Feature

Digital Pathology: A New Frontier in Education

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The microscope is arguably one of the most important tools used by pathologists. Although Antonio Benivieni (1443–1502), the "father of pathologic anatomy," conducted his pioneering work in the mid-to-late 1400s, it wasn't until the 1850s that Rudolf Virchow (1821–1905) first began using microscopes to study disease.[1] Surprisingly, the microscope existed for almost 200 years before Virchow applied its use to the science of pathology when the first compound microscope was created by Robert Hooke (1635–1703) of England in 1655.[2]

Today, microscopes are still a mainstay in the classrooms and laboratories of pathologists; however, pathology is undergoing a digital revolution enabled by virtual microscopy—the practice of converting entire glass microscope slides to high-resolution, whole-slide digital images. As a result, digital slide images can be viewed across a network, including the Internet, using specialized viewing software that provides more timely and accurate information compared with traditional methods.

With the emergence of digital pathology, today's students and pathologists are once again faced with an opportunity—a situation not unlike the one that Virchow encountered in the 1850s when he first applied the use of microscopy to the study of pathology. Significant technological advancements in the ability to digitize large numbers of glass slides, and the development of workflow tools that facilitate remote viewing and analysis, are enabling pathologists to substantially change how they learn and practice their profession.

A Multi-Faceted Educational Tool

Although the classroom offers a high utility environment for digital pathology in medical education, many other education-related areas also benefit from the use of digital pathology, including decision support, digital slide conferencing, proficiency testing, and quality assurance (**Figure 1**).

Classroom Teaching—Medical Education

Traditional pathology teaching methods include glass slides viewed under conventional microscopes as well as reliance on printed photomicrographs and 35-mm projection slides. Some newer textbooks even include a CD-ROM with images to be viewed on a computer. However, all of these images—whether digital or analog—are limited to showing a preselected area at a fixed magnification.

The medical, dental, and veterinary education markets have widely adopted digital pathology as an alternative to providing students with glass slide sets and conventional microscopes. Current microscope-based teaching methods are expensive and have significant limitations, such as:

- Glass slides get lost, break, and fade over time.
- Rare glass slides cannot be duplicated and made available to all students.
- Glass slides cannot be annotated.
- Student glass slides are often incomplete and not identical, which creates discrepancies in testing and scores.
- Independent, non-laboratory study time is limited by access to glass slides and microscopes.
- Replacing and maintaining microscopes and glass slide sets requires significant expenditures.

While it is important for students to be proficient in using microscopes, digital pathology has the opportunity to improve the classroom experience. Studies at the University of Iowa and elsewhere have shown that the majority of students believe that the use of digital slides enhanced their ability to learn.[3-6] Some of the outcomes related to implementation of virtual microscopy into histology and pathology courses at the University of Iowa include:

- A significant increase in efficiency and accessibility of virtual slides compared with traditional microscopy, expressed by both students and faculty.
- Increase in student skill in presenting morphologic findings on "slides" in small group case analysis sessions.
- A majority of students indicate that the image quality is as good as traditional microscopy.
- No change in student performance on photomicrograph or glass slide exams.
- Laboratory space utilization has markedly decreased.
- Student interest in pathology as a career has increased.

With digital pathology, students can access specimens via the Internet for review, and whole-slide imaging enables instructors and students to view and zoom in on any part of the digital slide, instead of a single field of view captured by a conventional CCD camera. Other benefits include:

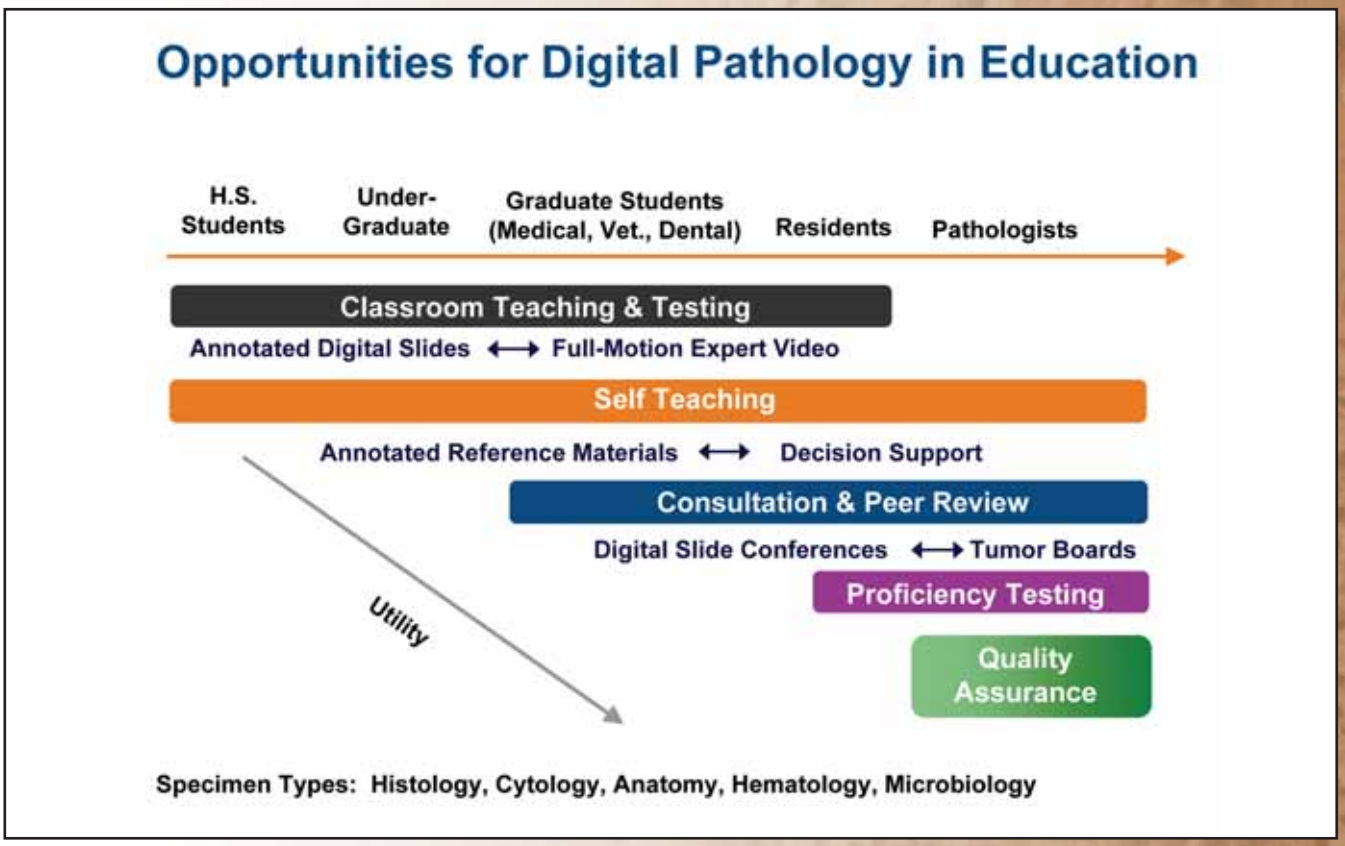
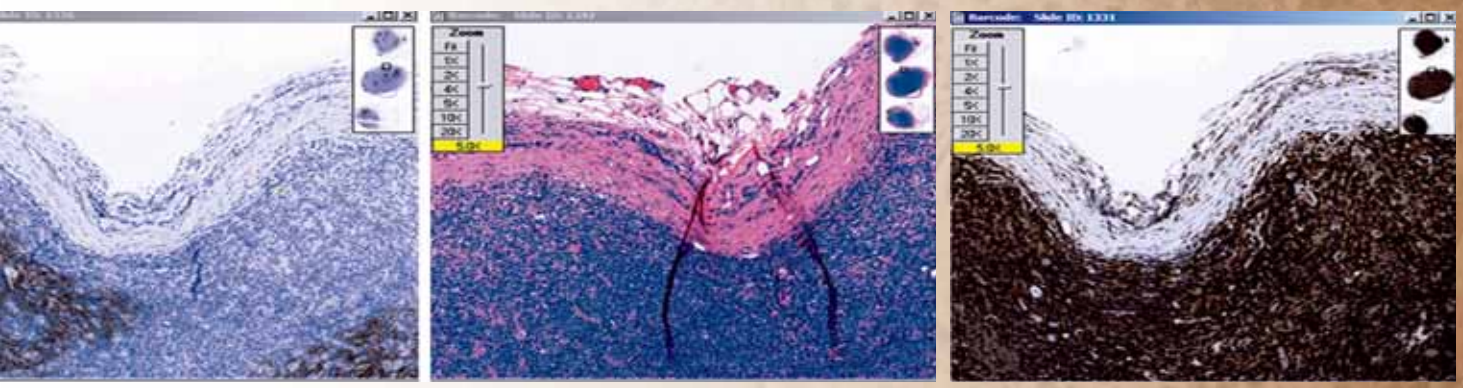


Figure 1_Opportunities for digital pathology in education.

- Digital slides are not subject to loss, breakage, and fading.
- Digital slides can be accessed 24/7 and often from remote locations via the Internet.
- Instructors can annotate digital slides and conduct side-by-side comparisons.
- Access to rare slides is improved.
- There is a reduced need for microscope rooms and the costs associated with microscope maintenance.
- Development time of new classroom curricula is reduced.

Decision Support

One of the most valuable benefits of digital slides is their use for decision support. Unlike references books, relevant details in a digital slide can be viewed "in context" to provide pathologists and students with comprehensive, evidence-based pathology content to facilitate self-teaching or decrease the time required by pathologists to research complex pathology cases. Annotated digital slide repositories are easy to create and can be organized to facilitate the retrieval of digital slides based on 1) meta-data that has been entered by a human to find digital slides exhibiting a specific attribute, or 2) the



intelligent retrieval of digital slides by a computer based on imagery data of interest to find digital slides that are similar to cells of interest, for example.

Over the course of their careers, many pathologists assimilate collections of glass slides that they sometimes use as reference slides for decision support. Digital pathology makes it possible to create a repository of personal digital slides that can be accessed by pathologists from anywhere at any time.

Conferencing

The accessibility of digital pathology information makes it easy to access and share digital slide images, to foster collaboration on cases, or to make presentations for educational conferences such as tumor boards. Digital slide conferences conducted via the Internet allow multiple parties to view the same digital slides simultaneously, in synchrony, such that every party sees the same portion of the digital slide at the same time. Each participant in a digital slide conference can view annotations created by others while at the same time adding annotations for others to see. A common cursor superimposed on the digital slide and visible to all conference participants can be manipulated by any conference participant.

In the past, presentations at educational conferences and tumor review boards were limited to embedding images in PowerPoint or using a traditional glass slide under a microscope connected to a projector. These methods incurred the costs of creating duplicate glass slides, as well as the risk of losing or damaging valuable material. In some cases, making duplicate glass slides was not an option because the laboratory could not spare precious tissue samples. But with digital pathology, the ability to easily access digital whole-slide images creates the opportunity to facilitate live, interactive discussions among peers. Digital slides can be accessed by participants in advance of the conference or meeting so they can review materials and prepare questions. Another alternative is to distribute digital slides via the Internet, or on portable digital media such as CD-ROMs or DVDs, in post-conference abstracts to allow participants to review the materials after the presentation.

Proficiency Testing

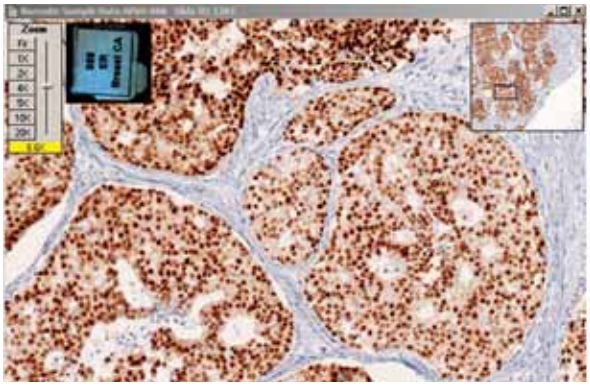
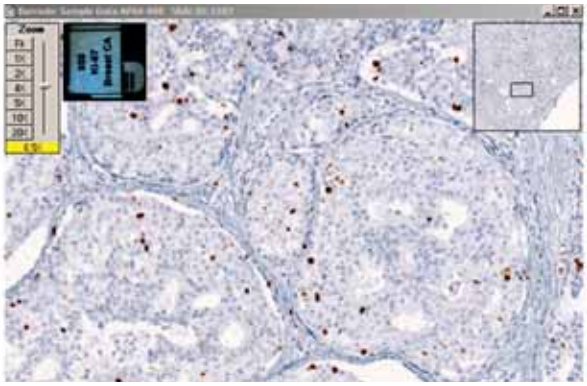
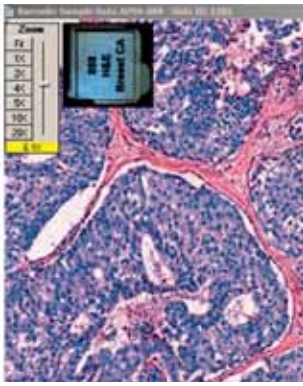
Ongoing proficiency testing may become yet another practical use of digital pathology as regulations permit. Staff at clinical laboratories are required to provide evidence of satisfactory performance in an approved proficiency testing service. Proficiency testing is designed to ensure that laboratory tests performed by all laboratories achieve an acceptable level of accuracy and consistency.

For example, since 1988, laboratories conducting Papanicolaus (Pap) tests have been required to test the proficiency of pathologists who review the slides. Currently, pathologists are mailed 5 glass slides for review and submit their answers. Using digital pathology to administer "virtual Pap tests" for proficiency testing via the Internet or other electronic media could reduce program costs for test administrators and increase convenience among test takers. A recent study evaluating the use of virtual microscopy for proficiency testing concluded that future use of the technology in "virtual Pap tests" is feasible and that participants steadily improved their accuracy and speed as they learned to operate the digital pathology application.[7]

Quality Assurance

In most quality assurance (QA) practices, organizations send a random selection of signed-out cases to a second pathologist for review. Due to the cost and difficulty of glass slide logistics, QA programs are normally operated as an intra-facility activity. It is likely, however, that intra-department and intra-facility QA reviews (over-reads) may introduce bias into the review process,[8] and that QA effectiveness may improve with inter-facility over-reads.[8]

In contrast, digital pathology makes it simple to make digital slides accessible to other facilities or organizations. In addition, many digital pathology solutions have the capability to conceal the original diagnosis and the identity of the pathologist who signed off on the original report, which would enable digital slide over-reads that are potentially free from bias by reducing the chances that the second reviewer can identify the sign-out pathologist or the original diagnosis.

Catalyzing a Transformation

Digital pathology is unlikely to make the microscope a relic. Virchow's use of the microscope transformed the practice of pathology, allowing pathologists to study diseases at a cellular level and to also share slides with colleagues for collaboration and with students for education. Digital pathology has the potential to catalyze a similar transformation and create opportunities in education beyond classroom teaching in areas such as decision support, digital slide conferencing, proficiency testing, and quality assurance. LM

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