

From glass slides to digital screens: A comparative appraisal of virtual microscopes dedicated to teaching histology

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Running Title: A review of virtual microscopes

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ABSTRACT

Introduction: Virtual microscopes offer great potential for teaching and learning, but the variety of platforms makes it challenging for educators to choose the right tool. This short communication aims to explore the existing resources available on the internet and present a comprehensive appraisal of currently active virtual microscopy (VM) platforms used in histology education, comparing their features and functionality. **Description of case:** Eighteen VM platforms met the eligibility criteria and were included in this investigation, majority of which were developed by institutions in North America. Seven virtual microscopes included a dynamic scale bar. Seven platforms allowed users to freely rotate digital slides, while only three platforms included labels on these slides. **Discussion and conclusion:** The summarized features and functionalities of VM platforms highlight their respective strengths and limitations, providing a practical resource for educators seeking to adopt or develop virtual microscopy tools that support interactive and engaging learning.

Keywords: dental education; educational technology; histology; review; teaching

CDHA Research Agenda category: capacity building of the dental hygiene profession

PRACTICAL IMPLICATIONS OF THIS RESEARCH

1. Virtual microscopes, digital tools that simulate the use of a traditional light microscope, are increasingly being adopted in higher education, especially for teaching histology.
2. Although oral histology is a crucial component of dental hygiene education, reports on the use of virtual microscopes in this area are uncommon.

3. This short communication provides a detailed, comparative analysis of currently active virtual microscopes, identifying their strengths, limitations, and the availability of oral histology collection. This can serve as a practical resource for dental and dental hygiene educators aiming to adopt or develop virtual microscopes as a teaching tool.

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INTRODUCTION

Virtual microscopes have increasingly become an essential educational tool and, in many cases, a practical alternative to traditional light microscopes in health sciences education.^{1,2} Their adoption has been especially significant in fields like histology, pathology, hematology, and microbiology, where high-resolution digital slides provide consistent, accessible, and interactive learning experiences.^{3,4}

Histology, the study of tissue structure under a microscope, is a major discipline in medical, dental, dental hygiene, and many other life science curricula.² Since the mid-19th century, instruction of histology has relied on light microscopes and glass-mounted specimens.^{3,4} This conventional approach typically requires each student or small group to have access to a microscope and glass slides, along with dedicated lab space, extended hours, and sufficient faculty to offer individualized guidance. Teaching with light microscopes also limits simultaneous viewing, which can hinder collaborative learning and efficiency.⁵

A virtual microscope is a computer- or internet-based tool that mimics the experience of using a traditional light microscope.^{3,6} Over the past decades, virtual microscopes have become increasingly adopted in North America as a teaching tool, with 67% of U.S. medical schools reporting exclusive use of this technology for histology laboratory instruction.⁴ Virtual microscopes have been shown to enhance learning efficiency,^{7,8} offer better access to digital slides outside of regular class hours,⁹ encourage collaborations,¹⁰ and support self-directed learning.^{11,12} Digital slides allow for identical microscopic images, standardized lessons and consistent assessments, features that are difficult to achieve with traditional light microscopes.¹³⁻¹⁵

Like many emerging technologies, the quality and user experience of virtual microscopes depend on several key factors. One of the most critical steps in developing a virtual microscope is

preparing digital scans from glass slides using Z-stacking technology, which enables users to view multiple focal planes along the Z-axis of tissue samples.^{16,17} While virtual microscopes offer numerous advantages, several studies have reported hesitancy among students and faculty in adopting this technology. Common concerns include limited image resolution, the absence of continuous Z-axis navigation, and an insufficient repository of high-quality digital slides.¹⁸⁻²¹

Although an increasing number of educational institutions are integrating virtual microscopes into their curricula, the availability of this platform as open educational resources (OER) remains limited. OER refers to any teaching and learning materials in the public domain that allow users to access, use, adapt, and redistribute them at no cost.²² In health professional education, most virtual microscopes have been designed and developed by medical schools, often restricted only for institutional students and faculty.¹⁻³ While dental and dental hygiene students also study oral histology in significant depth, dedicated VM platforms tailored to this field remain limited, and their use in dental hygiene education is rarely reported. Among the platforms available for public use, there is significant variation in the breadth of slide collections, image resolution, magnification levels, annotations, and interactive features. While these virtual microscopes offer great potential for enhancing teaching and learning, the sheer number and diversity of available platforms can make it challenging for educators to evaluate and choose the most suitable tools for their needs.

This short communication aims to present a comparative appraisal of the freely available current virtual microscopes developed to archive and display histology digital slides for educational purposes. The objective of our work is to answer the following research questions:

1. Which virtual microscopy (VM) platforms and/or digital histology slide collections are currently available free of charge for both students and faculty?

2. What are the main features and functions of each virtual microscope identified for histology education?

CASE DESCRIPTION

We conducted a systematic identification and comparative appraisal of virtual microscopes that are currently active on the internet. The steps of the web review are outlined below:

Identification and selection of virtual microscopes

Two rounds of Google searches were conducted using the keywords “virtual microscope histology” and “digital sandbox histology” to identify candidate virtual microscopy (VM) platforms. Each platform was screened against predefined criteria: eligibility required that platforms be freely accessible, in the English language, explicitly designed for histology education, and include a collection of digital slides with magnification capabilities that closely replicate the experience of using a conventional light microscope (Figure 1).

Data charting, collating, and summarizing

Each selected VM platform was thoroughly and independently examined by two authors to identify its content, features, usability, and supplementary resources. The extracted data were included in the constructed tables and cross-checked by a third author. Descriptive statistics were applied to provide numerical summaries of the characteristics of the selected virtual microscopes.

RESULTS

List of virtual microscopes that are freely accessible for teaching and learning of histology

Two rounds of searching yielded 290 results, of which 54 non-duplicate VM platforms were identified. After stepwise screening, 18 VM platforms remained in the list that are currently freely accessible for teaching and learning of histology (Figure 1).

Features and functions of the included virtual microscopes

A thorough review of the included virtual microscopes has identified four key features and functionalities that are commonly included in the platforms: magnification, rotation, annotation, and labels. Most (56%, n = 10) of the virtual microscopes reviewed were developed by institutions in the United States. Two platforms were created by organizations in the United Kingdom (11%, n = 2), and another two by organizations in Spain (11%, n = 2). The remaining four platforms were each developed by institutions from Canada (6%, n = 1, each), Russia (6%, n = 1, each), Denmark (6%, n = 1, each), and Belgium (6%, n = 1, each) (Table 1).

The digital slide gallery of the virtual microscopes was organized by tissue types, organs, and organ systems. Our review found that only a handful of virtual microscopes (33%, n = 6) stored adequate content that is related to oral histology (e.g., major salivary glands, tongue, oral mucosa, and tooth development). However, only 3 (17%) had a separate dedicated section for oral histology, and one VM platform was designed only for oral histology (Table 1).

Although the VM platforms were screened for their ability to magnify digital slides, the included platforms were further evaluated for the quality of magnification. Seventeen out of 18 virtual microscopes (94%, n=17) provided a flawless magnification experience when tested with a mouse on a computer. However, only a few platforms (n=7, 39%) included dynamic scale bars with magnification capability, serving as visual indicators of the magnification level and allowing for accurate measurements and size comparisons. Identifying microanatomical structures in a

histological section is a key learning goal in teaching histology. A small group of VM platforms (17%, n=3) provided labels on the digital slides (Table 1).

Besides the key features and functionality (magnification, rotation, annotation, and labels), several VM platforms included additional tools and resources to support teaching and learning of histology. Self-assessment questions and review materials were incorporated by two platforms (11%, n=2). One platform offered annotation tools for users (6%, n=1), which can be used to temporarily mark and label digital slides to assist in teaching digital histology labs. Four platforms presented the slides in a lesson-based manner (22%, n=4) (Table 1).

DISCUSSION

Many health professional schools around the world have adopted technology to convert light microscopic specimens into digital slides so they can be shared over computer networks and display systems, aiming to reach a larger audience in a cost-effective manner.⁴¹ Magnification, the apparent size of an object compared to its actual size, is the most important feature of any microscope.⁴² Unlike in a light microscope, where magnification is manually adjusted by changing objective lenses, a virtual microscope allows for instant magnification changes with a mouse click, removing the need for additional focus adjustments. This can cause learners to be unaware of the true scale of magnification for a tissue section.⁴³ A dynamic scale bar and an image of the actual glass slide in the inset can serve as visual indicators of magnification level and help users compare the sizes between the actual and magnified specimens.

Our investigation found that only seven virtual microscopes (39%, n=7) allowed their users to rotate the digital slides freely (Table 1), indicating that this feature receives less attention in VM platform design. Studies examining strategies used by dental students to develop mental models

of tissue sections observed in a virtual microscope reported that many students found the ability to magnify and rotate digital slides seamlessly and simultaneously helpful for building their understanding of the tissue sections.⁴¹

Wide diversity has been observed among the included virtual microscopes in terms of slide description and annotation. Four platforms are designed in a lesson-based manner,^{25,28,32,37} incorporating digital slides as examples within the description, or providing learning outcomes related to the given digital slides. Many other platforms only present a collection of digital slides organized by tissue or organ types.^{24,26,29,33,35} Including a minimal description of the respective tissue section on the slide can be extremely beneficial for both learners and educators. A study exploring students' feedback on a virtual microscope of pathophysiology as a teaching tool reported students' appreciation of digital slides with annotations and suggested including more annotations in the histological slides to highlight specific tissue characteristics.⁴⁴ While annotating a large data set is a manual and time-consuming task, there have been reports on using a deep learning workflow to reduce manual annotation of virtual cardiac cells.⁴⁵ A similar machine-learning approach may be beneficial for annotating large sets of digital histology slides to improve students' learning experiences in a VM platform.

On-slide labels are another useful, but rarely found, feature within the virtual microscopes. Only three platforms^{23,30,37} identified in our web-investigation offered some sort of labels on the digital slides. While digital slides without labels accurately mimic the experience of using a real light microscope, they require close involvement of instructors to help students identify the correct microanatomical structures. Two types of labels were found to be adopted by the VM platforms: 'show/hide' labels,³⁰ where students can toggle between hiding and revealing the labels; and interactive built-in labels,^{23,37} where choosing a label automatically magnifies that specific section

of the slide. Previous studies exploring students' perceptions of using a virtual microscope reported that students find interactive labels on digital slides helpful to identify the location of a structure and self-assess their sense of orientation.⁴³

Oral histology, a specialized branch within the broader field of histology, is a fundamental area of study for dental, dental hygiene, and other oral health students. Despite its importance, our comprehensive review identified only one VM platform dedicated exclusively to oral histology. Among the additional platforms assessed, only five offered a sufficient collection of oral histology slides to adequately support a dental curriculum, and just two of these featured a distinct section for oral histology. Dental and dental hygiene students rely heavily on tissue sections to understand the microanatomy and developmental biology of the teeth, jaws, face, oral cavity, and associated structures. We encourage institutions with VM collections, especially those featuring oral histology, to embrace OER principles and continue to enhance dental education through global sharing.

We acknowledge several limitations of this project. The search was conducted using only Google search engines, and the content was limited to histology. To evaluate the magnification and other properties of the virtual microscopes, only a computer and a mouse were used. The properties and functionalities of these platforms on a touch screen, tablet, or cellphone were not explored. The origin (species) of the digital slides and the licensing or attribution requirements for using images from these open platforms were also not investigated, which could be a focus of future research.

CONCLUSION

Histology knowledge is vital across medical, dental, dental hygiene, and other health sciences. Virtual microscopes can enhance teaching and learning, but the diversity of platforms makes selecting the right tool challenging. This short communication offers a comparative analysis of active platforms, providing educators and technologists with a practical resource for adopting or developing engaging virtual microscopes.

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FIGURES AND TABLES

Figure 1. A flow diagram showing the selection process of virtual microscopes

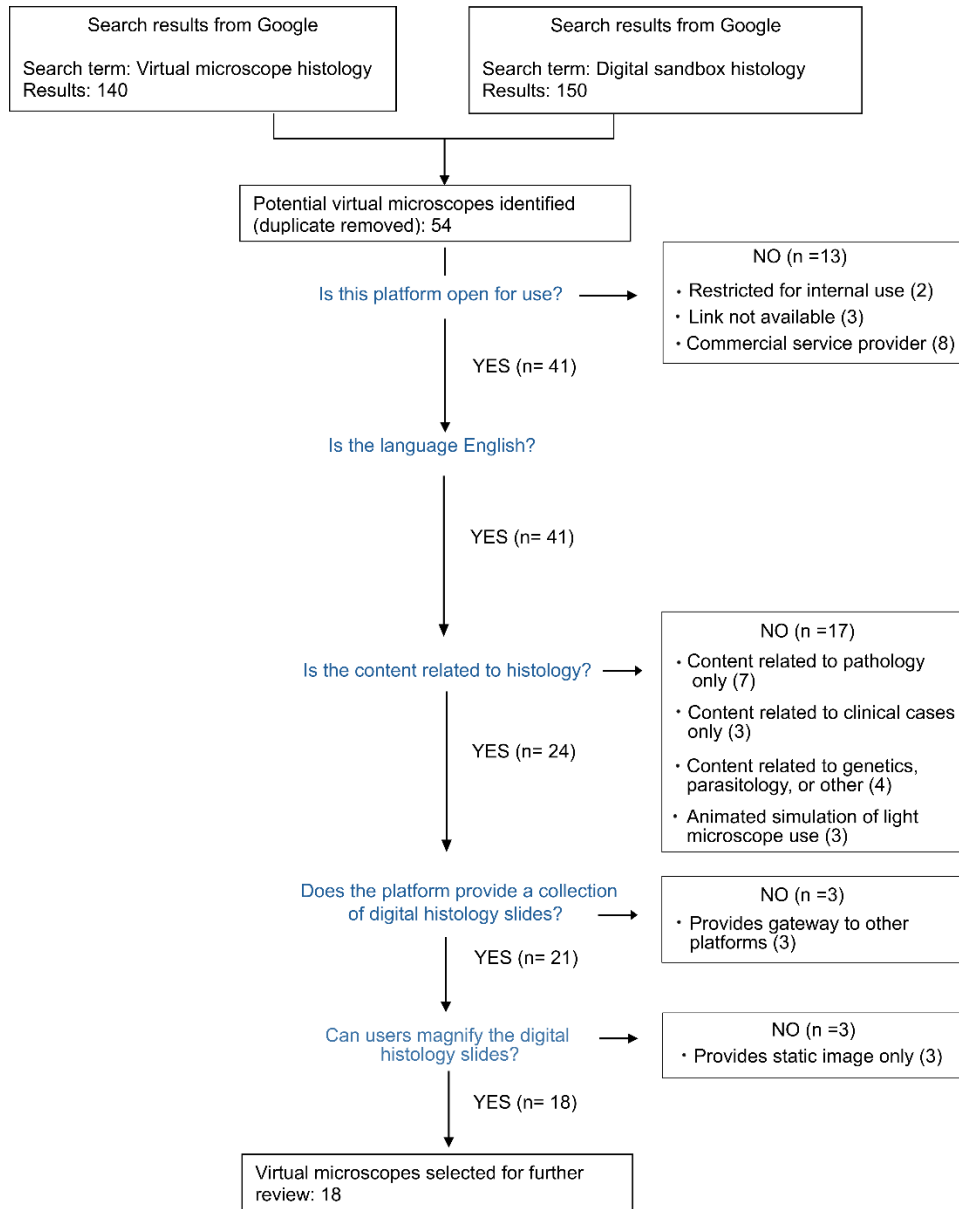


Table 1. Features of the virtual microscopes included in the short communication

Virtual Microscope Platform (With URL) [Accessed on July 31, 2025]	Content	Magnification		Can users rotate the digital slides?	Annotations and Labels		Oral Histology		Supplementary tools/resources for teaching and learning	Is the content lesson-based?
		Can users get a flawless magnification experience?	Are there dynamic scale bars?		Are there labels on the digital slides?	Is there a description of the slide content?	Is there adequate content for oral histology?	Is there a separate section for oral histology?		
Histology Guide ²³	Cells and tissues, Organ systems	YES	YES	NO	YES	YES	YES	NO	Quiz	NO
Virtual Histology ²⁴	Cells and tissues, Organ systems	YES	YES	YES	NO	NO	NO	NO	-	NO
Human Structure Virtual Histology ²⁵	Cells and tissues, Organ systems	YES	NO	YES	NO	YES	NO	NO	-	YES
The digital microscope 2.0 ²⁶	Organ systems, Pathology	YES	YES	YES	NO	NO	YES	NO	-	NO
Medical Histology and Virtual Microscopy Resources ²⁷	Cells and tissues, Organ systems, Pathology	YES	NO	YES	NO	YES	NO	NO	Annotation tools for users	NO
Michigan Histology ²⁸	Organ systems	YES	NO	NO	NO	YES	YES	YES	Review materials	YES
WSU SOM Virtual Microscopy ²⁹	Cells and tissues, Organ systems, Pathology	YES	YES	NO	NO	NO	YES	YES	-	NO
Atlas of plant and animal histology ³⁰	Cells and tissues, Organ systems	YES	NO	NO	YES	NO	NO	NO	-	NO
Self-Guided Virtual Histology Lab ³¹	Cells and tissues, Organ systems	YES	YES	YES	NO	NO	NO	NO	-	NO
Virtual Histology ³²	Cells and tissues	YES	NO	NO	NO	YES	NO	NO	-	YES
Virtual Microscope ³³	Cells and tissues, Organ systems	YES	NO	NO	NO	NO	NO	NO	-	NO

Virtual Microscope Platform (With URL) [Accessed on July 31, 2025]	Content	Magnification		Can users rotate the digital slides?	Annotations and Labels		Oral Histology		Supplementary tools/resources for teaching and learning	Is the content lesson-based?
		Can users get a flawless magnification experience?	Are there dynamic scale bars?		Are there labels on the digital slides?	Is there a description of the slide content?	Is there adequate content for oral histology?	Is there a separate section for oral histology?		
Virtual Pathology ³⁴	Tissue sections for organs, Pathology	YES	YES	YES	NO	NO	NO	NO	-	NO
IUSM Virtual Microscopy ³⁵	Tissue sections for organs	YES	NO	YES	NO	NO	NO	NO	-	NO
Virtual Histology ³⁶	Cells and tissues, Organ systems	YES	NO	NO	NO	YES	NO	NO	-	NO
Virtual Oral Histology Lab ³⁷	Oral histology	YES	NO	NO	YES	YES	YES	YES (only oral histology)	-	YES
Virtual Microscopy ³⁸	Tissue sections for organs, Pathology	YES	NO	NO	NO	NO	NO	NO	-	NO
PEIR-VM ³⁹	Tissue sections for organs, Pathology	YES	NO	NO	NO	NO	NO	NO	-	NO
HistoViewer ⁴⁰	Cells and tissues, Organ systems	NO	YES	NO	NO	NO	YES	YES	-	NO