Teaching the Clinical Interpretation of Peripheral Blood Smears to a Second-Year Medical School Class Using the PeripheralBlood-Tutor Computer Program

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The interpretation of peripheral blood smears has an important role in the diagnosis of hematologic diseases and is, therefore, part of the education of physicians and technologists. We describe a computer program, PeripheralBlood-Tutor (Lippincott-Raven, Philadelphia, Pa), that teaches the morphologic features of normal and abnormal peripheral blood smears; we also describe the evaluation of the effectiveness of the program in 133 second-year medical students who were required to use the program in their hematology course. The version of the PeripheralBlood-Tutor used in the study had 2 distinct but equivalent 20-question examinations; one examination, the pretest, was taken before the students viewed the contents of the program, and the other examination, the posttest, was taken after completing the program. The mean score on the pretest was 61% (SD, 14%), the mean on the posttest was 91% (SD, 10%), and the improvement was significant. In addition, 4 questions about peripheral blood smears, which were based on printed images, were administered at the end of the hematology course. The students scored an average of 2.75 (SD, 0.86), and a positive correlation was found between these scores and the scores on the Tutor posttest. The results of the study suggest that PeripheralBlood-Tutor is feasible to implement, and it helps students learn to interpret peripheral blood smears. The use of PeripheralBlood-Tutor is now a requirement in the medical school curriculum, the medical technology program, and the pathology residency at the University of Washington, Seattle. (Key words: Computer-assisted instruction; Peripheral blood; Medical education) Am J Clin Pathol 1998;109:514-520.

The evaluation of Wright-stained peripheral blood smears has a critical role in the diagnosis of hematologic disorders; therefore, learning this task is part of the education of medical students, medical technologists, pathology residents, and other health care trainees.

Traditional teaching of the morphologic features of peripheral blood smears, like the teaching of any microscope-based laboratory test, is a time-intensive process that typically requires an experienced teacher, a multiheaded microscope, and a set of glass study slides. In many medical schools and medical technology programs, time constraints on the faculty prohibit the extended teaching sessions necessary for such instruction, and well-organized study sets of glass slides are difficult to acquire and maintain. Although textbooks and atlases are useful references (eg, reference 1), the reproduction of the subtle morphologic features of peripheral blood smears is difficult.

Since 1992, our software development group at the University of Washington, Seattle, has been developing computer programs to overcome some of the drawbacks of the traditional instruction of image-based laboratory tests. Our previous work includes GramStain-Tutor (Lippincott-Raven, Philadelphia, Pa),2,3 which teaches the interpretation of direct Gram's stains, Urinalysis-Tutor (Lippincott-Raven),4 which teaches the microscopic examination of urine sediment, ANA-Tutor (Sanofi Diagnostics Pasteur, Redmond, Wash),5 which teaches the interpretation of the immunofluorescence assay for antinuclear antibodies, and others6-8 (for a review, see reference 9).

In this article, we discuss the most recent of our programs, PeripheralBlood-Tutor (Lippincott-Raven),
which uses approximately 150 high-resolution digital images to teach the clinical interpretation of the morphologic features of peripheral blood smears. We describe the contents of PeripheralBlood-Tutor, pointing out features that take advantage of computer technology. In addition, we describe the results of a study of the performance of 133 second-year medical students who were required to use the program in their medical school course in hematology. The study suggests that the program is feasible to implement and that it helps students learn to interpret peripheral blood smears.

METHODS

Program Development

PeripheralBlood-Tutor was designed, written, and tested by a team of physicians, medical technologists, graphic artists, and computer programmers. The program can run under the PC (Microsoft Windows) or Macintosh platforms. The Windows program is written in Microsoft Visual Basic for Windows (Microsoft, Redmond, Wash), and the Macintosh program is written in Prograph (Pictorious, Halifax, Nova Scotia).

The digital images in the program were derived from peripheral blood specimens submitted for morphologic evaluation at the hematology laboratories of Harborview Medical Center, Seattle, Wash, or the University of Washington Medical Center, Seattle. The images were obtained using a color CCD camera (Javelin Chromachip II model #JE3462RGB, Javelin Electronics, Torrance, Calif) that was mounted on a light microscope (Olympus model BH2, Olympus, Lake Success, NY). The camera was interfaced to a 80486 microcomputer (Gateway 2000, N Sioux Falls, SD) through a video imaging board (MVP-AT, Matrox Electronic Systems, Dorval, Quebec) that converted the analog signal from the camera into a digital image. The entire system was operated by Optimas image analysis software (Optimas, Edmonds, Wash). Some digital images were edited by using Adobe Photoshop (Adobe Systems, Mountain View, Calif) to adjust the images so they appeared nearly identical to the images seen visually in the microscope.

An early version of PeripheralBlood-Tutor was reviewed at the University of Washington and Harborview Medical Centers by a large group of students, residents, and faculty. These users provided detailed feedback that helped us revise the tutorial before its first general release.

Medical Student Evaluation

The subjects in the study were 133 members of the University of Washington second-year medical school class who were enrolled in 1996 in Human Biology 552, a 5-week, 27-hour course in hematology. The PeripheralBlood-Tutor was required in the course and could be used anytime during the 5 weeks. PeripheralBlood-Tutor was loaded on 12 computers in the University of Washington Health Sciences Library where students could log on at their convenience as many times as they wished during regular library hours. Directions for use were given to all students during class.

PeripheralBlood-Tutor includes two examinations. For the version used in this study, one of the examinations was the pretest and the other was the posttest, and the program required the students to take the pretest immediately after entering the program. Student identification numbers and test scores were recorded over the network in a Microsoft Access database (Microsoft).

A control group of 136 students who were second-year students enrolled in 1997 in Human Biology 552 was used to assess the equivalency of the pretest and posttest. For this group of students, the pretest and posttest were reversed relative to 1996. Thus, the 1996 pretest was the 1997 posttest and vice versa.

Statistical analyses were performed by using SPSS for Windows, version 7.0 (SPSS, Chicago, Ill). Student pretest and posttest data were compared with paired t tests and analysis of covariance. Bivariate Pearson-Product

Moment correlations were used to compare the relationships between variables.

**PROGRAM DESCRIPTION**

PeripheralBlood-Tutor is intended for a variety of health care workers and trainees, including physicians, medical students, medical technologists, and medical technology students. It is designed for users with minimal computer experience and is completely operated by pointing with the mouse and pressing the left mouse button. About 90 minutes are needed to complete the program.

A schematic of the program is presented in Figure 1. The program is divided into the following sections: Introduction, Cell Morphologies, Disease Associations, Image Atlas, and Final Examination. The Introduction covers basic facts about peripheral blood and its relationship to bone marrow, demonstrates the preparation of peripheral blood smears, illustrates the principles and technique of the Wright stain, and discusses the evaluation and examination of stained smears under the microscope. The Introduction uses a variety of teaching techniques, including a video clip to illustrate the technique of blood smear preparation, pop-up screens that show the microscopic appearance of user-selected locations on a blood smear, and graphic overlays to unambiguously highlight areas of interest.

The Cell Morphologies section consists of a basic introduction to cell structure and then subsections that systematically present normal and abnormal morphologic features for each of the major cell types. For cell structure, important features of RBCs are illustrated by using animation to show the biconcave disk structure and deformability (Fig 2). White blood cell and platelet structures are presented by using interactive illustrations in which the user points to the names of subcellular structures and then those structures become highlighted in the illustration.

For each cell type in the Cell Morphologies section, images of the normal maturation sequence are shown. In the case of RBCs or granulocytes, the user can choose to “morph” the images to watch the cells develop from the blast through the mature form. This dynamic display of the maturation sequence can be traversed in either direction by single steps or in its entirety. After viewing the maturation sequence for a cell type, the user can view the normal and abnormal variations for that cell type. Each variant presented is accompanied by a short morphologic description and an associated clinical fact. This is illustrated in Figure 3, which shows a screen from the section on variations in RBC shape.
The Disease Associations section is divided into subsections covering RBC, WBC, and neoplastic disorders. Because disease states often have multiple morphologic abnormalities in one or more hematopoietic cell lines, this part of the tutorial combines the individual morphologic features presented previously into commonly occurring collections of abnormalities characteristic of a specific disease state. This is particularly true of the neoplastic diseases in which the disorders are grouped as myelodysplastic, myeloproliferative, acute leukemia, or lymphoproliferative. The format is like that shown for cell morphologies and consists of images with succinct associated text.

The Image Atlas contains 118 images in the Cell Morphologies and Disease Associations sections. The user may select a single image to view or juxtapose any two images to allow comparison of the morphologic features. This feature is particularly useful when comparing morphologic features that have only subtle differences, and it allows the user to select the morphologic features that present the greatest difficulty. Figure 4 shows how the Image Atlas can be used to compare the appearance of lymphocytes in infectious mononucleosis and pertussis.

The Final Examination consists of 2 multiple choice tests of 20 questions each. The questions are presented in random order, and correct answers with explanations are provided for each question. The variety of question formats ranges from simple cell identification to the recognition of multiple abnormalities and the associated disease state. An example of a question and its answer is presented in Figure 5. In the commercially available version of the tutorial (Lippincott-Raven), users can take the examinations at any time and in either order. In the modified program used in this study, one of the examinations was randomly assigned as the pretest, and the other was the posttest. The modified program requires the students to complete the pretest before viewing the contents of the program. The posttest is taken after completing the program.

**RESULTS**

**Second-Year Medical Students, 1996**

A total of 133 medical students used Peripheral Blood-Tutor and took the pretest and posttest. The results for the 133 students are shown in the Table. The mean on the pretest was 61% (SD, 14%), and the mean on the posttest was 91% (SD, 10%). The pretest to posttest improvement was significant (P<.001; paired t test).

All 20 pretest items correlated significantly (P<.05) with the total score on the pretest, indicating that each
individual item was associated with overall performance on the pretest. On the posttest, 18 individual items correlated significantly \((P<.05)\) with the total posttest score.

At the end of the hematology course, the students took a 2-part written examination with a total of 150 questions. The examination did not contain questions about peripheral blood smears. The course director also administered 4 additional questions about peripheral blood smears to evaluate the retention of the material presented in PeripheralBlood-Tutor. These 4 questions were based on printed images, and the students scored an average of 2.75 \((SD, 0.86)\) correct. There was significant correlation \((r = 0.2; P<.05)\) between the scores on the Tutor posttest and the scores on the 4 questions. The Tutor pretest and posttest scores did not correlate with the total score on the hematology examination.

During the first year at the University of Washington medical school, students are located at 1 of 4 geographic sites. Of the 133 second-year students in the study, 72 were in Seattle during their first year and used GramStain-Tutor. The remaining 61 did not have experience with GramStain-Tutor. GramStain-Tutor has different content than PeripheralBlood-Tutor, but it has a similar style and structure because it uses the same software engine. We wanted to know if students who previously used GramStain-Tutor scored higher on PeripheralBlood-Tutor tests than students with no previous Tutor exposure. The test scores were virtually identical for the 2 groups. Both groups scored an average of 61% \((SD, 13\%)\) for each of the groups) on the pretest. The group that had used GramStain-Tutor averaged 91% \((SD, 8\%)\) on the posttest, and the group with no exposure to GramStain-Tutor averaged 90% \((SD, 12\%)\).

**Second-Year Medical Students, 1997**

To assess the equivalency of the pretest and posttest, the tests were reversed for the 136 second-year medical students enrolled in the Human Biology 552 course in 1997. The 1996 pretest items were used as the 1997 posttest, and the 1996 posttest became the 1997 pretest. The 1997 group scored an average of 61% \((SD, 10\%; range, 35–85)\) on the 1997 pretest and 89% on the 1997 posttest \((SD, 9\%; range, 50–80)\). The pretest to posttest improvement was significant \((P<.001; paired t test)\). Because 1996 and 1997 class performance was nearly identical despite reversing the tests, the pretest and posttest are approximately equivalent, and the improvement in test scores between pretest and posttest was not due to a less difficult posttest.
DISCUSSION

Medical students must learn to interpret the results of a number of microscope-based clinical laboratory tests, most importantly the peripheral blood smear, the analysis of urine sediment, and the direct Gram stain of body fluids. Despite the clinical significance of these tests, training in most medical schools has been eliminated or reduced during the preclinical years because the medical school curriculum is increasingly crowded, and the teaching of these tests requires a great amount of equipment, specimens, and supervised teaching time.

To overcome the problems associated with teaching these and other image-based tests, we have developed several computer programs. Three of these programs—PeripheralBlood-Tutor, GramStain-Tutor, and Urinalysis-Tutor—are now required in the University of Washington medical school preclerkship curriculum, and all of the programs are part of the medical technology curriculum and the pathology residency. In addition, the programs are optional assignments in a variety of fellowships and other residencies in the medical school.

The current study focused on PeripheralBlood-Tutor. Our results indicated that PeripheralBlood-Tutor helped medical students learn to interpret peripheral blood smears. This was shown by the significant improvement between the students’ Tutor pretest and posttest scores and by the positive correlation between posttest scores and scores on 4 questions about peripheral blood smears that were administered with the final examination at the end of the hematology course.

The results we obtained with PeripheralBlood-Tutor are similar to those we obtained in a 2-year study of GramStain-Tutor, when its use was required of 2 consecutive classes (N>70 each year) located at the University of Washington, Seattle campus. In addition, similar results have been obtained recently in a study of Urinalysis-Tutor (Aston et al, unpublished data, 1997) when its use was required of 150-second year medical students.

In addition to its role in the medical school curriculum, the PeripheralBlood-Tutor is of primary importance in the clinical laboratory where it is used as a supplement to supervised instruction. The trainees, whether medical technologists, medical technology students, physicians (especially pathology residents and hematology fellows), or medical students, start the hematology rotation by completing PeripheralBlood-Tutor. This allows the trainees to acquire substantial basic knowledge of morphologic hematology. Having learned the basics, the trainees can move on to more complex subjects. Instructors are relieved of the potentially monotonous task of teaching basic concepts or vocabulary and can focus instead on in-depth discussions of interesting cases and more advanced material.

Another important clinical laboratory use of PeripheralBlood-Tutor is as a reference. Cases may be clarified by using the Image Atlas for comparison with difficult cases. With the recent completion of a quarterly subscription service, PeripheralBlood-Review (Lippincott-Raven), which provides additional examination questions and adds images to the PeripheralBlood-Tutor atlas, the atlas of available images can be continually expanded, creating an even more useful reference tool.

Our future plans are to develop and evaluate more computer tutorials. Recently completed works include Parasite-Tutor (Lippincott-Raven), which covers the laboratory diagnosis of medically important parasites, Microscopy-Tutor (Lippincott-Raven), which teaches the principles and practice of light microscopy, and Nail-Tutor (Lippincott-Raven), which teaches the diseases of the nails. A work in progress is Mycology-Tutor, which covers the laboratory diagnosis of medically important fungi. We are also considering logical extensions of our work in hematology. This could include a tutorial about the morphologic features of bone marrow and a tutorial about the interpretation of the histograms produced by many automated hematology instruments.

We are continuing our studies of the effectiveness of PeripheralBlood-Tutor, GramStain-Tutor, and Urinalysis-Tutor in the medical school curriculum and are expanding these studies into the medical technology program. A long-term goal is to study the effectiveness of some of the new programs mentioned. We hope that these studies will give us feedback that we can use to improve later versions of the software.

We have described PeripheralBlood-Tutor, a computer program that effectively teaches the interpretation of peripheral blood smears. The program has been successfully implemented in a variety of settings at the University of Washington.

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REFERENCES


Additional information about educational software development in the Department of Laboratory Medicine, University of Washington, is available on the World Wide Web (http://www.labmed.washington.edu/tutors/tutor.Home.html).