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MEDICAL EDUCATION

Profile of On-Line Anatomy Information Resources: Design and Instructional Implications

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This study is based on a review of 40 on-line anatomy web resources compiled from sites selected from our own searches as well as sites reviewed and published by an external group (Voiglio et al., 1999, Surg. Radiol. Anat. 21:65–68; Frasca et al., 2000, Surg. Radiol. Anat. 22:107–110). The purpose of our survey was to propose criteria by which anatomy educators could judge the characteristics of the currently available web-based resources for incorporation into the courses they teach. Each site was reviewed and scored based on a survey matrix that included four main categories: 1) site background information, 2) content components, 3) interactivity features, and 4) user interface design components. The average score of the reviewed sites was 3.3 of the total possible score of 10, indicating the limited use of computer-based design features by the majority of sites. We found, however, a number of programs in each of the survey categories that could serve as prototypes for designing future on-line anatomy resources. From the survey we conclude that various design features are less important than the comprehensiveness, depth, and logical organization of content. We suggest that the content should be sufficient for supporting explicitly defined educational objectives, which should target specific end-user populations. The majority of anatomy programs currently accessible on-line fall short of these requirements. There is a need for a coordinated and synergistic effort to generate a comprehensive anatomical information resource that is of sufficient quality and depth to support higher levels of learning beyond the memorization of structure names. Such a resource is a prerequisite for meaningful on-line anatomy education. Clin. Anat. 16:55–71, 2003. © 2002 Wiley-Liss, Inc.

Key words: on-line anatomy resources; anatomy education; distance learning

INTRODUCTION

Computers are assuming an increasingly widespread role as conduits of anatomical information in educational as well as clinical settings. Computer-based anatomy programs can not only supplement traditional instructional methods (Habbal and Harris, 1995; Cahill and Leonard, 1997) but they can also offer potentially revolutionary ways for representing anatomical knowledge (Rosse, 1995; Brinkley and Rosse, 1997). The first comprehensive image dataset of a human male and female cadaver, made available by the National Library of Medicine's Visible Human Project, is a notable example of an anatomical knowledge resource that is fostering this revolution (Ackerman, 1999). Free access to this data set has boosted the design of innovative computer-based approaches for manipulating and visualizing graphical data of the human body.

Evolving web-based applications that can render and display voluminous anatomical data and images offer a glimpse of how anatomic knowledge may soon be represented and accessed on-line. Today, hundreds of websites dedicated to anatomy can be found over the Internet. In addition, scores of CD-ROMs and videodisks are produced for reference and tutorial purposes in anatomy. The possibility of accessing on-

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line interactive images to gain spatial knowledge of human anatomy may well trigger a radical departure from traditional ways of learning anatomy from textbooks, printed atlases, and even cadaver dissection.

At the moment, "stand alone" products, such as CD-ROMs, are probably the most popular medium. The World Wide Web, however, offers an unprecedented potential for accessing and integrating a large variety of computer-based anatomy programs, including such unique resources as the Visible Human. This is the reason for focusing our study solely on those anatomy resources that are available through the web.

Despite the proliferation of on-line anatomy material, only a few studies have attempted to examine the general usefulness or educational effectiveness of the design features embedded in these on-line resources. For example, Berry et al. (1998) developed a web-based questionnaire for evaluating selected websites in clinical chemistry, radiology, and medical physics. The questions related to general suitability (correctness of materials, appropriateness of the level for the intended course), user interface (navigation, robustness/reliability of the site), and the presentation style (hypertext vs. linear mode of presentation, type of instructional materials). With the exception of radiology, the authors found that most of the materials on the web were not well developed for supporting meaningful educational experiences. Two related studies by Voiglio et al. (1999) and Frasca et al. (2000) carried out evaluations of selected web-based anatomy sites. Four medical students reviewed these websites and ranked them according to the navigability of the site (level of ease to move from one page to another), illustrations (quality of images), text (value and amount of text), and presentation (visual aspect and legibility). On a scale of 0 being the lowest and 5 the highest, most of the reviewed anatomy sites received a score of 2 or 3. The difficulty of rating the quality of anatomy websites was evidenced by the contradictory scores assigned to the same sites in their two studies. The broad rating categories may account for some of the contradictory scores. These two surveys, performed largely by the same authors, illustrate the difficulty of using subjective criteria in the evaluation of educational programs.

The purpose of this survey was to obtain a profile of currently available on-line anatomy information resources. Our initial intent was that the survey results should inform us about the desirable design features of the evolving Digital Anatomist interactive atlases (http://www9.biostr.washington.edu/da.html), which we have been developing at the University of Washington. We recognized, however, that the data we obtained would also be useful to other authors of anatomy websites as well as to anatomy course directors who contemplate the adoption of web-based educational programs.

This study is based on a review of 40 on-line anatomy web resources compiled from sites selected from our own searches as well as those reviewed and published by an external group (Voiglio et al., 1999; Frasca et al., 2000). Based on long-standing experience in teaching anatomy and developing computer-based anatomy information systems, we focused our survey on key design components that are qualitatively distinct from those found in printed materials. Each site was reviewed and scored based on a survey matrix we developed. We describe in the Methods section specific components of the survey matrix and our biases that are reflected in the development of the matrix. The results section summarizes scores of the reviewed sites in the survey categories along with illustrative examples, followed by a discussion of instructional and design considerations for improving on-line anatomy information resources.

SURVEY METHODS

Development of the Survey Matrix

The difficulty in surveying on-line information has been discussed in a number of studies: 1) the continued availability of sites is uncertain (Berry et al., 1998), 2) the reliability and validity of rating instruments are questionable (Eysenback and Diepgen, 1998), 3) evaluation methodology can be highly subjective (Jadad and Gagliardi, 1998), and 4) the rating methodology of on-line health information may not be appropriate for evaluating on-line instructional materials (Pealer and Dorman, 1997). Recognizing these limitations for evaluating on-line resources, one of us (SK) developed a survey matrix form and used it to review the selected sites (Table 1). Four main categories were designated for survey: 1) site background information, 2) content components, 3) interactivity features, and 4) user interface design components. These survey categories were in part derived from guidelines developed for evaluating health-related websites (Geiger et al., 1998; Kim et al., 1999; Winker et al., 2000) and from our own notions of computer-based instructional design features we considered important.

Using the survey matrix, the site review was conducted in three stages. First, two authors (CR, SK) separately reviewed all sites and checked whether survey items were present or absent in the sites. These authors had working knowledge of French and German to review sites primarily written in these

TABLE 1. Survey Matrix, Distributed Scores, and Weighting

Survey category/items	Score	Weight
A. Site background information		
1. Is an institution name specified on the home page?	1	
2. Are authors specified on the home page?	1	
3. Is information for contacting authors available?	1	
4. Is the original posting date specified?	1	
5. Is there a revision date specified?	1	
Sub-score for site background information	5	10%
B. Content components		
1. Which content context is provided?		
a. Is the subject area specified in the title?	1	
b. Is the scope of content area indicated?	1	
c. Is the intended target audience described?	1	
d. Are objectives indicated?	1	
2. Does the site use multiple image sources (drawings, CT, MRI, photographs, Visible Human, x-rays, models)?	1	
3. Are 3D models of anatomical structures included?	1	
4. Are labels available?	1	
5. Are other textual materials available (descriptions, glossary)?	1	
6. What self-evaluation features are available?		
a. Are there self-evaluation modules?	1	
b. Are 3D models included in self-evaluation?	1	
c. Is feedback given for correct and incorrect answers?	1	
d. Is explanation provided?	1	
e. Are scores tracked and summarized for users?	1	
Sub-score for content components	13	50%
C. Interactivity features		
1. Dynamic display of on and off labels	1	
2. Collapsible/expandable hierarchy of terms	1	
3. Highlighted regions by contour or color	1	
4. Sound	1	
5. Zooming	1	
6. Rotation	1	
7. Assembling/disassembling of anatomical structures	1	
8. Fly through anatomical region	1	
Sub-score for interactivity features	8	20%
D. User interface design components		
1. Is a help menu available?	1	
2. Is a site map or table of contents available?	1	
3. Are navigational links embedded in all pages?	1	
4. Are links to home page available in all pages?	1	
5. Does each page have distinct headers?	1	
6. Do content materials fit in one page to minimize scrolling?	1	
7. Is there a regional context model for sectional images?	1	
Sub-score for user interface design components	7	20%
Total weighted score [$(5 \times 0.1) + (13 \times 0.5) + (8 \times 0.2) + (7 \times 0.2)$]	10	100%

languages, but also utilized Altavista on-line translation service (http://babelfish.altavista.com/) to validate the accuracy of translation as needed. Second, both authors reviewed together the sites to confirm the availability of the survey items in each site. Third, a score of 1 was entered for each available survey item and 0 for missing items. A maximum possible total score of 10 was derived by assigning different weighting to each survey category: site background information was assigned 10%; content components, 50%; interactivity features, 20%; and user interface design components, 20%. Data were entered and analyzed to calculate means and standard deviations using the SPSS (Statistical Package for the Social Sciences, Version 10).

Limitation of the Survey Matrix

We acknowledge several limitations of the survey matrix. First, whereas we consulted the literature for developing items related to "Site Background Information" and "User Interface Design Components," items in the categories of "Content Components" and "Interactivity Features" were largely derived from our own biases related to the types of design features that can enhance computer-based learning resources. Second, two authors (CR, JB) were closely involved in the development of the Digital Anatomist. To avoid over-representing the Digital Anatomist in the sampled sites, we included in this survey only one of the three web atlases of Digital Anatomist despite the fact that

TABLE 2. Steps in the Selection of the 40 Anatomy Websites Reviewed

	Internal list	External list
Sources	Meta-engine search On-line health directories Professional organizations	Not reported
Initial list	105 sites	Not reported
Primary exclusion criteria	No distinct institutional ID Only syllabi and notes No educational relevance Sites for product advertisement	Sites with loading problem Pathologic or veterinary content No teaching components Solely designed for commercial purpose
Final list	38 sites	48 sites
Secondary exclusion criteria	Duplicate sites with external list Not accessible	No distinct institutional ID Only syllabi and notes No gross/neuroanatomy contents Not accessible
Combined	40 sites	

The internal list was initially compiled based on on-line searches of anatomy sites. The initial list of 105 sites was reduced to 38 sites after applying the primary exclusion criteria (row 3). The external list was published by Frasca et al. (2000), in which primary exclusion criteria were specified. After combining the two lists, a total of 86 sites were reduced to the combined list of 40 based on the secondary exclusion criteria (row 5).

each atlas has unique features. Although the matrix was primarily developed by a medical educator with interests in evaluation, the other authors involved with Digital Anatomist had an unavoidable influence on the survey design because all three authors were at the same institution. Third, we did not include in the survey subjective judgments about the adequacy and accuracy of content available in the selected sites or the educational usefulness of the various design features. Such subjective ratings would undoubtedly have affected the score and rank order of the reviewed sites. In acknowledging these biases, we point out that to our knowledge no other evaluation has explicitly stated such biases, even though all evaluations are inevitably influenced by the choice of evaluation items.

Site Selection

The reviewed on-line anatomy sites in this study were collected from two sources: 1) an internal list of sites selected by the authors, and 2) an external list of sites reviewed by Frasca et al. (2000). Table 2 illustrates the steps by which the final list of 40 on-line anatomy sites was compiled.

Compilation of internal list. We used three information sources for selecting on-line anatomy sites. First, we conducted a search using Metacrawler (http://www.metacrawler.com/) based on the key words “anatomy” plus “education.” The Metacrawler searched through seven commercial search engines: Alta Vista, Excite, Infoseek, Lycos, Thunderstone, Webcrawler, and Yahoo and returned all sites containing the key words. This list was augmented by collecting sites from health directories that provided evaluated information resources. These directories included Medical Matrix developed by Healthtel Corporation (http://www.medmatrix.org/SPages/Anatomy.asp), HealthWeb provided by the University of Chicago (http://www.healthweb.org/), and Organizing Medical Networked Information (http://omni.ac.uk/). We also reviewed websites of academic institutions and professional organizations that provided links to Internet resources in gross anatomy and neuroanatomy to identify anatomy websites. These resources included the American Association of Anatomists (http://www.anatomy.org/anatomy/nresource.htm), the American Association of Clinical Anatomists (http://www.clinicalanatomy.org/html/websites.html), and Martindale’s Health Science Guide of UC Irvine (http://www-sci.lib.uci.edu/HSG/MedicalAnatomy.html).

After eliminating duplications among the three sources, 105 anatomy sites devoted to gross anatomy and neuroanatomy were retained for further scrutiny. This list of sites was further reduced using the following four criteria: 1) sites had to include distinct institutional headers and identifications, 2) sites solely containing syllabi and lecture notes without content-based learning modules were excluded, 3) because our primary focus was on educational relevance, sites primarily showing visualization techniques using anatomy were excluded, and 4) sites had to offer content materials that could be interacted with on-line. Therefore, sites containing advertisements for anatomy CD-ROMs or videodisks were excluded. After applying these criteria to the 105 sites, a total of 38 were retained for further review.

Review of externally compiled sites. Frasca et al. (2000) reviewed 48 anatomy websites and published their URL addresses. The study was an update of an earlier review (Voiglio et al., 1999). The authors used the following criteria for eliminating sites: 1) sites with loading problems, 2) sites containing pathologic or veterinary anatomy, 3) sites without teaching components, and 4) sites solely designed for commercial purposes (Table 2). Each of the 48 sites received scores for navigability, illustration, text, and presentation; the sites were ranked in accordance with their total scores (the maximum score being 20).

Merging of internal and external lists. We combined our list of sites with the list published by Frasca et al. (2000). We reviewed a combined total of 86 sites based on the criteria presented in Table 2. The final combined list of 40 sites was retained for survey after eliminating 46 duplicate, inaccessible, and irrelevant sites. The 40 sites included 21 from the internal list, 13 from the external list, and six sites included in both lists. The URLs of these selected sites are listed in Appendix 1 and are accessible via http://faculty.washington.edu/~sarakim/anatomy_list.html.

RESULTS

Our findings about the reviewed sites are presented under the following categories: 1) general characteristics, 2) overall rating, and 3) analysis of survey categories. In these categories we present examples that illustrate the pertinent design features.

General Characteristics

Table 3 summarizes background information the sites provided about their scope and contents (see Appendix 2 for more detailed site-specific information). The majority of the sites were developed in the U.S. by academic organizations. Thirteen sites originated in other countries (e.g., Australia, Britain, France, Switzerland). Contents of three of seven German and French sites were also available in English (see Appendix 2 under Language). Commercial sites designed by Gold Standard Media (Sites 3 and 4) provided free access with registration at the time of our review, but require a paid subscription as of August, 2001. Atlas was the predominant mode of presentation, followed by textbook. Only two sites presented their content in the form of tutorials. The site by the University of California at Davis (Site 23) was devoted entirely to self-evaluation modules and was categorized as other. Contents in about half of the sites were organized regionally (head and neck, thorax, etc.), followed by organs and organ systems. Three sites used dual modes (i.e., heart with nervous system). Memorial University in Newfoundland, Canada (Site 14) was the only site that organized its contents according to different training levels of students. Approximately one-third of the sites used slice stacks, the majority of which were from the Visible Human (see Image Source column in Appendix 2). Figures 1 and 2 illustrate examples of how the Visible Human slices were organized. Lastly, three sites from one institution (University of Iowa, Sites 26–28) included a statement to the effect that they had been peer reviewed internally.

TABLE 3. Overall Profile of Reviewed Sites[a]

Category	Sites *n* (%)
Geographical distribution	
U.S.	27 (68)
France	4 (10)
Germany	3 (8)
UK	1 (3)
Other	5 (13)
Type of organization	
Academia	30 (75)
Private sector	9 (23)
Military	1 (3)
Content presentation	
Atlas	21 (53)
Textbook	17 (43)
Tutorial	2 (5)
Other	3 (8)
Combined mode	3 (8)
Content organization	
Total mode	40 (100)
Regional	22 (55)
Organ specific	8 (20)
Systemic	7 (18)
Dual (regional and systemic)	3 (8)
Type of slice stack	
Total	12 (30)
Visible Human slice stack	
Organ specific	0
Regional	8 (20)
Non-Visible Human Slice Stack	
Organ specific	3 (8)
Regional	1 (3)

[a] $n = 40$.

Overall Rating

The summary of the overall ratings is presented in the order of the total score and broken down by survey categories (Table 4). The average rating was 3.3 of a maximum score of 10.

We emphasize that according to this rating scale, the total score may not indicate the overall quality of a site we analyzed. A relatively low score in each of the categories may result in a total score similar to one yielding a high score in one or two categories while receiving no scores in other categories at all. More meaningful than the mean score is the information provided by the analysis of individual categories presented in the following section. It also deserves reiteration that the scores give no indication of the sites' presumed usefulness in particular educational settings.

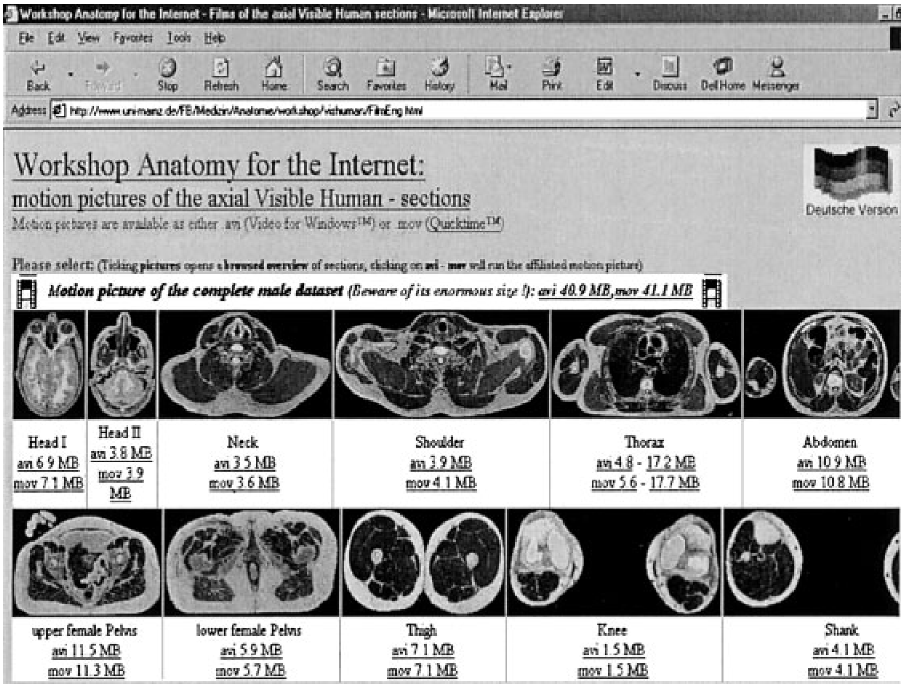

Fig. 1. A screen shot from "Workshop Anatomy for the Internet," University of Mainz, Germany. Site 29 makes available images of the Visible Human organized in axial sections. Clicking on each section links to a stack of slices that may be displayed with or without labels.

Analysis of Survey Categories

The description of the findings is based on the survey categories presented in Table 1.

Site background information. Ten sites received the maximum adjusted score of 0.5 in this category. Table 5 summarizes the number and proportion of sites that include each item about site background information. The home pages of the majority of the sites include information related to their institution and authors. Approximately half of the sites provide the original and revision dates, which may indicate to users whether sites maintain and update their contents.

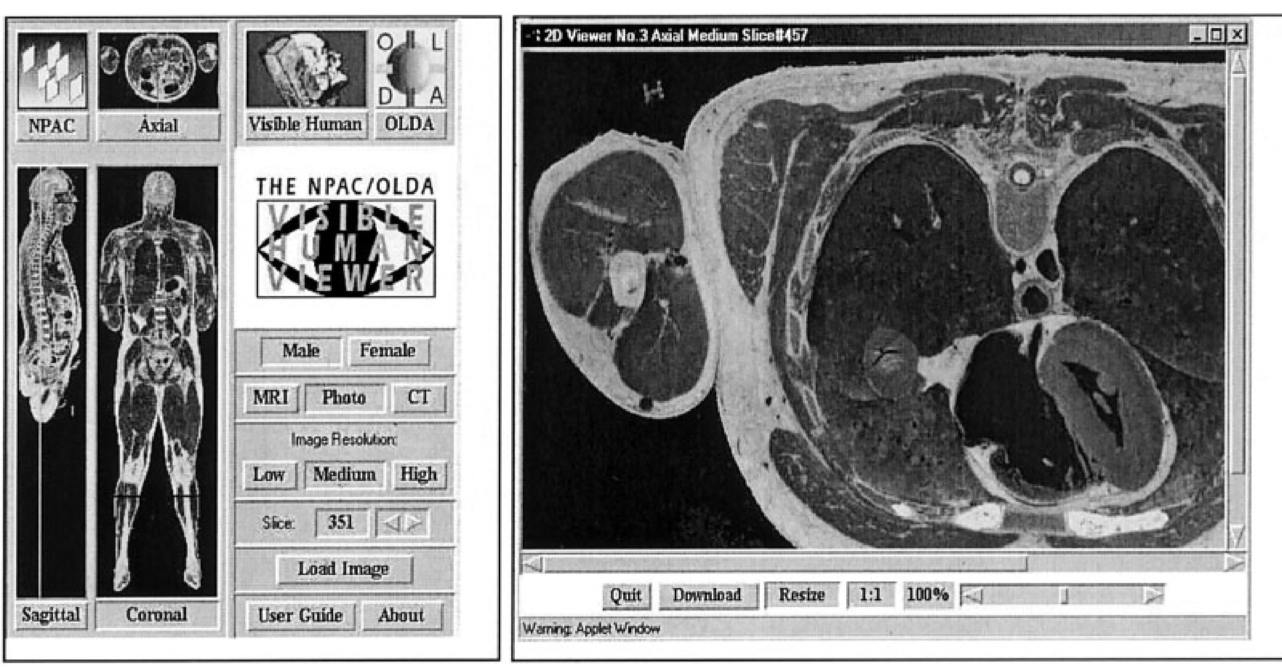

Fig. 2. A screen shot from "NPAC Visible Human Viewer," Syracuse University (Site 19). The Visible Human images can be loaded by moving bars in axial, sagittal, and coronal image viewing panels (left image). Corresponding MRI or CT images can also viewed. The loaded slice is shown in a separate 2D viewer (right image) and the users can download or resize the image.

TABLE 4. List of Reviewed Sites by Survey Rating

Site ID	Institution: Site Title	Site Background (max = 0.5)	Content Components (max = 6.5)	Interactivity Features (max = 1.6)	User Interface (max = 1.4)	Total Score (max = 10)
32	University of Utah: Hyperbrain	0.3	4.5	0.4	1.0	6.2
35	University of Washington: Thoracic Viscera	0.4	3.5	1.0	1.2	6.1
27	Univ. of Iowa, Virtual Hospital: Lung Anatomy	0.5	3.5	0.2	1.2	5.4
34	University of Washington: BrainInfo	0.3	3.0	1.0	1.0	5.3
28	Univ. of Iowa, Virtual Hospital: The Human Brain	0.5	3.5	0.0	1.0	5.0
2	Centre dilmagerie Diagnostique: Atlas of Human Ana.	0.5	3.0	0.0	1.4	4.9
3	Gold Standard Media: Radiologic Anatomy	0.2	3.5	0.4	0.8	4.9
13	Loyola University: Cross Sectional Anatomy	0.5	3.5	0.4	0.4	4.8
30	University of Newcastle: Eye Tutorial	0.3	3.5	0.2	0.6	4.6
37	University of Wisconsin: Global Brainstem	0.4	2.5	0.2	1.2	4.3
23	University of California, Davis: Human Gross Ana.	0.2	3.5	0.0	0.2	3.9
29	University of Mainz: Workshop Anatomie Fur Internet	0.4	2.5	0.4	0.6	3.9
17	Queensland Univ. of Technology: The Digital Anatomy	0.5	2.0	0.4	0.8	3.7
21	Uniformed Services Univ.: Radiologic Anatomy	0.4	2.0	0.4	0.8	3.6
9	Intellimed Int'l Corp: Human Anatomy On-Line	0.1	2.0	0.2	1.2	3.5
15	Philipps Universitat: Anatomie-Web	0.2	2.5	0.0	0.8	3.5
26	Univ. of Iowa, Virtual Hospital: Pelvis & Perineum	0.5	2.0	0.0	1.0	3.5
39	Washington University: Guided Tour of Visible Human	0.4	2.5	0.2	0.4	3.5
6	Harvard University: The Whole Brain Atlas	0.5	1.5	0.4	1.0	3.4
14	Memorial Univ. Newfoundland: Ana. of the System	0.3	2.5	0.0	0.6	3.4
5	Harvard University: Atlas of Brain Perfusion SPECT	0.4	2.0	0.2	0.6	3.2
12	Laurie Imaging Center: MRI Anatomy Atlases	0.3	2.0	0.0	0.8	3.1
4	Gold Standard Media: Cross Sectional Anatomy	0.2	2.0	0.4	0.4	3.0
20	Trautline: Anatomie Atlas	0.5	1.5	0.0	1.0	3.0
33	University of Washington: Anatomy Modules	0.5	1.5	0.2	0.8	3.0
16	Physical Therapy Central: Skeletal Muscles	0.3	2.0	0.0	0.4	2.7
7	Harvard University: SPL/NSL Anatomy Browser	0.0	1.5	1.0	0.0	2.5
40	Wheeless' Textbook of Orthopaedics	0.3	1.5	0.0	0.6	2.4
31	University of Pennsylvania: Interactive Knee	0.4	1.5	0.2	0.2	2.3
8	Institut D' Anatomie De Paris: Le Squelette	0.2	1.0	0.6	0.4	2.2
36	University of Washington: Musculoskeletal Atlas	0.2	1.0	0.0	1.0	2.2
19	Syracuse University: NPAC Visible Human Viewer	0.5	1.0	0.2	0.4	2.1
22	University of Arkansas: Gross Anatomy	0.2	1.5	0.0	0.4	2.1
25	University of Colorado: Visible Human Browser	0.2	1.5	0.0	0.4	2.1
11	Laboratoire d'Anatomie-Nancy: Radioanatomie	0.1	1.5	0.0	0.2	1.8
18	Southern California Orthopaedic Inst.: Anatomy Inf.	0.4	1.0	0.0	0.4	1.8
1	Albert Szent-Gyrgyi Medical Univ.: Radiologic Ana.	0.3	1.0	0.2	0.2	1.7
10	Laboratoire d'Anatomie de Lille: Anatomie	0.3	1.0	0.0	0.4	1.7
24	University of Chicago: Neuroanatomy Collection	0.3	0.5	0.0	0.8	1.6
38	University Paris-Sud: Uro. Anatomie	0.0	0.5	0.0	0.2	0.7

[a]Sites with a total score above the average are shaded.
Maximum scores are derived based on the number of items in each review category and on the percentage weight assigned to each category as follows: 1) Site Background Information (10%), $5 \times 0.1 = 0.5$; 2) Content Components (50%) $13 \times 0.5 = 6.5$; 3) Interactivity Features (20%) $8 \times 0.2 = 1.6$; 4) User Interface Design Components (20%) $7 \times 0.2 = 1.4$.

TABLE 5. Sites with Items Related to Site Background Information[a]

Survey item	Sites *n* (%)
Is an institution name specified on the home page?	30 (75)
Are authors specified on the home page?	29 (73)
Is information for contacting authors available?	33 (83)
Is the original posting date specified?	21 (53)
Is there a revision date specified?	17 (43)

[a]$n = 40$.

Content components. None of the sites provided all the information we sought and, therefore, none received the maximum adjusted score of 6.5 in this category. Table 6 summarizes the number and proportion of sites in the survey category of content components.

Whereas most sites specify their subject areas in their titles, less than half of the sites provide information on the scope of the content, intended target audience, and objectives of the program. More than

TABLE 6. Sites with Items Related to Content Components[a]

Survey item	Sites n (%)
Is the subject area specified in the title?	34 (85)
Is the scope of content area indicated?	13 (33)
Is the intended target audience described?	11 (28)
Are objectives indicated?	13 (33)
Does the site use multiple image sources (drawings, CT, MRI, photographs, Visible Human, x-rays, models)?	25 (63)
Are 3D models of anatomical structures included?	3 (8)
Are labels available?	28 (70)
Are other textual materials available (descriptions, glossary)?	21 (53)
Are there self-evaluation modules?	7 (18)
Are 3D models included in self-evaluation?	0
Is feedback given for correct and incorrect answers?	5 (13)
Is explanation provided?	3 (8)
Are scores tracked and summarized for users?	5 (13)

[a]n = 40.

half of the sites offer multiple image sources (drawings, radiologic sectional images, photographs, Visible Human, X-rays, and 3D graphical models). Only three sites make use of 3D graphical models whereas the rest of the sites use 2D images or 2D slices. Labels are available in the majority of the programs and more than half include other textual materials, such as descriptive paragraphs and glossary. Twelve sites have no labeling at all and another 12 sites rely on hard-coded labels analogous to those in textbooks and printed atlases. Self-evaluation modules are available in only seven programs. Such evaluations make use of 3D graphical images in only one of the programs. Only five sites include feedback on the correct and incorrect responses and three sites provide additional explanation. Five sites offer a summary of user performance during or at the end of the tests.

Interactivity features. Figure 3 summarizes the proportion of sites with respect to different interactivity features. Only about half of the sites incorporate interactivity features. This survey category received the lowest overall score (Table 4). Dynamic labeling, the most extensively employed interactivity feature, is present in 40% of the sites. Seven types of dynamic labeling are found in these sites: 1) clicking on a button turns on or off some kind of label, 2) clicking on preset symbols (e.g., numbers) displays labels, 3) clicking on uncontoured images displays labels, 4) clicking on contoured images displays labels, 5) scanning of the mouse over uncontoured images shows labels, 6) scanning of the mouse over contoured images shows labels, and 7) building of customized pin diagrams shows all or selected labels.

Figures 4 and 5 illustrate the critical role of interactive structure identification for both browsing and testing. In HyperBrain (University of Utah) (Site 32), contours in different colors outline structures as they appear in sections of the brain; names are displayed as the cursor traverses over them (Fig. 4A). For a pathway quiz, HyperBrain presents a diagram and a number of terms from which the answers to the questions may be selected (Fig. 4B,C). When the correct choice is selected in the term list, or when the user requests the answer to the question, the graphics illustrating the answer are added to the diagram (Fig. 4C). Thus, the diagram, or interactivity with it, is not required for performing the test; the challenge in the questions is verbal, rather than spatial.

The Digital Anatomist atlases (Fig. 5) present 3D graphical models of body parts (regions), in which anatomical structures have been reconstructed from their contours in serial, axial slices of cadaver specimens (Conley et al., 1992) (Site 35). These structures are labeled by their anatomical name, making it possible to retrieve them individually from a repository, and furthermore, construct and deconstruct a body

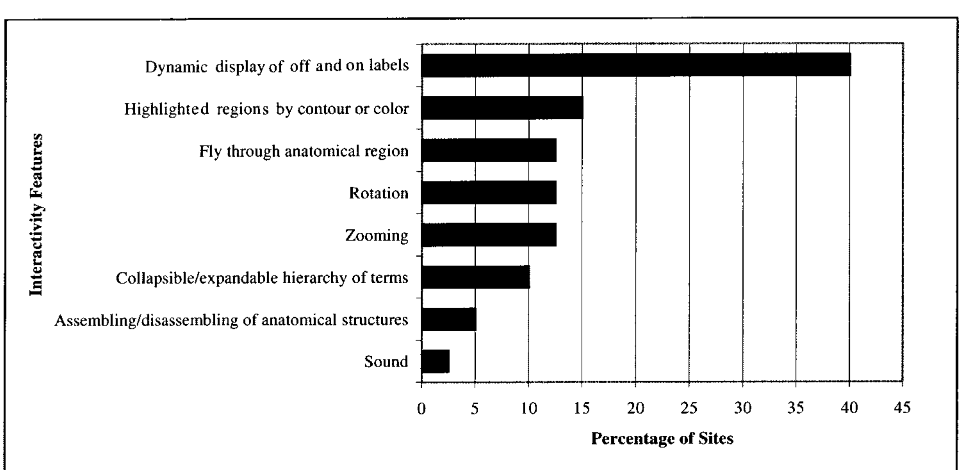

Fig. 3. Percentage of sites with different interactivity features.

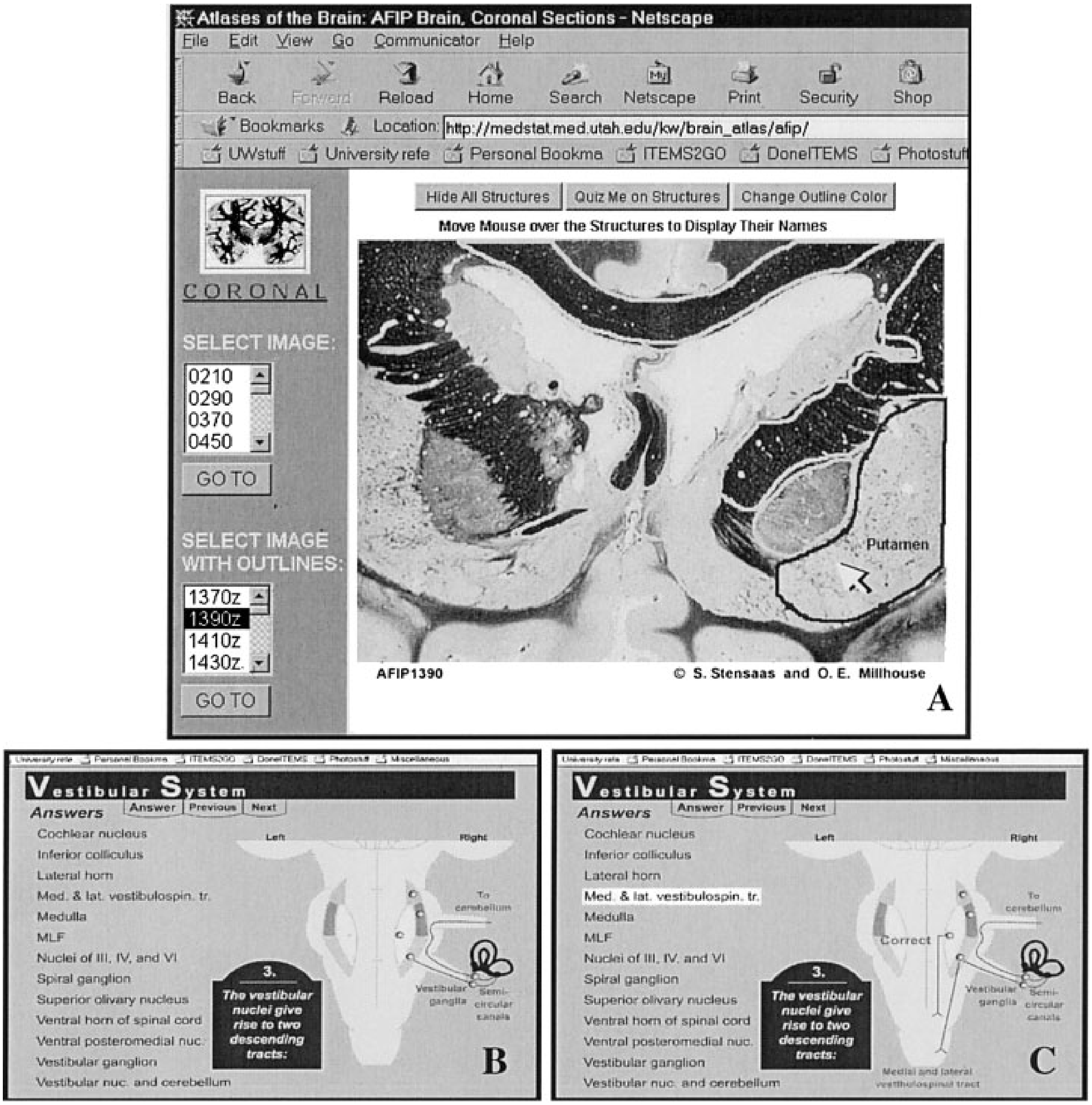

Fig. 4. Screenshots from "HyperBrain," University of Utah (Site 32), to illustrate interactive labeling (**A**) and a pathway quiz (**B**,**C**). Structures are outlined in a brain slice and the color of their contours can be changed; their names are displayed within the image as the mouse scans over each structure. A naming quiz can be activated for the image. A pathway quiz is based on more complex questions (B,C). (B) presents the third question in a quiz; the diagram includes the structures that correspond to the correct answers to Questions 1 and 2, which are also labeled (Vestibular ganglia, Semicircular canals). In (C) the correct answer to Question 3 has been selected in the term list, which adds the graphics and terms to the diagram.

part or a scene (Brinkley et al., 1999). To identify these structures on the surface of the graphical models, which are also seen by users in the web atlases, 2D images of these 3D models are segmented and labeled (Fig. 5A). Such double labeling can reveal or hide the outlines of selected structures with or without displaying their names (Fig. 5B). These features of the Digital Anatomist make it possible to identify structures during both browsing (Fig. 5B) and a naming quiz (Fig. 5C) through interaction with the static, graphical 3D models. Such naming quizzes (Fig. 5B,C) test the most elementary kind of anatomic knowledge. Cognitively higher level tests may be developed with the "Build URL for Custom Pin Diagram" button available in any page of Digital Anatomist (Fig. 6). In the new page, numbers may be substituted for any of the structure names (under Options). Functional and developmental questions may then be composed, which must be answered in terms of the numbered structures. For instance, if all the large vessels shown in

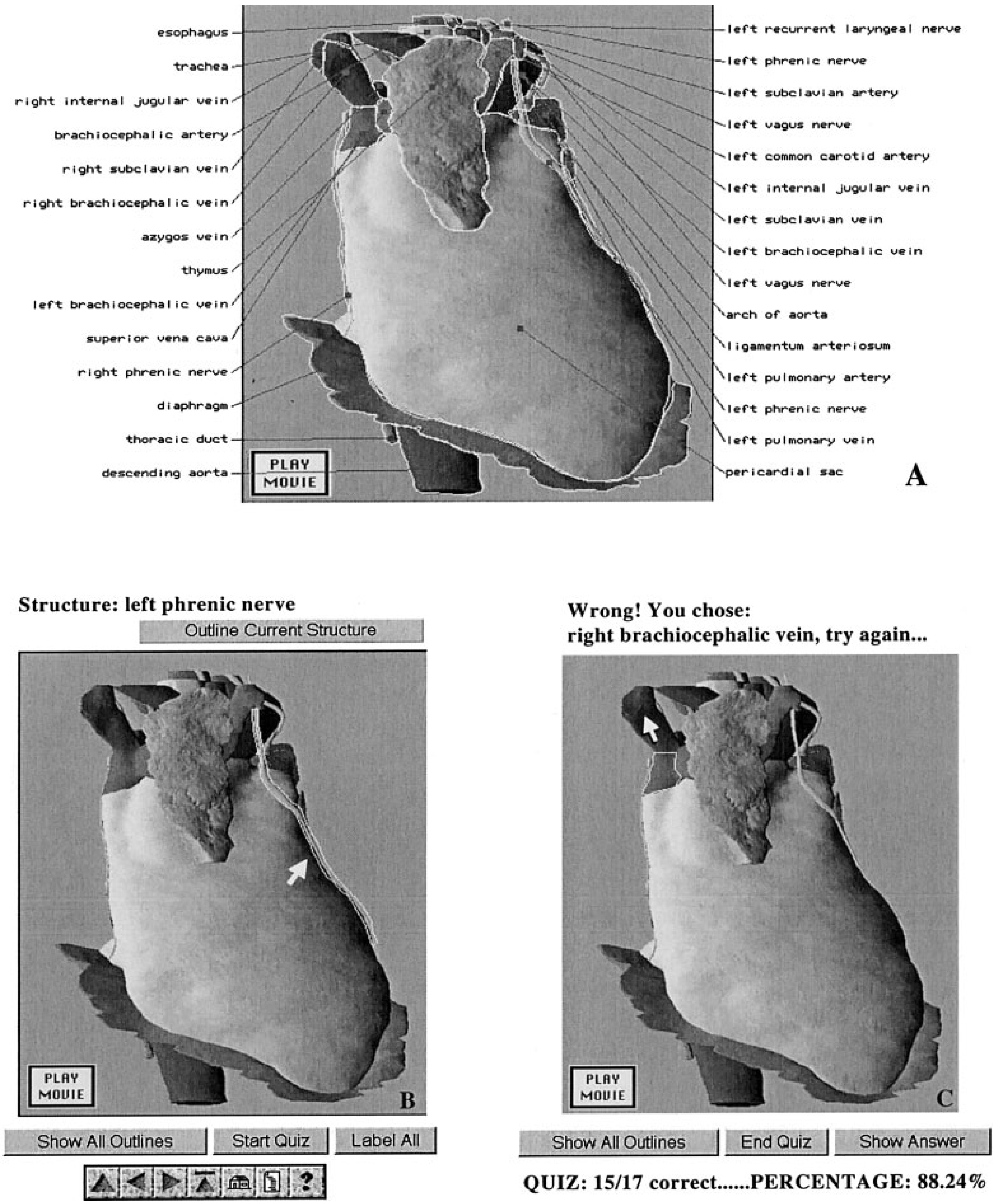

Fig. 5. Screenshots of a composite 3D graphical model (generated by David M. Conley) from the Digital Anatomist Interactive Atlas of Thoracic Viscera, University of Washington (Site 35), to illustrate structure identification. **A:** Shows the segmented surface of the model (generated by clicking "Custom Pin Diagram" in an atlas page). A leader line originates from the geometric center of each of the areas contoured with white lines (that is calculated automatically) and points to the corresponding anatomical terms, which are retrieved from a database. The figure, although not well suited for educational purposes, illustrates how interactions shown in (**B**) and (**C**) are supported. B: In response to a click on the image, the name of the targeted structure is displayed; clicking the "outline" button adds its contour. "Start quiz" activates a naming test shown in (C). The structure identified by the cursor (arrow) was selected in response to the random question "Click on superior vena cava," which prompts a feedback on the correctness of the response. "Show answer" identifies the correct structure with a superimposed contour. The score is displayed on each web page.

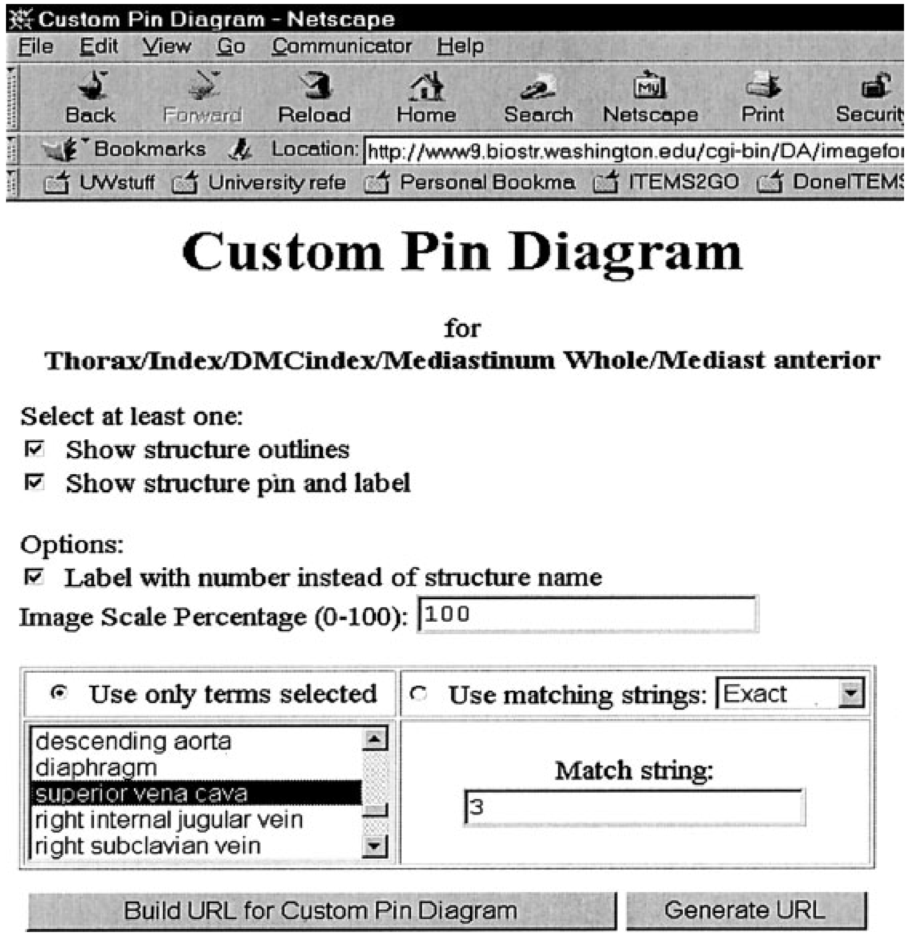

Fig. 6. Screenshot from the Digital Anatomist Interactive Atlas of Thoracic Viscera, University of Washington (Site 35), showing the interface for the generation of test questions at cognitive levels higher than structure identification. For explanation see text.

Figure 5 were tagged with numbers through the "URL builder," the following kinds of questions can be asked:

- Pulsations of which structure may be palpated in the neck?
- Which structure is derived from the right common cardinal vein?

Very few sites exploit such interactivity features as fly-through, rotating, and zooming. The SPL/HSL Anatomy Browser (Harvard University; Site 7) (Fig. 7) includes disassembly of the volumetric dataset of the head. Clicking on the image removes layers of volumetric data but individual structures cannot be manipulated.

The most ambitious interactivity relates to the manipulation of anatomic entities through simulating dissection. The Harvard site is one of only two programs among the 40 we reviewed that provides for such interactivity; the second one is Digital Anatomist. Although Voxelman (Höhne et al., 1995) allows interactive removal of subvolumes from a volumetric, segmented, anatomic dataset, it is not accessible over the web and therefore could not be included in this survey. As illustrated by the Digital Anatomist, prerecorded animations come closest to real time, interactive, virtual dissection (Fig. 8).

User Interface Design Components

Table 7 presents the number and proportion of sites that include various user interface design components that can enhance navigation of content materials. Approximately half of the programs fail to include instruction of how to use the site; only about 25% of the sites provide a site map displaying the contents of their programs. Whereas most of the sites include distinct headers in all pages, the majority of the reviewed sites do not provide aids for navigating their content. For the viewing of slice stacks, a sketch of the regional view provides a valuable navigational guide. This feature, integrated in seven of the reviewed sites, can be useful in two ways: 1) the regional model provides a visual context for users when selecting a sectional image, and 2) the regional model serves as a navigation tool for users when they directly click

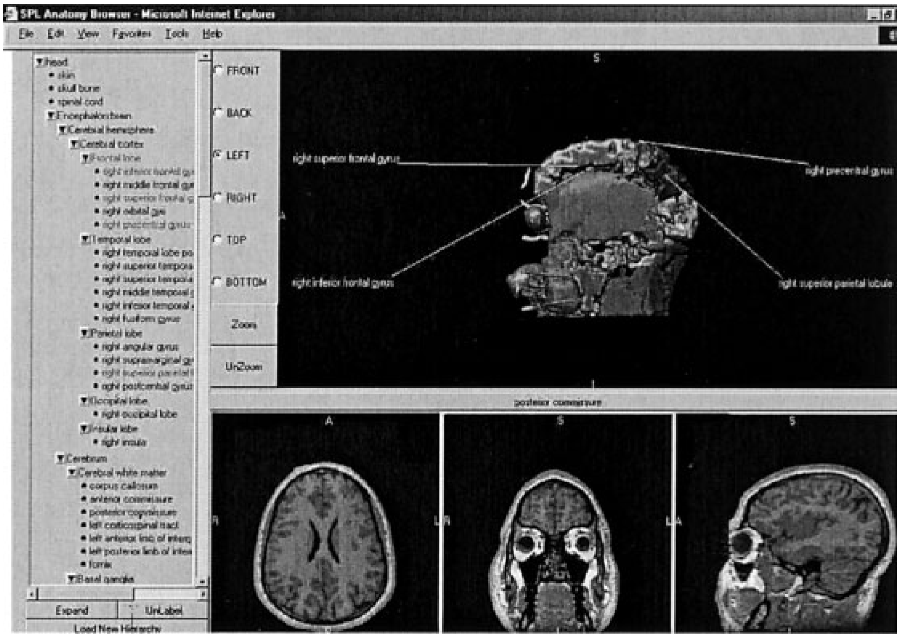

Fig. 7. A screen shot from "SPL/NSL Anatomy Browser," Harvard University (Site 7). A collapsible/expandable hierarchy of terms appears on the left-hand side and a 3D graphical model as well as clinical images appear on the right. Images can be zoomed, rotated, or annotated by clicking on the hierarchy of terms.

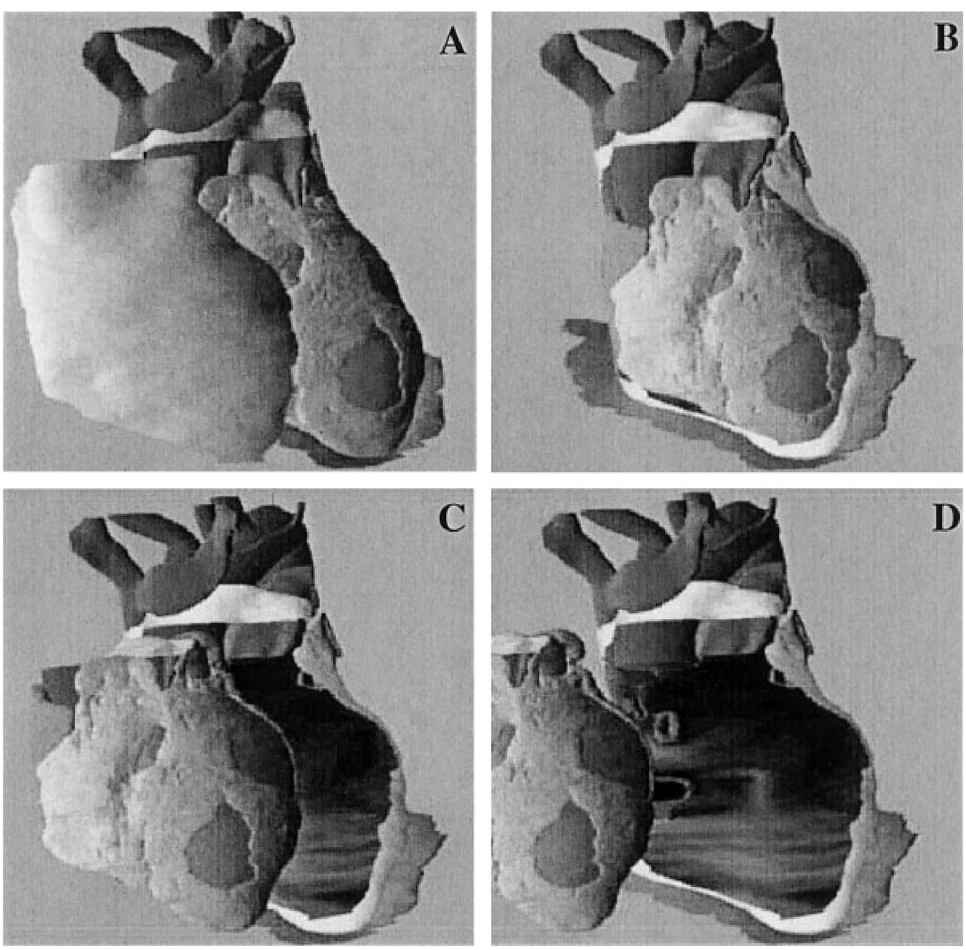

Fig. 8. Screenshots of frames of a digital animation (QuickTime movie), generated by David M. Conley from the Digital Anatomist Interactive Atlas of Thoracic Viscera, University of Washington (Site 35). **A:** The anterior wall of the pericardial cavity is lifted off. **B:** Anterior view of the heart in situ. **C:** After transection of the great vessels, the heart is lifted of the pericardial cavity. **D:** View into the oblique pericardial sinus.

TABLE 7. Sites with User Interface Design Components[a]

Survey item	Sites n (%)
Is a help menu available?	17 (43)
Is a site map or table of contents available?	9 (23)
Are navigational links embedded in all pages?	21 (53)
Are links to home page available in all pages?	26 (65)
Does each page have distinct headers?	34 (85)
Do content materials fit in one page to minimize scrolling?	20 (50)
Is there a regional context model for sectional images?	7 (18)

[a]n = 40.

on numbered slice lines to retrieve a different slice. Figure 9 presents a screen shot of one exemplar site from the Center of Diagnostic Imagery from Switzerland (Site 2), which includes a number of the user interface design components described above.

DISCUSSION

The purpose of our survey was to gain an overall impression of the kinds of computer-based methods that have been applied to the representation and manipulation of anatomic knowledge in educational programs currently accessible through the World Wide Web. In the introduction, we explained our rationale for limiting the survey to this particular electronic medium. We acknowledge in the methods section our possible biases in this survey due to our long-term development of the Digital Anatomist, one of the sites included in the survey. This circumstance may partly account for the fact that the Digital Anatomist is rated second among the 40 reviewed sites. We believe, however, that the biases do not compromise the data we have presented for at least two reasons: 1) we confined our ratings to the presence or absence of methods for presenting anatomic information on the web, and 2) we refrained from making subjective judgments about the educational value of the programs and methods that we reviewed. As noted earlier, the highest rating is an indication of the number of computer-based methods a program incorporates, rather than that of the educational value of the program. The latter judgment is heavily influenced, among other factors, by the purpose and the target audience for which the program is designed. In this survey, making such judgments is particularly difficult because few sites declared their objectives and target audiences.

We hope that the survey categories we used for this study (Table 1) will provide a useful checklist for authors of anatomy websites about the kinds of methods they should consider incorporating into the programs they are developing. This checklist should also raise the awareness of anatomy course directors about the features they should look for when they consider supplementing or replacing printed educational materials with those available on the web. The results we present provide information about the kinds of methods that are currently employed and the extent of their use. More importantly perhaps, our survey also points to important gaps and deficiencies in both the methods and the content of current anatomy websites. Our findings may therefore have important implications for curricular plans and for the priorities educational software developers wish to set for themselves.

In the remainder of this section, we discuss design considerations that we feel need attention by the developers of on-line anatomy educational materials.

Scope of Contents

Although a large number of anatomy sites are accessible over the web, their scope of content is variable. Often, the title of the program is too broad as well as misleading when compared to the actual content. A handful of sites use the title "Anatomy" without reflecting the specific scope of the content. Even though we did not specifically include it in the survey, lack of comprehensiveness stands out as a major problem among the sites. Images of the whole body are available in only nine of the 40 sites. Given the fact that the generation of computer-based representations of the whole body is very costly and requires institutional commitment, a high priority should be given to integrating and correlating programs that are limited to discrete parts of the body. The Internet provides the medium for drawing together geographically dispersed resources. Individual sites could focus on particular parts of the body in depth, rather than producing superficial representations of the whole body. There is a need for addressing the barriers that currently make such integration and synergy a major challenge.

Content Organization

The majority of programs are predominantly image-based and function as atlases, which reflects the image-intensive nature of anatomy and emphasizes the importance of the spatial components of anatomic knowledge. Tutorial is the least developed mode for content organization. A site from the University of Newcastle, England (Site 30), offers an example of how a tutorial might be designed based on specific learning objectives integrated in the content. Ultimately, however, the most desirable system would rely on generalizable anatomy information resources, which could be presented in different organizational

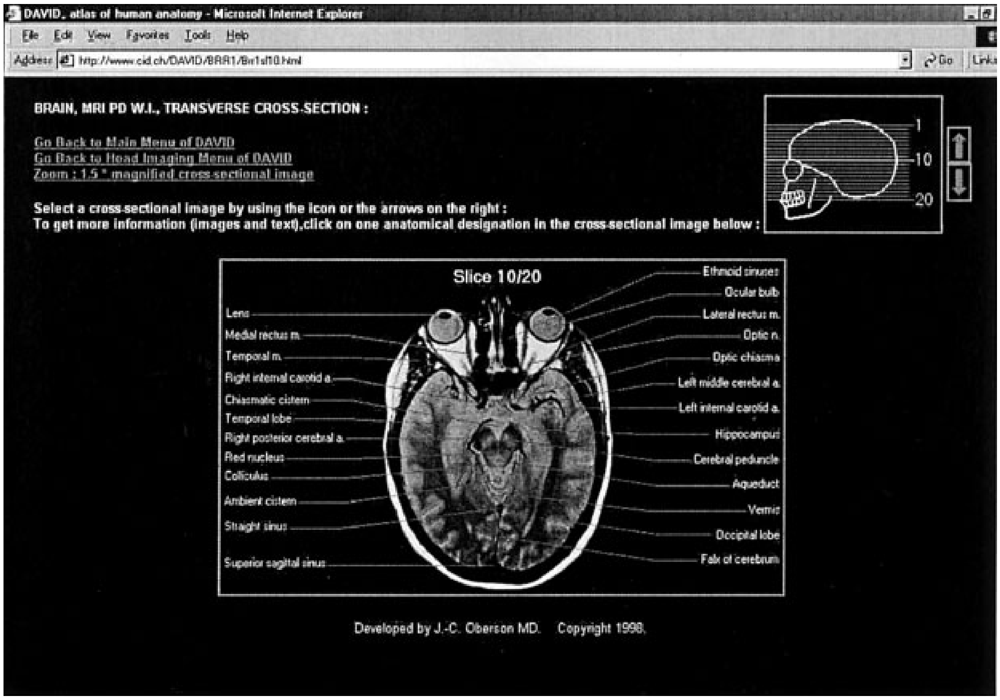

Fig. 9. A screen shot from "DAVID: Atlas of Human Anatomy," Center of Diagnostic Imagery, Switzerland (Site 2). A header is integrated in the upper left corner with navigational links appearing under the header. The thumbnail image on the upper right shows the slice line that corresponds to the image. A user can click directly on the thumbnail image to view a different slice.

modes (didactic, tutorial, systemic, regional) according to the preference of educators and students.

3D Representation of Anatomy

Relatively few programs exploit the unique opportunities offered by computers for representing the third dimension of spatial anatomy. Illustrations prepared by artists with the aid of computer programs predominate along with 2D slices of the body, which are derived either from volumetric radiologic data or from the Visible Human. Although most clinical imaging relies on sectional views of the body, learning anatomy from sections promotes memorization of discrete slices. Unless such slices are integrated in the 3D context of a body part, in our opinion, the development of spatial reasoning skills will be compromised.

Verbal Knowledge Components

Symbolic (verbal) or non-image-based components of anatomic knowledge command much less attention by program developers than do images. Such information is limited largely to the names of structures by labeling images. In many instances, the association of terms with images is hard-coded, similar to that in printed materials, although there were several programs that make use of dynamic labeling in response to user demands. Although we found several programs that offer glossaries and text descriptions, none of them use methods of knowledge representation that can support queries submitted by the user. In other words, all programs lack inference capabilities, a requirement for inherent "intelligence." At this stage, one mouse click returns one isolated fact or image in all of the programs. Incorporating artificial intelligence methods in anatomy education programs remains a major challenge.

Self-Evaluation Modules

Self-evaluation questions are largely limited to the identification of structures on 2D still images. As features become available for directly interacting with 3D graphical models, innovative testing methods need to be developed that can assess spatial understanding of anatomy. Boosting non-image content of the programs will also enhance the ability for testing levels of comprehension that go beyond recalling the names of structures.

Interactive Features

Several sites make use of creative features that enhance interaction with the images. These features include zooming to different levels of magnification and resolution, collapsible and expandable hierarchies of terms that automatically correlate with details displayed in the images, and audio feedback to self-evaluation questions. Whereas interactivity of these features can make learning fun, we believe that such features are of secondary importance in comparison with the need for a comprehensive and logical organization of content.

User Interface Design Components

Content materials need to be supported by sound interface design principles. Without intuitive navigational tools, users can get disoriented in the site and feel frustrated by their inability to access and manipulate the materials. Slightly more than half of the 40 reviewed sites provide such navigational structures. We urge developers of on-line anatomy resources to conduct usability sessions with the potential target audience to identify the interface issues that best meet their needs.

CONCLUSIONS

The availability of educational resources on the web has given rise to plans for on-line courses, curricula, and even an on-line university. Anatomy is a fundamental knowledge domain in the training of all health professionals because it provides the basis for other biomedical disciplines, such as physiology and pathology, as well as clinical practice. Therefore, the first requirement for making on-line health education possible is to establish knowledge resources that can provide anatomic information over the web. This information should be comprehensive and of sufficient depth and quality for meeting the objectives of various curricula in the health professions. Our survey points to the need for comprehensive resources that integrate image-based anatomic knowledge with logically structured verbal knowledge. Ideally, a universal and sharable resource could provide the anatomic information for all educational purposes. This comprehensive resource should then be filtered for meeting educational objectives at different levels. The National Library of Medicine's Visible Human (Ackerman, 1999) and Unified Medical Language System (UMLS) (Lindberg et al., 1993) projects represent the first step toward making such a universal resource a reality. Such basic anatomy resources have to be embellished with images of living and dissected anatomical specimens, radiologic and other clinical images, examples of normal and disrupted functions, clinical cases, and methods for self-evaluation. To generate such a universal and sharable anatomic educational resource, it is inevitable that several geographically dispersed groups would need to collaborate, pool their expertise and share the results of their endeavors. Professional organizations, such as the American Association of Anatomists (AAA) and the American Association of Clinical Anatomists (AACA), should exert a leadership role in promoting the coordination of synergistic initiatives to assure the quality and interoperability of web-based educational programs.

REFERENCES

Ackerman MJ. 1999. The Visible Human Project: a resource for education. Acad Med 74:667–670.

Berry E, Parker-Jones C, Jones RG, Harkin PJR, Horsfall HO, Nicholls JA, Cook NJA. 1998. Systematic assessment of World Wide Web materials for medical education. J Am Med Inform Assoc 5:382–389.

Brinkley JF, Wong BA, Hinshaw KP, Rosse C. 1999. Design of an anatomy information system. IEEE Comput Graphics Appl 19:38–48.

Brinkley JF, Rosse C. 1997. The Digital Anatomist distributed framework and its applications to knowledge-based medical imaging. J Am Med Inform Assoc 4:165–183.

Cahill DR, Leonard RJ. 1997. The role of computers and dissection in teaching anatomy: a comment. Clin Anat 10: 140–141.

Conley DM, Kastella KG, Sundsten JW, Rauschning W, Rosse C. 1992. Computer-generated three-dimensional reconstruction of the mediastinum correlated with sectional and radiological anatomy. Clin Anat 5:185–202.

Eysenback G, Diepgen TL. 1998. Towards quality management of medical information on the internet: evaluation, labeling, and filtering of information. BMJ 317:1496–1502.

Frasca D, Malezieux R, Mertens P, Neidhardt JPH, Voiglio EJ. 2000. Review and evaluation of anatomy sites on the Internet (updated 1999). Surg Radiol Anat 22:107–110.

Geiger O, Monkman DA, Karlinsky HJ. 1998. The presence of Canadian hospitals on the World Wide Web: an empirical analysis. MD Comput 15:49–56.

Habbal OA, Harris PF. 1995. Teaching of human anatomy: a role for computer animation. J Audiov Media Med 18:69–73.

Höhne KH, Pflesser B, Pommert A, Riemer M, Schiemann T, Schubert R, Tiede U. 1995. A new representation of knowledge concerning human anatomy and function. Nat Med 1:506–511.

Jadad AR, Gagliardi A. 1998. Rating health information on the Internet: navigating to knowledge or to Babel? JAMA 279: 611–614.

Kim P, Eng TR, Deering MJ, Maxfield A. 1999. Published criteria for evaluating health related web sites: review. BMJ 318:647–649.

Lindberg DAB, Humphreys BL, McCray AT. 1993. The unified medical language system. Methods Inf Med 32:281–291.

Pealer LN, Dorman SM. 1997. Evaluating health-related web sites. J Sch Health 67:232–235.

Rosse C. 1995. The potential of computerized representations of anatomy in the training of health care providers. Acad Med 70:499–505.

Voiglio EJ, Frasca D, Malezieux R, Moreau S, Rodier MN, Neidhardt JPH. 1999. Prospecting and evaluation of the anatomy sites on the internet. Surg Radiol Anat 21:65–68.

Winker MA, Flanagin A, Chi-Lum B, White J, Andrews K, Kennett RL, DeAngelis CD, Musacchio RA. 2000. Guidelines for medical and health information sites on the internet: principles governing AMA web sites. JAMA 283:1600–1606.

APPENDIX 1. List of URLs of Reviewed Anatomy Web sites[a]

Institution: Title Page	Source	URL
1 Albert Szent-Gyrgyi Medical Univ.: Radiologic Ana.	Kim	http://web.szote.u-szeged.hu/Radiology/Anatomy/
2 Centre d'Imagerie Diagnostique: Atlas of Human Ana.	Both	http://www.cid.ch/DAVID/Mainmenu.html
3 Gold Standard Media: Radiologic Anatomy	Kim	http://www.gsm.com
4 Gold Standard Media: Cross Sectional Anatomy	Kim	http://www.gsm.com
5 Harvard University: Atlas of Brain Perfusion SPECT	Kim	http://brighamrad.harvard.edu/education/online/BrainSPECT/Normal_Anat/Normal_Anat.html
6 Harvard University: The Whole Brain Atlas	Both	http://www.med.harvard.edu/AANLIB/home.html
7 Harvard University: SPL/NSL Anatomy Browser	Kim	http://splweb.bwh.harvard.edu:8000/pages/papers/AnatomyBrowser/current/models/brain+ nose/java/brain+nose.html
8 Institut D' Anatomie De Paris: Le Squelette	Frasca	http://www.biomedicale.univ-paris5.fr/anat/
9 Intellimed Int'l Corp: Human Anatomy On-Line	Both	http://www.innerbody.com/html/indexbody.html
10 Laboratoire d'Anatomie de Lille: Anatomie	Frasca	http://home.nordnet.fr/~mbaroncini/
11 Laboratoire d'Anatomie-Nancy: Radioanatomie	Frasca	http://www.med.univ-rennes1.fr/cerf/edicerf/RADIOANATOMIE/TABMAT.html
12 Laurie Imaging Center: MRI Anatomy Atlases	Kim	http://www.laurie.umdnj.edu/database/frameanat.html
13 Loyola University: Cross-Sectional Anatomy	Both	http://www.meddean.luc.edu/lumen.MedEd/GrossAnatomy/GA.html
14 Memorial Univ. Newfoundland: Ana. of the System	Both	http://www.med.mun.ca/anatomyts/gross.htm
15 Philipps Universitat: Anatomie-Web	Frasca	http://stud-www.uni-marburg.de/~Hoffmann
16 Physical Therapy Central: Skeletal Muscles	Frasca	http://www.ptcentral.com/muscles
17 Queensland Univ. of Technology: The Digital Anatomy	Kim	http://www.dal.qut.edu.au/
18 Southern California Orthopaedic Inst.: Anatomy Info	Both	http://www.scoi.com/index.html
19 Syracuse University: NPAC Visible Human Viewer	Kim	http://www.dhpc.adelaide.edu.au/projects/vishuman2/
20 Trautline: Anatomie Atlas	Frasca	http://www.trautline.de/medizin/anatomie/ueber.htm
21 Uniformed Services Univ.: Radiologic Anatomy	Kim	http://radlinux1.usuf1.usuhs.mil/rad/iong/homepage.html
22 University of Arkansas: Gross Anatomy	Kim	http://anatomy.uams.edu/htmlpages/anatomyhtml/gross_atlas.html
23 University of California, Davis: Human Gross Ana.	Kim	http://medocs.ucdavis.edu/CHA/400
24 University of Chicago: Neuroanatomy Collection	Kim	http://neuroanatomy.bsd.uchicago.edu/
25 University of Colorado: Visible Human Browser	Kim	http://www.uchsc.edu/sm/chs/browse/browse.htm
26 Univ. of Iowa, Virtual Hospital: Pelvis & Perineum	Kim	http://www.vh.org/Providers/Textbooks/pelvis/pelvis.home.html
27 Univ. of Iowa, Virtual Hospital: Lung Anatomy	Kim	http://www.vh.org/Providers/Textbooks/LungAnatomy/LungAnatomy.html
28 Univ. of Iowa, Virtual Hospital: The Human Brain	Frasca	http://www.vh.org/Providers/Textbooks/BrainAnatomy/BrainAnatomy.html
29 University of Mainz: Workshop Anatomie Fur Internet	Frasca	http://www.uni-mainz.de/FB/Medizin/Anatomie/workshop/vishuman/Filme.html
30 University of Newcastle: Eye Tutorial	Frasca	http://numedsun.ncl.ac.uk/~nds4/tutorials/eye/index.html
31 University of Pennsylvania: Interactive Knee	Kim	http://www.rad.upenn.edu/rundle/InteractiveKnee.html
32 University of Utah: HyperBrain	Kim	http://www-medlib.med.utah.edu/kw/brain_atlas/
33 University of Washington: Anatomy Modules	Frasca	http://www.rad.washington.edu/anatomy/index/html
34 University of Washington: Brain Info.	Kim	http://braininfo.rprc.washington.edu/mainmenu.html
35 University of Washington: Atlas of Thoracic Viscera	Frasca	http://www1.biostr.washington.edu/DigitalAnatomist.html
36 University of Washington: Musculoskeletal Atlas	Kim	http://eduserv.hscer.washington.edu/hubio553/atlas/index.html
37 University of Wisconsin: Global Brainstem	Kim	http://www.anatomy.wisc.edu/bs/text/bs/bs.htm
38 University Paris-Sud: Uro. Anatomie	Frasca	http://www.uro.bicetre.org/uroanatomie/Uroanat.htm
39 Washington University: Guided Tour of Visible Human	Kim	http://www.madsci.org/~lynn/VH/
40 Wheeless' Textbook of Orthopaedics	Frasca	http://www.medmedia.com

[a]Sites accessible at http://faculty.washington.edu/~sarakim/anatomy_list.html

APPENDIX 2. Summary of Main Features of Reviewed On-Line Anatomy Websites

	Institution: Title Page	Type[a]	Format[b]	Language[c]	Content of anatomy	Image source[d]	Interactive features	Plug-in program	Self Evaluation module
1	Albert Szent-Gyrgyi Medical University: Radiologic Anatomy	A	TB	E	System	XR, CT, MRI	No	N/A	No
2	Centre d'Imagerie Diagnostique: Atlas of Human Anatomy	C	A, TB	E	Region	D, CT, MRI	Yes	N/A	No
3	Gold Standard Media: Radiologic Anatomy	C	A, TB	E	Region	D, P, XR, CT, MRI	Yes	QuickTime	Yes
4	Gold Standard Media: Cross Sectional Anatomy	C	A	E	Region	VH	Yes	Shockwave	No
5	Harvard University: Atlas of Brain Perfusion SPECT	A	A	E	Organ	CT, MRI	No	N/A	No
6	Harvard University: The Whole Brain Atlas	A	A	E	Organ	CT, MRI	Yes	Java/Media	No
7	Harvard University: SPL/NSL Anatomy Browser	A	A	E	Region	GM	Yes	Java	No
8	Institut D' Anatomie De Paris: Le Squelette	A	A	E,F	System	D	Yes	QuickTime	No
9	Intellimed Int'l Corp: Human Anatomy On-Line	C	A	E	System	D	Yes	Java	No
10	Laboratoire d'Anatomie de Lille: Anatomie	C	TB	F	Region	D, P	No	N/A	No
11	Laboratoire d'Anatomie-Nancy: Radioanatomie	A	TB	E,F	Region	D, CT, MRI	No	N/A	Yes
12	Laurie Imaging Center: MRI Anatomy Atlases	A	A	E	Region	CT, MRI	No	N/A	No
13	Loyola University: Cross Sectional Anatomy	A	A, T	E	Region	VH, CT, MRI	Yes	QuickTime	Yes
14	Memorial University Newfoundland: Ana. of the System	A	TB	E	Mixed	D, SM, XR, CT, MRI	No	N/A	No
15	Philipps Universitat: Anatomie-Web	A	TB	G	Mixed	D	No	N/A	Yes
16	Physical Therapy Central: Skeletal Muscles	C	TB	E	System	No images	No	N/A	No
17	Queensland University of Technology: The Digital Anatomy	A	A	E	Region	VH, CT, MRI	Yes	Win Media	No
18	Southern California Orthopaedic Inst.: Anatomy Info	C	TB	E	Region	D	No	N/A	No
19	Syracuse University: NPAC Visible Human Viewer	A	Other	E	Region	VH	Yes	Java	No
20	Trautline: Anatomie Atlas	C	TB	G	Mixed	D	No	N/A	No
21	Uniformed Services University: Radiologic Anatomy	M	A	E	System	XR, CT, MRI	Yes	N/A	No
22	University of Arkansas: Gross Anatomy	A	A	E	Region	D, P, CT, MRI	No	N/A	No
23	University of California, Davis: Human Gross Anatomy	A	Other	E	Region	SM, P	No	N/A	Yes
24	University of Chicago: Neuroanatomy Collection	A	A	E	Organ	P	No	N/A	No
25	University of Colorado: Visible Human Browser	A	Other	E	Region	VH	No	N/A	No
26	University of Iowa, Virtual Hospital: Pelvis & Perineum	A	TB	E	Region	D, CT, MRI	No	N/A	No
27	University of Iowa, Virtual Hospital: Lung Anatomy	A	TB	E	Organ	XR, CT, MRI	Yes	QuickTime	No
28	University of Iowa, Virtual Hospital: The Human Brain	A	TB	E	Organ	D, P	No	N/A	No
29	University of Mainz: Workshop Anatomie Fur Internet	A	A	E,G	Region	VH, other	Yes	QuickTime	No
30	University of Newcastle: Eye Tutorial	A	T	E	Organ	D, SM	No	N/A	No
31	University of Pennsylvania: Interactive Knee	A	A	E	Region	VH, CT, MRI	Yes	N/A	No
32	University of Utah: HyperBrain	A	A	E	Organ	D, CT, MRI	Yes	Java	Yes
33	University of Washington: Anatomy Modules	A	TB	E	Region	D, XR, CT, MRI	Yes	QuickTime	No
34	University of Washington: Brain Info	A	A	E	Organ	D, P, GM	Yes	QuickTime	No
35	University of Washington: Atlas of Thoracic Viscera	A	A	E	Region	GM, XR, CT, MRI	Yes	QuickTime	Yes
36	University of Washington: Musculoskeletal Atlas	A	A	E	System	D	No	N/A	No
37	University of Wisconsin: Global Brainstem	A	TB	E	Region	D, CT, MRI	Yes	Shockwave	Yes
38	University Paris-Sud: Uro. Anatomie	A	TB	F	Region	D	No	N/A	No
39	Washington University: Guided Tour of Visible Human	A	A	E	Region	XR, VH	Yes	N/A	No
40	Wheeless' Textbook of Orthopaedics	C	TB	E	System	D, CT, MRI	No	N/A	No

[a]A, academic; C, commercial; M, military.
[b]A, atlas; TB, textbook; T, tutorial.
[c]E, English; G, German; F, French.
[d]D, drawing; GM, graphical model; SM, solid model; XR, Xrays; VH, Visible Human; P, dissection photo; CT, MRI.