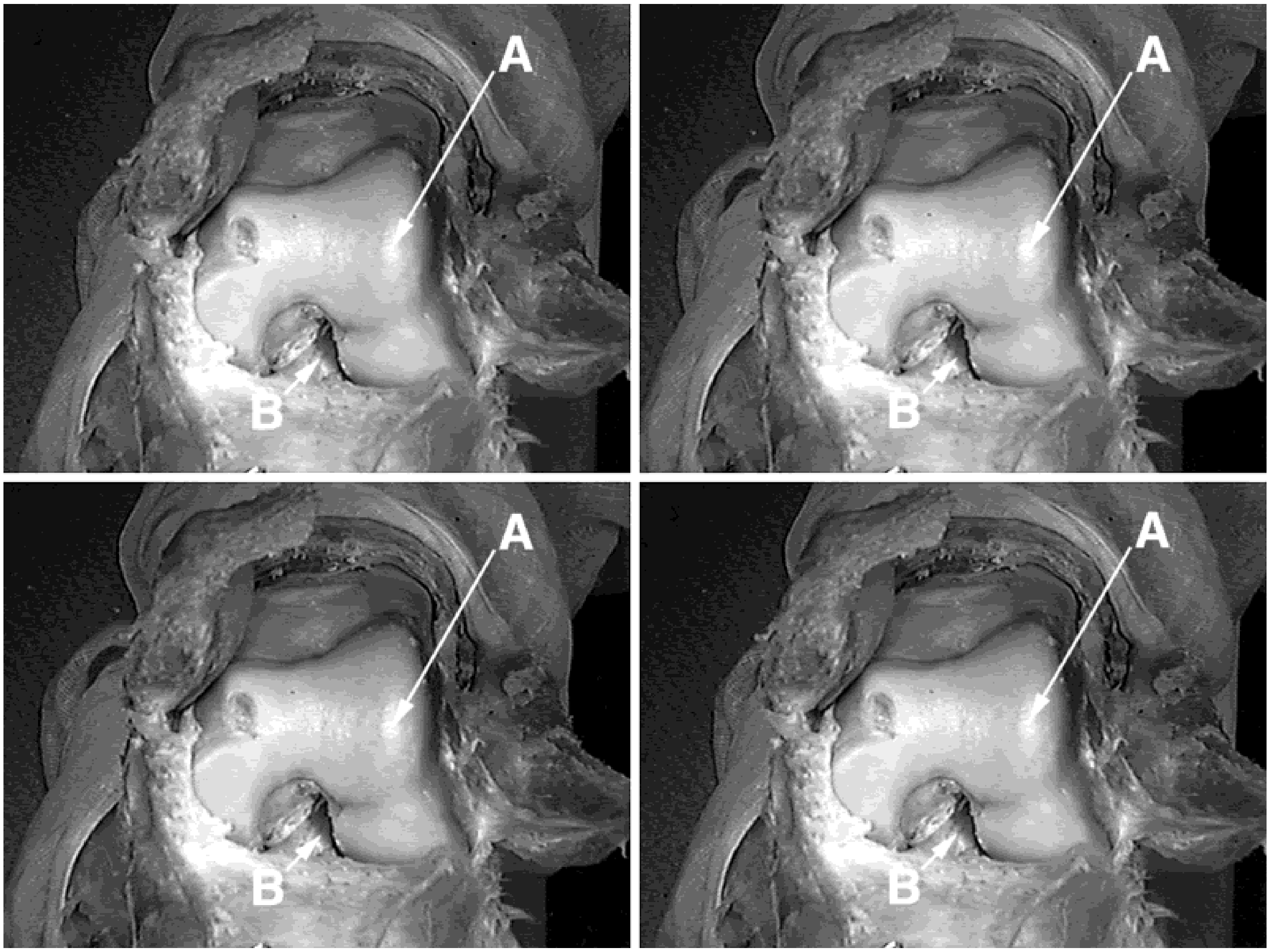


**Fig. 1.** Composite binocular stereograms rendered from a labelled Virtual Practical question image. The images were created using original digital image pairs and printed on a Fujix digital RGB printer using Adobe PhotoShop. The upper image pair may be viewed by holding the page 1–2 feet from your face, centering over the thin line between images, and crossing your eyes. With a little practice, a third converged 3D image will appear between separate left and right images. The lower image pair may be converged with a standard photographic stereopair viewer (e.g., Taylor-Merchant Stereopticon 707, or equivalent).

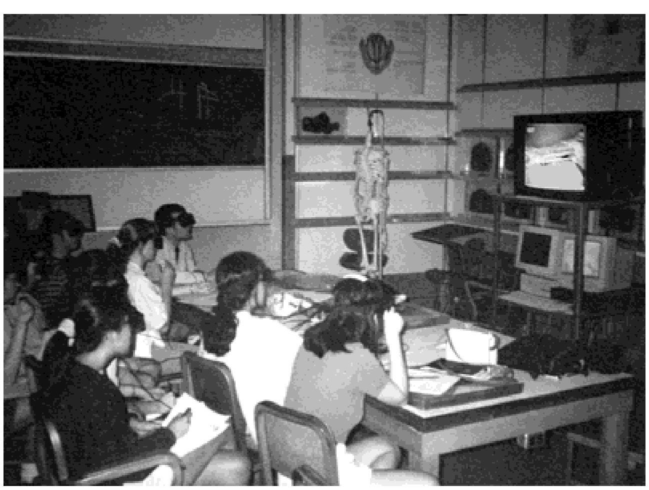

**Fig. 2.** UCLA medical students take a virtual practical exam.

the appropriate odd/even monitor scan lines. A driver interface (StereoDriver 2000, 3DTV Corp., San Rafael, CA) was attached to the Amiga's built-in NTSC video output to provide scan-synchronized switching (60 Hz) of goggle right/left eye occlusion. A connector box supported the simultaneous use of up to 16 goggles.

## RESULTS

At run-time, student users were able to choose regional "subexaminations" (i.e., upper limb, lower limb, thorax, or abdomen; regions covered for the midterm) by clicking on the control buttons of a screen-level starting menu. Choosing "Thorax," e.g., immediately displayed the first thoracic image/ question. When viewed through the 3D glasses, all anatomical specimens were perceived to be located behind (deep to) the surface of the screen. A screen-level button, located in an upper corner of each question/image, allowed the user to advance to the next image/question in a regional sub-examination. At the end of each sub-examination, the starting menu reappeared, allowing the user to exit or to choose another region.

The program was initially tested as a voluntary class exercise *in place of the customary, cadaver-based, student-run practice practical* held annually prior to the conventional mid-term examination. Like the practice practical, use of the program was intended to familiarize "naive" students with realistic, two-part questions based on a variety of different anatomical specimens, with a time limit of 90 seconds to answer each question pair. In a further simulation of the experience of the real (for-credit) midterm practical examination, students were required to answer program questions in writing on standard answer sheets. Answer keys were subsequently posted, allowing students to self-score their performance by region. Approximately half of the class (75 of 155 students) elected to take the examination program in shifts, in groups of 16 or fewer students per shift. Sixty-four of these students submitted their names, permitting identification of their scores on the real midterm practical exam. The mean score of these students was 88%, which was identical to the overall average for all students who took the real midterm practical exam. This overall mean real midterm practical test score was higher than that of the preceding 3 years (85%, 86%, and 82%). However, due to the design of this project, it was not possible to determine statistical validity and to define an effect of virtual practical administration on student performances.

Students were verbally requested to give the developer their suggestions and criticisms of the program and its technology. In general, the Virtual Practical and virtual anatomy techniques were enthusiastically received by the medical students. The most common feedback was a request for more material to be presented in this stereo 3D format. The most common complaint was that the images seemed to flicker, a consequence of driving the glasses at 60 Hz so that each eye's view was displayed at 30 Hz (which is less than the human flicker-fusion frequency). Three users reported that they did not perceive anatomical specimen images in stereoscopic 3D. This effect was assumed to be due to strong monocular dominance and/or uncorrected refractive error, since none of the students reported previous diagnosis of amblyopia.

## DISCUSSION

As described here, the most important aspect of our virtual anatomy technology is the computer-based presentation of photorealistic stereoscopic 3D images of anatomical dissections. In formal terms, "dichoptic stimuli" (different images presented to each eye) are used to generate "binocular stereopsis," the impression of object depth. The exclusively binocular cues to depth, vergence position of the eyes and binocular disparity (parallax), are used by the human visual processing system to provide an innate ability to discriminate object dimensions that cannot be obtained from single, fixed images (Howard and Rogers, 1995). Virtual anatomy images can thus convey intrinsic information about structural relationships that cannot be revealed in standard monocular images.

For the current generation of anatomy instructors, perhaps the most familiar tool for demonstrating anatomical structures in 3D has been the Bassett (1952) Stereoscopic Atlas. This relatively low-cost and "low-tech" resource employed photographic media (Sawyer ViewMaster viewers and Kodachrome image "wheels") and printed guide books that showed structural labels and descriptive text for each specimen stereogram. For identifications of features, the user was thus forced to "jump" between the two-dimensional printed text/diagrams in the guide book and the 3D stereo viewer images. The virtual anatomy programs described here and in Trelease (1996) were designed to be able to superimpose identifying labels and text on the stereoscopic 3D images themselves. Furthermore, virtual practical program multimedia capabilities supported the use of digitally recorded audio narrations that eliminated the need for additional (and potentially visually challenging) image titling in order to convey examination questions. Additional interactive controls allowed user selection of separate regional subexaminations (useful for assessing individual strengths and weaknesses) and implemented an automatic question timer that further simulated real practical examination conditions. This computer-based virtual anatomy technology thus offered some distinctive advantages over more conventional photographic and printed stereoscopic 3D image presentation media.

As used in the Virtual Practical, the greatest limitation of active, binocular stereoscopic display technology may be its failure to work with users having strong monocular dominance, uncorrected refractive error, or clinically defined amblyopia. Based on a number of different studies (Ciuffreda et al., 1991) the reported prevalence of amblyopia varies from 1–4.8% (in school-age children) to 1–4.0% (in military personnel). Personal experience with 3D Explorer, the Virtual Practical, and several hundred medical undergraduates, however, suggests that the inability to perceive stereoscopic 3D may be expected in 2% or less of the targeted student population. This further suggests that current in-class use of stereoscopic 3D virtual anatomy programs should be optional or voluntary in order to avoid inadvertent discrimination against students having impaired binocular stereopsis.

At the time this Virtual Practical program was being developed, Time-Mosby released the CD-ROM-based Clinical Anatomy Interactive Lab Practical program developed at Stanford University School of Medicine (Kim et al., 1995). Shortly thereafter, CIBA-Geigy released the Interactive Atlas of Human Anatomy (Dalley and Myers, 1995) also on CD-ROM, supporting an interactive examination identifying structures "tagged" on the anatomical illustrations of Frank Netter. Both of these programs have far more content and greater interactivity than the Virtual Practical described in this article, allowing students a very comprehensive practice examination covering many or most of the important structures of the human body. Virtual Practical images differ in that the users can view 24-bit (16.7 million) color photographic-quality images in full stereoscopic 3D. The Clinical Anatomy Interactive Lab Practical displays 8-bit (256) color, partial screen digitized images of real human dissection specimens, whereas the Netter Atlas employs 8-bit digitized versions of Frank Netter's classical anatomical illustrations. Recently, A.D.A.M. Software released the A.D.A.M. Practice Practical program (Pawlina and Olson, 1996) based on the colorful, idealized illustrations of the A.D.A.M. "digital dissector" combined with digitized two-dimensional images from the Bassett collection, all at 8-bit (256 color) resolution. Although the emphasis of the Virtual Practical project was on maintaining maximum color resolution in order to obtain maximum anatomical image realism, it should be noted that a few studies have argued that 8-bit images may provide optimal computer graphics fidelity for certain specific applications. In a controlled study of pathologists evaluating the quality of 24 and 8-bit microscopic images, Doolittle et al. (1997) found that adaptive palette, diffusion dithered 8-bit color digital pictures proved statistically indistinguishable from 24-bit versions. In another controlled study of 8, 16, and 24-bit digital endoscopic images of gastrointestinal lesions, Vakil and Bourgeois (1995) found that the 256 color images were expertly judged to be of diagnostic quality and 41% of the time were found indistinguishable from their higher color resolution counterparts. However, to date no specific, definitive studies have been performed on perceived differences in 24 and 8-bit anatomical images, and the conclusions of the aforementioned reports may reflect the influences of clinical diagnostic standards and a concern with optimal image compression for image transmission efficiency. In this context, Perednia et al. (1995) have emphasized the importance of controlled, receiver operating characteristic studies for comparing resolution imaging modalities for specific medical disciplines.

Current efforts for the Virtual Practical focus on completing acquisition of images for head and neck and pelvic region components, completing coverage of all major anatomical regions. Continuing development of similar virtual anatomy applications has included the acquisition of a large number of stereoscopic images of whole and sectioned brains and brainstems. The initial focus will be to develop practical examination and brain dissection viewing programs for supporting primary instruction in neuroanatomy.

At the time work was first begun on this 3D multimedia methodology (1989), the Amiga was the only personal computer system capable of handling interlaced high-resolution graphics and driving liquid crystal 3D viewing systems without additional expensive custom display hardware and other modifications. In the past few years, however, manufacturers have produced new, low-cost stereoscopic display systems for popular personal computers. Although this project committed early to using the Amiga for acquisition, initial software development, and runtime program execution, all stereographic images have been archived in a 24-bit color bit map format easily converted into graphics files (e.g., TIFF, PICT, and GIF) for use on MS-DOS/Windows and Apple Macintosh systems. The interplatform transportability of the archival image format and the range of structures imaged have thus provided the capability for a variety of different programs to be developed for widely used personal computers.

Work is currently underway to transport the 3D Explorer (Skull) and Virtual Practical applications to DOS/Windows (Intel central processor) compatible personal computers using a new stereoscopic 3D display viewing system, VR Surfer, developed by VREX (Ithaca, NY). Advantages of the VREX hardware include wireless (infrared-driven) viewing glasses, a simplified driver interface that attaches to standard PC display (SVGA) connectors, and low cost (~$100 for the driver interface hardware, software, and single viewing glasses). With appropriate monitors and PC SVGA video display boards, VR Surfer glasses can be driven at shutter rates of up to 100 Hz, eliminating the flicker perceived by users at a 60 Hz driver frequency. In addition to individual Windows workstation configurations, we have established that our virtual anatomy images can be distributed and displayed via the World Wide Web using the Netscape Navigator browser and VREX driver software running under Microsoft Windows 95 and Windows NT. We have established a Pentium Web test server (neurobiocomp.medsch.ucla.edu/vrx/) running Microsoft Windows NT Server 4.0 and Internet Information Services 3.0 software, and work has begun on networked version of our virtual anatomy software.

Given the ongoing evolution of personal computer systems with progressively faster central processors, higher graphical resolutions, accelerated display systems, and larger storage capacities, greatly improved 3D structure simulations and interactive programs can be expected at relatively low costs. A particularly promising convergence of such system capabilities with available 3D structure databases would include VR "dissection" and exploration of the Visible Human anatomy. Despite the apparent attractiveness of new computer methodologies, however, it is the opinion of this author that present and future virtual anatomy applications would best serve to complement and not to replace lectures on anatomy and the unique kinesthetic learning experiences that take place within the student dissection laboratory. In this regard, the author strongly agrees with the major editorial positions stated by Cahill and Leonard (1997) in "The Role of Computers and Dissection in Teaching Anatomy: A Comment" as published in this journal.

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