Case Report

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Histoscope: A Web-Based Microscopy Tool for Oral Histology Education

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Objectives: Histology, the study of tissue structure under a microscope, is one of the most essential yet least engaging topics for health professional students. Understanding tissue microanatomy is crucial for students to be able to recognize cellular structures and follow disease pathogenesis. Traditional histology teaching labs rely on light microscopes and a limited array of slides, which inhibits simultaneous observation by multiple learners, and prevents in-class discussions. We have developed an interactive web-based microscopy tool called "Histoscope" for oral histology in this context. **Methods:** Good quality microscope slides were selected for digital scanning. The slides were scanned with multiple layers of z-stacking, a method of taking multiple images at different focal distances. The digital images were checked for quality and were archived on Histoscope. The slides were annotated, and self-assessment questions were prepared for the website. Interactive components were programmed on the website to mimic the experience of using a real light microscope. **Results:** This web-based tool allows users to interact with histology slides, replicating the experience of observing and manipulating a slide under a real microscope. Through this website, learners can access a broad array of digital oral histology slides and self-assessment questions. **Conclusions:** Incorporation of Histoscope in a course can shift traditional teacher-centered histology learning to a collaborative and student-centered learning environment. This platform can also provide students the flexibility to study histology at their own pace.

Keywords: Histology, Education, Web-Based Microscope, Self-Assessment, Dental Education

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I. Introduction

Histology, the study of tissue structure under a microscope, has always been the principal approach to the structural analysis of living organisms at the cellular level. Understanding tissue microanatomy is essential to train medical, dental, and other health professional students to recognize cellular structures, comprehend the structure-function relationship of cells and tissues, and follow disease pathogenesis. However, this branch of science has been described as one of the least engaging topics by health professional students [1]. The traditional method of teaching histology relies on light microscopes, which does not allow simultaneous observation by multiple people, prevents interactive in-class discussions, and thus fails to motivate students [2].

At the School of Dentistry at the University of Alberta, students extensively study oral histology to learn about teeth and surrounding oral structures, their development, and developmental anomalies. Besides regular didactic lectures, students attend histology lab sessions in which they share a limited number of light microscopes and glass slides to view tooth and oral structures. The microscopic slides used for teaching are decades old, with some being extremely rare and irreplaceable.

A growing number of universities and medical schools worldwide are embracing digital slides as an alternative to traditional light microscopes [3,4]. The incorporation of virtual microscopy in histology and pathology courses has improved in-class teaching environments [3,5] and student performance [6]. The number of websites archiving digital histology slides is also growing internationally. For example, "The SecondLook" is a collection of histology slides developed by the University of Michigan [7]. "Oral Histology" created by the University of Kentucky College of Medicine contains a collection of annotated but low-resolution images of oral histology slides [8]. However, the existing web-based histology databases lack sufficient, high-quality resources from the oral cavity, which are critical for dentistry students. Most of the publicly available histology databases provide either annotated or non-annotated images without the ability to switch from one to the other, which does not allow learners to perform active memory recall after learning. Other drawbacks of the existing virtual microscopy websites are the quality of graphical resolution [9] and lack of z-axis information, which is essential for reconstructing the three-dimensional visualization of cellular structure [10]. Moreover, in most online sources, users cannot manipulate images to observe structural details. The few websites that provide the ability to zoom in and out permit users to expand a picture only at a predefined location. The inability to magnify any region of interest limits learners' freedom to explore the histological section and restricts their curiosity, reducing the student-centeredness of their learning. Furthermore, the COVID-19 pandemic has moved most university teaching online, necessitating an alternative way to teach histology virtually yet in an interactive and engaging manner.

In this context, we have developed a web-based interactive microscopy tool called "Histoscope." We have scanned our existing oral histological slides in high resolution and archived them on our website. The site allows users to interact with the digital slides and self-assess their knowledge of oral histology.

II. Methods

1. Slide Digitalization and Organization

The School of Dentistry has a collection of oral histology glass slides to teach histology labs with light microscopes. We curated those slides for quality and rarity and selected the best slides for whole-slide scanning using an Aperio Digital Slide Scanner (Leica Biosystems, Wetzlar, Germany). We chose the slides to represent the oral mucosa, oral structures, tooth, tooth development, and facial structure development. The slides were scanned with 25 layers of z-stacking, an image-processing method of taking multiple images at different focal distances and combining them to make a composite image. This technique, also known as focus stacking, is useful for capturing in-focus images of objects under high magnification as the depth of field decreases with magnification [11].

The histology glass slides were scanned under 20× or 40× magnification depending on the specimen's size and the

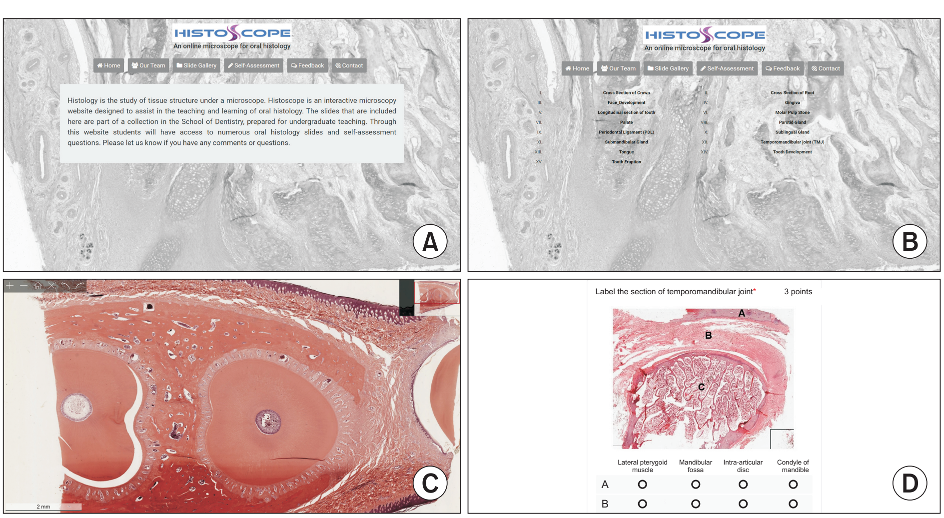

Figure 1. Snapshots from the Histoscope website. (A, B) The contents of the website are organized under six tabs. (B) Digital slides are arranged in 15 groups under the "Slide Gallery" tab. (C) Snapshot of a slide showing the cross-section of a dental root. (D) Sample question from the Self-Assessment section of the website (D).

structural details required for teaching oral histology. The slides scanned under 40× magnification has a resolution of 0.247 microns per pixel (MPP); the resolution was 0.497 MPP for the slides scanned under 20× magnification. The image bit depth was 8 bits for all the digital slides.

Digital scans of the slides were further checked for quality

Table 1. List of digital slides included in the "Slide Gallery" of Histoscope

Digital slides	Properties		
	Scanning magnification	Resolution (MPP)	Pixel dimension
Cross section of crown			
Cross section of tooth crown (incisor)	20×	0.497	17,987 × 13,230
Cross section of a tooth crown (premolar)	20×	0.497	35,975 × 28,613
Cross section of occlusal surface (molar)	20×	0.497	21,585 × 19,294
Cross section of root			
Cross section of root I	40×	0.247	37,800 × 21,881
Cross section of root II	40×	0.247	39,600 × 24,359
Cross section of root III	40×	0.247	50,399 × 28,112
Cross section of root, periodontal ligament, alveolar bone I	40×	0.247	54,000 × 49,764
Cross section of root, periodontal ligament, alveolar bone II	40×	0.247	52,199 × 33,395
Cross section of root, periodontal ligament, alveolar bone III	40×	0.247	50,399 × 39,356
Face development			
Cross section of embryo head (day 23)	20×	0.497	8,993 × 9,648
Cross section of embryo head (developing tongue, palate) I	20×	0.497	10,792 × 13,916
Cross section of embryo head (developing tongue, palate) II	20×	0.497	10,972 × 13,919
Cross section of embryo head (developing tongue, palate) III	20×	0.497	12,591 × 15,064
Cross section of embryo head (developing tongue, palate) IV	20×	0.497	10,792 × 15,729
Cross section of embryo head (face development) I	20×	0.497	21,585 × 13,619
Cross section of embryo head (face development) II	20×	0.497	21,585 × 13,045
Gingiva			
Longitudinal section of tooth, gingiva I	20×	0.497	55,762 × 28,349
Longitudinal section of tooth, gingiva II	20×	0.497	52,164 × 28,198
Longitudinal section of tooth, gingiva III	20×	0.497	57,561 × 25,626
Longitudinal tooth section			
Longitudinal ground section of tooth I	20×	0.497	34,176 × 15,701
Longitudinal ground section of tooth II	20×	0.497	41,372 × 19,779
Oblique section of tooth	20×	0.497	26,981 × 20,181
Longitudinal ground section of tooth III	20×	0.497	34,176 × 18,663
Pulp stone			
Tooth cross section with pulp stone I	40×	0.247	48,600 × 33,743
Tooth cross section with pulp stone II	40×	0.247	66,599 × 47,051
Palate			
Anterior palate I	40×	0.247	28,800 × 78,829
Anterior palate II	40×	0.247	28,800 × 78,830
Anterior palate III	40×	0.247	23,400 × 78,854
Anterior palate IV	40×	0.247	23,400 × 78,856

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Table 1. Continued 1

Digital slides	Properties		
	Scanning magnification	Resolution (MPP)	Pixel dimension
Parotid gland			
Cross section of parotid gland I	20×	0.497	34,176 × 17,838
Cross section of parotid gland II	40×	0.247	72,000 × 35,946
Cross section of parotid gland III	40×	0.247	75,600 × 29,470
Cross section of parotid gland IV	40×	0.247	63,000 × 27,881
Cross section of parotid gland V	40×	0.247	54,000 × 37,850
Periodontal ligament			
Cross section of root, periodontal ligament, alveolar bone I	40×	0.247	54,000 × 49,764
Cross section of root, periodontal ligament, alveolar bone II	40×	0.247	52,199 × 33,395
Cross section of root, periodontal ligament, alveolar bone III	40×	0.247	50,399 × 39,356
Sublingual gland			
Cross section of sublingual gland I	40×	0.247	59,399 × 50,399
Cross section of sublingual gland II	40×	0.247	52,199 × 50,928
Cross section of sublingual gland III	40×	0.247	52,199 × 51,262
Submandibular gland			
Cross section of submandibular gland I	40×	0.247	46,800 × 40,366
Cross section of submandibular gland II	40×	0.247	50,399 × 52,758
Cross section of submandibular gland III	40×	0.247	55,800 × 46,282
Temporomandibular joint (TMJ)			
Cross section of adult TMJ I	20×	0.497	39,573 × 38,056
Cross section of adult TMJ II	20×	0.497	41,372 × 40,021
Cross section of adult TMJ III	20×	0.497	46,768 × 37,196
Cross section of adult TMJ IV	20×	0.497	44,969 × 39,758
Tongue			
Cross section of tongue I	20×	0.497	23,384 × 28,673
Cross section of tongue II	20×	0.497	23,384 × 29,572
Cross section of tongue III	20×	0.497	26,981 × 25,530
Cross section of tongue IV	20×	0.497	25,183 × 21,910
Cross section of tongue V	20×	0.497	23,384 × 28,255
Cross section of tongue VI	40×	0.247	48,600 × 57,230
Cross section of tongue VII	20×	0.497	35,975 × 18,656
Cross section of tongue VIII	20×	0.497	34,167 × 16,192
Cross section of tongue IX	20×	0.497	34,167 × 22,859

and resolution, organized in groups, annotated, and archived on the Histoscope website under the Slide Gallery tab (Figure 1). Currently, the website contains 76 digital slides representing teeth and surrounding oral structures.

2. Self-Assessment Question Preparation

We prepared a series of questions (Figure 1D) which were incorporated into the website under the Self-Assessment tab. The questions are grouped to correspond to the Slide Gallery organization, so students can choose to test their knowledge of a specific area of the oral cavity. Currently, we have 35 image-labeling and structure-identification questions on our website, which are randomized each time a user takes the test.

Table 1. Continued 2

Digital slides	Properties		
	Scanning magnification	Resolution (MPP)	Pixel dimension
Tooth development			
Developing tooth germ I	20×	0.497	19,786 × 28,606
Developing tooth germ II	20×	0.497	21,585 × 30,655
Bell stage of tooth development I	20×	0.497	21,585 × 42,668
Bell stage of tooth development II	20×	0.497	43,170 × 24,872
Bell stage of tooth development III	20×	0.497	23,384 × 39,290
Bell stage of tooth development IV	20×	0.497	26,981 × 44,779
Bell stage of tooth development V	20×	0.497	23,384 × 41,182
Bell stage of tooth development VI	20×	0.497	19,786 × 29,511
Tooth eruption			
Cross section of erupting tooth I	20×	0.497	26,981 × 27,831
Cross section of erupting tooth II	20×	0.497	30,579 × 26,829
Cross section of erupting tooth III	20×	0.497	30,579 × 24,025
Cross section of erupting tooth IV	20×	0.497	30,579 × 26,253
Cross section of erupting tooth V	20×	0.497	41,372 × 27,757
Cross section of erupting tooth VI	20×	0.497	41,372 × 27,758
Cross section of erupting tooth VII	20×	0.497	39,573 × 29,828
Cross section of erupting tooth VIII	20×	0.497	39,573 × 29,826
Cross section of erupting tooth IX	20×	0.497	37,774 × 21,687
Cross section of erupting tooth X	20×	0.497	35,975 × 22,846
Cross section of erupting tooth XI	20×	0.497	39,573 × 34,683
Cross section of erupting tooth XII	20×	0.497	41,372 × 32,695

3. Design and Layout of the Website

We aimed for a simple, responsive design with a minimum number of tabs and minimal text for easy navigation. For structural consistency, the title "Histoscope" and the background frame are kept visible on all pages (Figure 1A, 1B). The colors of the headings, tabs, and background were chosen for aesthetic harmony. The contents of the website are organized under six tabs. Digital slides are arranged in fifteen groups under the Slide Gallery tab (Figure 1A, 1B, Table 1). The Self-Assessment tab guides users to a series of questions to test their oral histology knowledge. The website also has an option for users to contact the authors and provide feedback for further improvement (Figure 1A).

4. Incorporation of Interactive Components

We designed Histoscope as an interactive microscopy tool. This interface's primary goal is to mimic the experience of viewing slides through a real light microscope with the ability to manipulate and view various areas of the histological section, which is rare in the existing online histology databases. Our website was programmed with the Python programming language and uses Flask as a web framework, resulting in a dynamic platform capable of processing user requests and interacting with them accordingly. Users can load a digital slide of their choice in high resolution, rotate the slides as needed, toggle to full screen, and change the magnification in any mouse-pointed location. The digital slides on our website were scanned using the z-stacking technique to provide continuous z-axis information. Z-stacking allows for a greater depth of field and a unique ability to magnify a digital image at any given area and maintain a perfectly focused, high-resolution field-of-view (Figure 2). The slide viewer of the website provides an inset telescope box on the upper-right corner of the screen. When zooming in on fields of view, the inset shows a box outlined in red, delineating the exact position of the area being viewed

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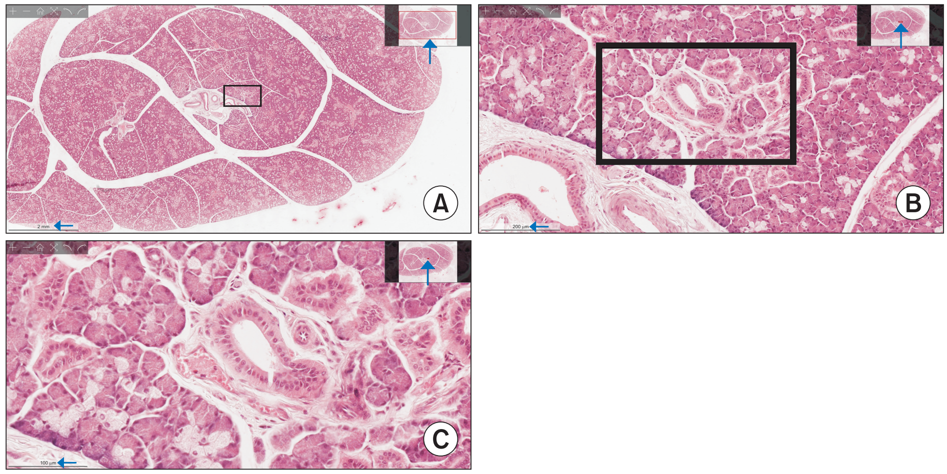

Figure 2. Application of z-stacking to provide in-focus images in high magnification. The slide collection of Histoscope was scanned using the z-stacking technique to allow the ability to magnify the digital slides and still get an entirely focused, high-resolution field-of-view. (A–C) A tissue section of a salivary gland, gradually magnified from low (A) to higher (B, C) magnification. The red box in the inset of each slide indicates the viewing area (arrow) and the scale bar at the bottom left shows the degree of magnification of the slide (arrow). The black box in the middle indicates the area that was being magnified. As the slides are viewed under higher magnification, the scale bar changes (from 2 mm to 100 μm), and the red box in the inset becomes smaller. Z-stacking enables the user to observe structural details under a higher magnification, mimicking the experience of using a light microscope.

on-screen with respect to the entire viewable field (Figure 2). After magnification, the user can navigate the magnified slide by grabbing the slide with a hand tool or by simply moving the red box in the inset (Figure 3). The slides are annotated by content experts to identify major structural components within a tissue section. Users can either "show" or "hide" the annotations, which allows them to self-test their learning (Figures 1C, 3).

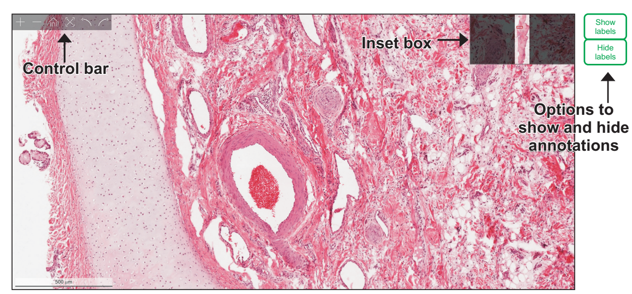

Figure 3. Snapshot from the slide viewer of Histoscope. The user can activate the inset box on the upper-right corner of the slide viewer simply by the mouse pointer's motion. While zooming in, the inset shows a box outlined in red, delineating the exact position of the area being viewed on-screen with respect to the entire viewable field. The control bar in the upper-left corner allows the user the zoom in, zoom out, rotate, and toggle to full-screen mood. "Show Labels" and "Hide Labels" allow users to show or hide the slide annotations.

III. Results

The completed website includes 76 high-quality and rare sections of the tooth, oral structures, and development of tooth and facial regions, which are not readily available in any public online databases. A complete list of all the digital slides incorporated into our slide gallery is shown in Table 1. The digital images were scanned using a focus stacking technology to mimic the experience of focusing through a real light microscope (Figure 2). We have included an option to show or hide annotations to enable users to perform active memory recall (Figure 3). Self-assessment questions on our website allow learners to self-test their knowledge on oral histology (Figure 1).

IV. Discussion

Computer-based technologies to teach histology have increased over the years [3,12,13]. Virtual microscopy has improved learners' performance in many training programs [3,5,14]. Some known limitations of this technology are low graphics resolution and lack of z-axis information [9,10]. With Histoscope, we aimed to overcome the shortcomings of previous virtual histology databases and to create an interactive and dynamic platform to mimic the experience of using an actual light microscope. The incorporation of our web-based microscope will stimulate active learning and student engagement. Educational theories suggest that adults learn proficiently when they are fully engaged in learning [15]. Active engagement also helps develop critical thinking skills in adults [16]. The use of web-based microscopy in conjunction with an actual light microscope is supported by Mayer's cognitive theory of multimedia learning, which states that using two or more of each of the modalities of delivery, presentation, and sensory systems will support effective learning [17]. We believe that Histoscope will complement traditional teaching with the light microscope and allow students to study histology at their own pace.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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