UniTwain: A Cost-Effective Solution for Lean Gross Imaging

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Abstract

Background: Gross imaging of surgical specimens is paramount for the accurate gross examination and diagnosis of disease. Optimized imaging workflow can facilitate consistently high-quality gross photographs, especially in high-volume, metropolitan hospitals such as ours. Most commercial medical gross imaging technology provides ergonomically well-designed hardware, remotely operated cameras, intuitive software interfaces, and automation of workflow. However, these solutions are usually cost-prohibitive and require a large sum of capital budget. **Materials and Methods:** We applied lean techniques such as value stream mapping (VSM) to design a streamlined and error-free workflow for gross imaging process. We implemented a cost-effective technology, UniTwain, combined with high-resolution webcam to achieve the ideal results. **Results:** We reduced the mean process time from 600 min to 4.0 min (99.3% decrease in duration); the median process time was reduced from 580 min to 3.0 min. The process efficiency increased from 20% to 100%. The implemented solution has a comparable durability, scalability, and archiving feasibility to commercial medical imaging systems and costs four times less. The only limitations are manual operation of the webcam and lower resolution. The webcam sensors have 8.2 megapixel (MP) resolution, approximately 12 MP less than medical imaging devices. However, we believe that this difference is not visually significant and the effect on gross diagnosis with the naked eye is minimal. **Conclusions:** To our knowledge, this is the first study that utilized UniTwain as a viable, low-cost solution to streamline the gross imaging workflow. The UniTwain combined with high-resolution webcam could be a suitable alternative for our institution that does not plan to heavily invest in medical imaging.

Keywords: Gross imaging, lean, TWAIN, UniTwain

Introduction

Gross specimen photography is a crucial component of anatomic pathology practice and often essential for accurate interpretation of microscopic images. Thus, acquisition of high-quality images, appropriate metadata, and easy access and retrieval at a multidisciplinary level, is a significant part of patient-centered health care.[1] Pathology departments use various systems to integrate image acquisition, storage, and retrieval into a deliberately designed and streamlined workflow to expedite gross image review. Consumer-type digital cameras are widely used in pathology laboratories to capture gross images of specimens and document significant findings.[2] Many of these cameras prove too delicate to be used daily in a busy anatomic pathology laboratory or are ergonomically intrusive to the process of specimen grossing. Image files are manually relabeled to the appropriate case number and stored, in batches, on a shared drive accessible to medical staff and referenced during case finalization.

However, transferring hundreds of files from a digital camera to a shared drive is a labor-intensive process, and saving files on a shared drive alone has limited capabilities for image integration with anatomic pathology laboratory information systems (AP-LISs). These flaws result in significant amounts of time spent on nonproductive tasks, such as waiting for files to copy, or retrieving mislabeled files during times of high specimen volume. Furthermore, scaling up and maintaining the archiving system presents challenges in personnel requirements and data integrity. A higher volume of photos would require more manual labor to transfer, relabel, and archive image files and thus more opportunities for mislabeling or misplacement

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of data. Finally, there is a lack of available data on quality standards for gross specimen photographs.[3] The ever-evolving field of digital photography and increasing number of options of consumer digital cameras make it difficult to ascertain what image file characteristics produced by these devices matter most for accurate and timely diagnosis.

We applied lean principles to our gross specimen photography workflow with the goals of defining acceptable image quality standards, improving image acquisition and case association times, and increasing accessibility of images. Proposed solutions required a combination of software, to address image data integrity and accessibility, and hardware, to address image quality standards and ergonomics. We aim to describe the defined image quality standards for gross photographs and show how lean techniques such as value stream mapping (VSM) can be used, as a process improvement initiative, in developing a cost-effective solution to streamline gross imaging workflow.

Literature review

Lean industrial production principles were originally developed by Toyota to eliminate manufacturing inefficiencies, subsequently popularized by Womack and Jones, and shown to be applicable to a variety of fields, including pathology.[4-6] Lean principles involve defining value, or the customer's need for a specific product, and mapping the value stream, or all processes involved in delivering a final product from its raw materials. The next steps are identifying key steps in the current workflow, recognizing areas of improvement or wasteful steps, and testing proposed solutions.[5,7] Current-state workflow is modeled using a VSM, which defines the start and end points for a product or service and classifies the steps in between as either value adding or nonvalue adding. Briefly, value-adding processes are those for which a customer is willing to pay, and which change the shape, form, or function of a product. By contrast, nonvalue-adding processes are those which do not change a product in meaningful ways; the time spent waiting for a gross photograph to be transferred from one storage device to another does not contribute to its functional value. Nonvalue-adding activity can be further categorized into two types. Not necessary nonvalue-added activities consume resources but create no value in the eyes of the customer. These activities are pure waste. If the activity cannot be eliminated, it becomes a necessary nonvalue-added activity, which is required in order for a system to operate but add no value from the customer's perspective. Waste can be defined as time wasted waiting between or during steps, defects in a finished product, or poor quality of a product. A summary important concept in lean principles is provided in Table 1.

MATERIALS AND METHODS

Setting

Our institution, to the author's knowledge, is the largest pathology laboratory in the Northeast United States and thus values both efficiency and accuracy when processing and evaluating surgical specimens. We process over 54,000 surgical cases per year and a total of 100,221 specimens with a steady 4% increase in annual caseload in the past 2–3 years. We approximately capture 23,0000 images every year. Our grossing laboratory is 400 square feet and maintains 11 grossing workstations. All grossing workstations and laboratory staff workstations are equipped with Dell P2213 (Round Rock, TX, USA, 2013) computer monitors, which display images and text at 1680 × 1050 pixels across a diagonal length of 22 inches, or 90 pixels per inch (ppi). All workstations run using the Windows 10 operating system and Power Path (v. 10.3.2.27, Sunquest, Tucson, AZ, USA) as the AP-LIS.

Study design

We established value as obtaining a high-resolution image compliant with defined standards, which would be easily integrated into a corresponding pathology report in the AP-LIS with zero error and minimal amount of manual work. We then applied a VSM to define our current-state workflow and illustrate all activities required to capture a gross image and deliver it to a pathologist. Next, we identified value-adding and wasteful steps and sought software and hardware solutions to address areas of waste. Finally, we created a future-state VSM to evaluate our improvements how well our proposed solution satisfied the original goals.

Defining an image quality standard

Image quality standards for gross specimen photography were defined through extensive literature search using search terms: pathology, gross, specimen, photography, image, quality, and standards.

Proposed solutions

We sought both software and hardware components that would fulfill our requirements for a new workflow solution and improve our process cycle time. We searched for software by consulting our department's AP-LIS team and through standard Internet search, using both search engines and user forums. We searched for hardware through consultation with major electronic store managers, specialty photography store managers, and standard Internet search. We compared multiple hardware options using cost, image capture resolution, power source, and convenience of use as measures, before choosing one to use in a future-state workflow model.

Value stream mapping for future-state workflow

We documented the VSM for our proposed future-state workflow by implementing our software and hardware solutions at a single laboratory workstation, and observing media supervisors, pathology residents, and pathology attendings, starting from specimen accession and ending with to delivery of a gross specimen image to a pathologist during case preview and sign-out. A new process cycle efficiency was calculated by dividing the time spent on value-adding activities by the total process time.

RESULTS

Defining our imaging quality standard

Despite a thorough literature search to determine image resolution requirements, we could not find an established

Table 1: Lean Principles Key Definitions

Lean Principle Key Terms:	Definitions
Value-added activity	Activities in the workflow process for which a customer is willing to pay. For instance, diners are willing to pay for a chef to prepare their meal (however, they are not willing to pay the chef twice if the chef makes a mistake the first time, nor are they willing to pay more the longer they have to wait for their meal).
Non-value-added activity	An activity for which a customer is not willing to pay. This type of activity is typically classified as one of the 7 types of waste per the Lean management system.
Necessary non-value added activity	Required in order for a system to operate, but add no value from the customer's perspective.
Not-necessary non-value-added activity	Consumes resources but create no value in the eyes of the customer.
Waste	Any element or by-product of the workflow that does not add value to a process, from the perspective of the customer. The Lean management system commonly classifies waste into 7 categories: transportation (movement of items), inventory (items waiting to be used), motion (movement of individuals), waiting (individuals waiting to do something), overproduction (making more of something than is needed), over processing (working harder than is needed to produce something), and defects (processes that need to be reperformed).
Process-cycle efficiency	This parameter, which measures what percentage of a process is considered to constitute value-added activity, is calculated by dividing the total value-added time in a process by the total process time. Perfect efficiency (100% process cycle efficiency) is the goal, although that is virtually impossible to achieve.

standard for the resolution of digital gross images. A few articles stated a required resolution of 3–5 megapixels (MPs). Most medical imaging vendors offer cameras with 20 MP resolution. There has been a huge increase in the resolution of consumer-type cameras in the last few years ranging from 41 MP camera phones to 61 MP digital single-lens reflex cameras.[8,9] However, it is unclear how high of a resolution value is required for digital gross imaging.

For publication purposes, the print standard is 300 dots per inch (dpi).[10] If we use photo dimensions of 8 × 10 inches, both on screen and in print, as standard viewing size, which necessitates that gross photos be captured at the resolutions of at least 900 × 720 pixels for screen viewing, and 3000 × 2400 pixels for print (one pixel per print dot). Thus, we ultimately used the high-resolution requirement as our image capture standard, which is 3000 × 2400 pixels, or 7.2 MPs.

Furthermore, there are a number of other factors that contribute to overall digital image quality, which include contrast, low-light image capturing capabilities, and whether a camera employs optical or digital zoom. Many of these factors are inherent to the light sensor built into the digital camera, or the camera's internal processing unit.[11]

Current-state workflow

The gross images were captured in a point-and-shoot fashion using two entry-level handheld digital cameras, Nikon Coolpix W100 (Tokyo, Japan, 2016), at resolutions of 8.2 MPs, which require removable memory cards and rechargeable batteries. The cameras were shared among seven different prosectors during grossing. The specimen number was written on a disposable ruler and placed adjacent to the specimen in the gross image. This number was the only case identifier used for subsequent manual relabeling, sorting, and archiving of image files. The digital image was saved into a compact memory card in standard Joint Photographic Experts Group format, and a random number assigned to the file by the digital camera. The media supervisor would collect the memory cards and copy their contents entirely to the shared network drive using

a different workstation at the end of the working day. During this process, the media supervisor read the number on the ruler in each photo, manually created a folder corresponding to the written case number, and transferred all images showing the same case number into their corresponding folder using the drag and drop function. Individual image files in each folder were not further labeled or specified, and pathologists accessing these images could not quickly find pictures for a particular section or part of a case. After transferring images, the supervisor would delete all data on each memory card and place the cards back into the cameras. During case review, pathologists and residents browsed through the image folders in the shared drive to view gross photographs while concurrently navigating the laboratory information system, as shown in Figure 1. In 2018–2019, the total number of gross specimen images captured, manually relabeled, and saved on the shared drive was 22,217. There were 6,750 new folders created to sort these images. A total of 34.8 gigabytes of hard drive memory were required for storage.

There were various areas of improvement identified using our VSM, as shown in Figure 2. Notably, the limited number of functioning cameras led to unnecessary movement and wait times, as prosectors often left their stations to search for an available camera, which usually was located across the room. The cameras also frequently contained depleted batteries, requiring time spent retrieving a spare replacement battery. Concurrently, other prosectors often had to walk around the laboratory to find grossing equipment, which represented a potential safety hazard, especially during times of high specimen volume in a crowded gross room. These additional movements, by lean principles, represent the wasteful activities of motion and wait. Furthermore, these unnecessary movements in an already limited space with sharp objects and biohazardous chemicals caused concern for employee safety regarding potential injury and toxin exposure. The image relabeling and transferring process took a lot of time and comprised the main nonvalue-adding activity in the imaging process. Furthermore, manually relabeling images during times of high specimen and
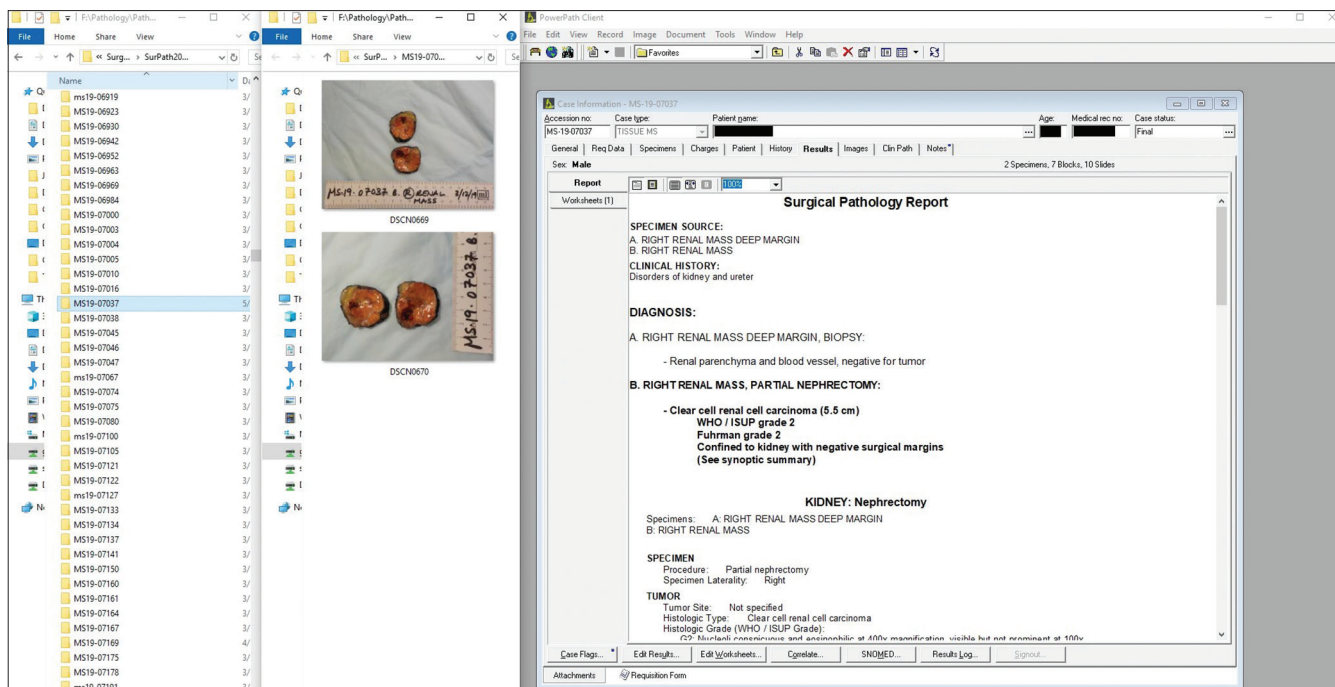
Figure 1: A technician manually creates folders in a shared drive corresponding to each case number, and sorts image files from the camera memory card into these folders using a ruler in each photograph, which is labeled with the case number and specimen type. Pathologists were required to access this shared drive while also navigating the LIS during case sign-out. LIS: laboratory information system
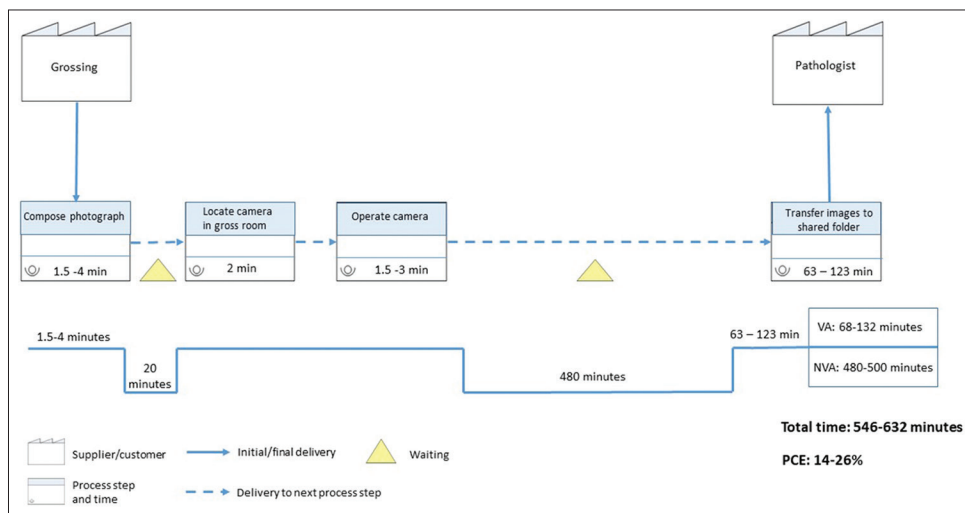

Figure 2: Value-stream map for image documentation before process improvement. The previous process had a total time of 480-500 minutes, of which 68-132 minutes were non-value-added time. VA indicates value-added activities; NVA, non-value-added activities; PCE, process-cycle efficiency

image capture volumes increased the risk of mislabeling or misplacing image files on the shared drive. Another issue was the complexity of retrieval and review of images at the time of sign-out. The pathologists were unable to reference the photos directly in the LIS. They had to open the directory and browse through the folders to find the corresponding images.

Figure 2 illustrates the value-stream map for the preimplementation state showing the total processing time 546–632 min, 500 of which were not necessary nonvalue-added activities or waste. The major waste was the 8 h (or 480 min) waiting time for manual extraction of images from memory card. This translated to process cycle efficiency of 14%–26%, meaning that 74%–86% of the entire process time consisted of nonvalue-added activities.

Proposed solution requirements

We established the following requirements when considering solutions to address areas of improvement identified on our current-state VSM:

1. Imaging devices should be provided at each station – prosectors should not be required to search for

available cameras in the gross laboratory

2. Elimination of the manual work required to relabel images – images should be automatically saved and associated with corresponding case numbers assigned in AP-LIS at the time of image capture

3. Streamlined image retrieval process for fast reference at the time of sign-out-real-time integration of the captured image to the corresponding case in AP-LIS.

In addition, the preservation of image resolution and quality would facilitate accurate interpretation of gross findings, provide viewable attachments on reports released to clinicians, and aid potential scholarly contributions. Based on the above requirements, we selected the following solutions for software and hardware components of our future process design.

Software solution

Most current AP laboratory information systems in the market include a native image import and database storage function, called TWAIN. TWAIN is a data handling standard that was developed in the early 1990s to facilitate communication between scanners and software used in personal computers, much like how HTTP is a standard for how data are transmitted across the Internet for communication between computers. Thus, we required software that could interface directly with our AP-LIS's image import function using a TWAIN protocol and would act as a data bridge between an image capture device and the AP-LIS case editor.

UniTwain (Terminal Works Ltd., Rijeka, Croatia) fulfilled our software requirements and presented an elegant solution for our future workflow. [12] UniTwain, as the title describes, stands for universal TWAIN driver. UniTwain is created using the Microsoft .NET framework, and it is HIPPA compliant for use in medical environments. UniTwain uses the Advanced Encryption Standard, 128-bit encryption, for data protection.

UniTwain is a software that allows users to create a TWAIN data connection between specific archiving programs, such as TWAIN-compliant AP-LIS, and image capture devices, such as digital cameras. In other words, UniTwain applies the TWAIN data protocol to image data acquired from any compatible camera and, in real time, sends it to any computer program

that handles image files. In our case, we installed UniTwain and specified our AP-LIS as the application to which image files would be sent. After this initial specification, our AP-LIS recognized "UniTwain" as the mode through which images would be imported, without having to open the UniTwain application again, and the UniTwain application functions could be accessed directly from our AP-LIS during gross dictation. Moreover, this helped limit our hardware search to TWAIN-compliant cameras and devices.

The different ways of importing image files using UniTwain can best be described by going through various modules included in the software:

Camera module

This module checks the PC for all available cameras using a wired, such as a USB cable. The devices can vary from simple webcams, security cameras, and high-resolution fixed cameras to specialized probes used by dentists. As such, this module exhibits many use case scenarios, particularly in the medical and law enforcement fields (e.g., mug shots). Users can capture images with ease and access camera settings to adjust image resolution directly from the UniTwain application, as demonstrated in Figure 3. In summary, the camera module allows capturing images by any compatible camera device and importing the images to any TWAIN-compliant database program.

Mobile module

This module enables users to capture images from mobile phones, wirelessly, using a TWAIN protocol. The only requirements are that the mobile phone should have the UniTwain app installed and be connected to the same WiFi network as the workstation running UniTwain. The mobile app supports both iOS and android operating systems and is simple to navigate. The captured images are transferred directly to the LIS application without being saved in the mobile devices for compliance with HIPAA. This module represents an ideal solution for imaging large specimens and autopsies, which are hard to move and position for photography from different angles.

In addition to the above modules, UniTwain has an editor function, which displays a simple interface with basic image

Table 2: Comparison of Imaging Devices

| Imaging Options	Cost:	Image Capture Resolution	Power Supply	Ergonomics:	TWAIN Compliant
Logitech BRIO Webcam	$223.98	8.3 MP	Continuous	Compose and capture image by manipulating the flexible mounting arm, controlling camera functions from workstation.	YES
Apple iPhone	$749.00	12 MP	24+hrs.	Flexible mounting arm that was able to support the relatively lightweight webcam was unable to support the weight of the iPhone.	YES
Nikon Coolpix W100	$182.97 ($20,000 labor cost for maintaining archival system)	13.2 MP	8 hrs.	Handheld camera that required additional personnel to create and maintain a separate gross image database in a shared network drive.	No
SPOT Gross Imaging	$20,000 per station	20 MP	Continuous	Overhead camera that could be remotely controlled from the workstation computer and interfaced with a proprietary image capture and archiving laboratory information system.	No
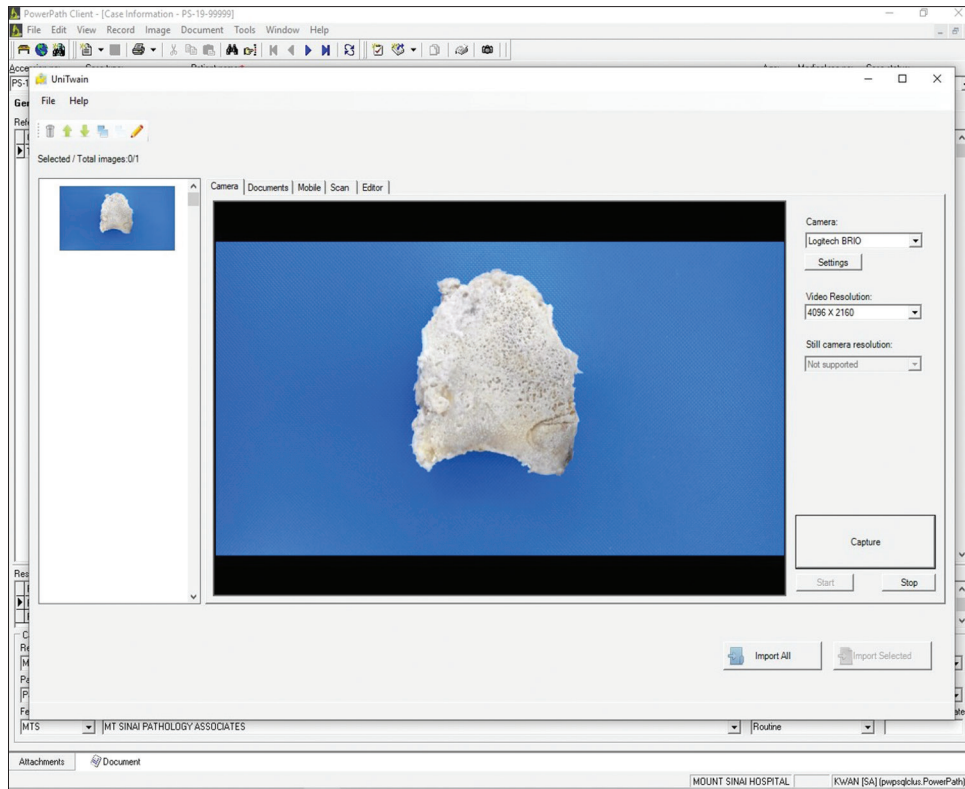
Figure 3: The UniTwain Camera module can be accessed directly from the LIS during gross specimen dictation, with real time control over the camera's functions, including resolution specification, and image capture
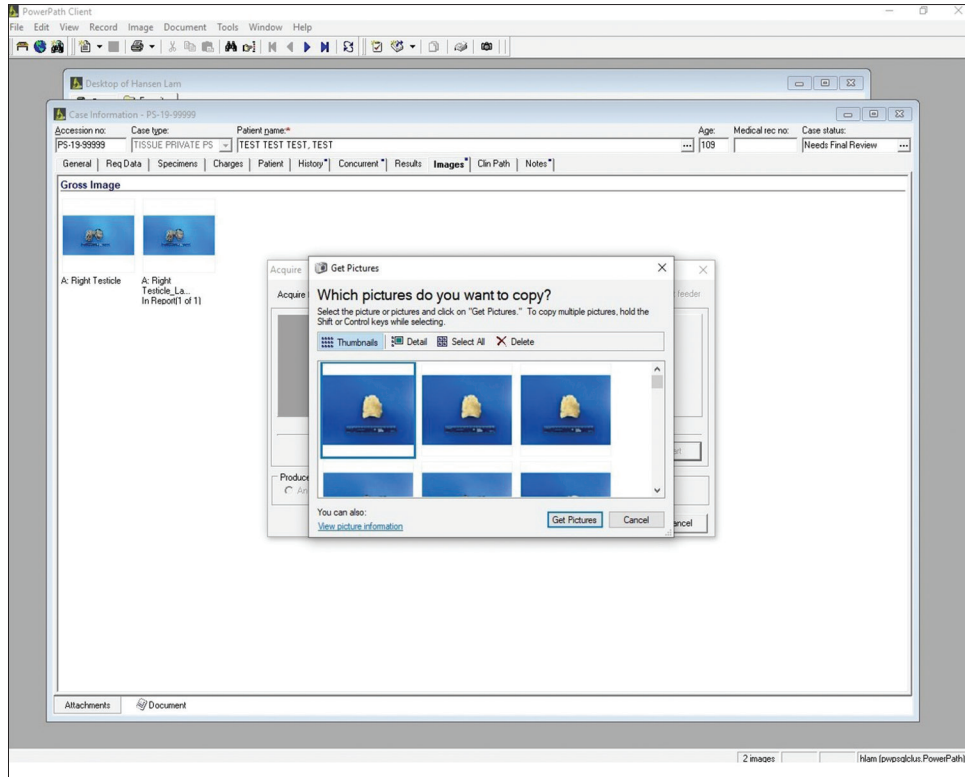

Figure 4: User is able to select which captured images to save to the case record for future access. These images are automatically assigned the same case number as that being dictated, and users can specify specimen type before saving

correction options. Before images are saved to the AP-LIS, all captured images are presented to the user to allow editing and selection of which images should be saved or discarded. The saved images are then automatically labeled with the case and specimen number of the open case in the AP-LIS, and the user can edit the title of each image to indicate what viewers should focus on. A useful preview section is also available to allow users to verify that taken images are correct before uploading to the AP-LIS, as demonstrated in Figure 4.

Hardware solutions

We required an image capture device that was TWAIN-compliant, lightweight and easily maneuverable for photography, capable of high-resolution image capture, able to be implemented at every prosector's workstation, and powered by a durable source. These features would keep interruption of gross specimen dissection at a minimum while reducing unnecessary movement in the grossing room. A table summarizing our hardware option comparison, using cost, image resolution, power source, and ease of use, is included in Table 2.

After careful review of a plethora of available options and consultations with photography experts, we selected the BRIO webcam (Logitech, PN 960-001105).

Cost analysis

Table 3 demonstrates the cost comparison among different imaging devices, including the cost of purchase, installation, disk, and network monitoring and the maintenance of the interface and archival system.

We used full-time equivalent to calculate the personnel cost of maintaining the archival system in a consumer-type camera solution. Approximately 2 h was spent each day to do the manual labeling of each image file and creating an individual folder pertaining to the case number in the shared drive.

2 (hours per day) × 5 (working days per week) × 52 (week per year) = 520 h per year.

520/8 h per working day = 65 working days.

In other words, a full-time employee devotes 65 working pay-days to performing the manual work of maintaining the archival system, which translates to an approximately $20,000 per year cost.

The commercial medical gross imaging systems are usually entire hooded grossing workstation custom built with an overhead camera that could be remotely controlled from the workstation computer and interfaced with an archiving system.[13,14] This would replace a hooded grossing station in a pathology laboratory and cost approximately $20,000 per station, with additional maintenance and support fees.

The consumer-type digital camera appeared to be the most inexpensive hardware solution. However, this approach also held the highest cost in terms of development and maintenance of a separate archival system. When considering the total cost of purchasing the hardware, and implementing and maintaining an image management system, the webcam paired with UniTwain was the most cost-effective solution.

Future-state value stream mapping

Images were captured by first selecting the image import function in the AP-LIS during case gross dictation, which automatically recognized the Logitech BRIO webcam through UniTwain. The prosector could then briefly manipulate the webcam mounting arm, using the live view from the AP-LIS, to compose the desired image, and capture images from the AP-LIS at the click of a button. Images were imported into the AP-LIS within seconds, automatically saved to the correct case and specimen number, and shown to the prosector for confirmation. The prosector then had the option of creating digital markups to highlight important gross findings or features, using features inherent in the AP-LIS. The prosector could continue with gross dictation, uninterrupted, and upon completion, no additional work had to be done to transfer or relabel image files. During case preview or sign-out, only image files associated with a particular case were displayed using large thumbnails in the AP-LIS image tab and could be viewed with ease if gross findings needed to be referenced.

Implementation of the proposed future workflow using the webcam and UniTwain software resulted in a decrease of repetitive movements, time spent transferring and sorting images, and potential for injury during specimen grossing. The redesigned workflow allowed a webcam to be placed at every workstation using a flexible mounting arm [Figure 5], with one end clamped onto a free surface at the grossing station and the other arm fastened to the webcam. The UniTwain software was installed on individual computers at each grossing station. The webcam was connected directly to the workstation computer via USB 3.0 cable and mounted to the workbench

Table 3: Cost comparison of common technology approaches for pathology gross imaging management

|	Webcam	Consumer digital camera	Medical imaging vendors
Hardware	Webcam $178 Mounting holders $28 Card $13	Camera x 2~ $200 Flash Memory Cards (128 MB) $50	Camera with rail and foot switch
Total hardware cost	$219 x11=$2409	$250	$15000 x11 =$165,000
Annual cost of maintenance			
image archival	0	65 working days/year =$20,000/year	0
LIS interface	$199 x11= $2189	0	LIS vendor: $1100-$1500 Imaging vendor: $6000-$27000
Total	$4598	$20,250	$172,000-193,500
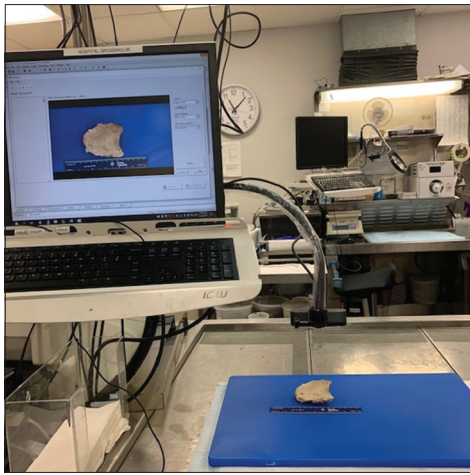
Figure 5: UniTwain interfaces directly with the AP-LIS to allow real time view of specimens from the workstation before image capture

in a nonobstructive manner. Prosectors were now able to take specimen photographs at any time during grossing without moving away from their stations. They could control the webcam directly from the AP-LIS [Figure 6] while completing gross dictation. Labeling rulers were replaced with re-usable plastic rulers that demonstrated scaled in each photograph, and specimen identifiers were created within the AP-LIS for each photo as it was taken and saved to the case. Prosectors found that an LED ring light, already present at every grossing station, could be clamped onto the same end as the webcam in such a way where it would always be projecting light from behind the camera and could be easily turned on or off by the flip of a switch [Figure 7]. The media supervisor no longer needed to retrieve memory cards, transfer image files, and interpret labeled rulers to sort photographs. Our AP-LIS also had native support for image annotation by prosectors, allowing them to denote areas of interest on images before saving. Furthermore, pathologists and residents were able to view specimen images within the LIS during case finalization and sign-out, with the option of including specific images on the final report for reference by clinicians. Finally, image quality was uncompromised for print purposes, with the BRIO able to capture at resolutions of 3840 × 2160 pixels, or 8.3 MPs, well above our capture standard of 7.3 MPs. Images could be displayed using the 300 ppi/dpi standard at sizes of 8 inches by 10 inches or smaller, which was more than adequate for comfortable viewing on our workstation monitors or printed reports.

Figure 6 shows the value-steam map for the postimplementation state. We reduced the total process time to 2–4.5 min, which translates to a 99.7% decrease in process time with zero nonvalue-added activity. The new process results in a process cycle efficiency of 100%.

DISCUSSION

Lean principles and VSM can be applied anatomic pathology laboratories, and specifically, to gross specimen imaging, to
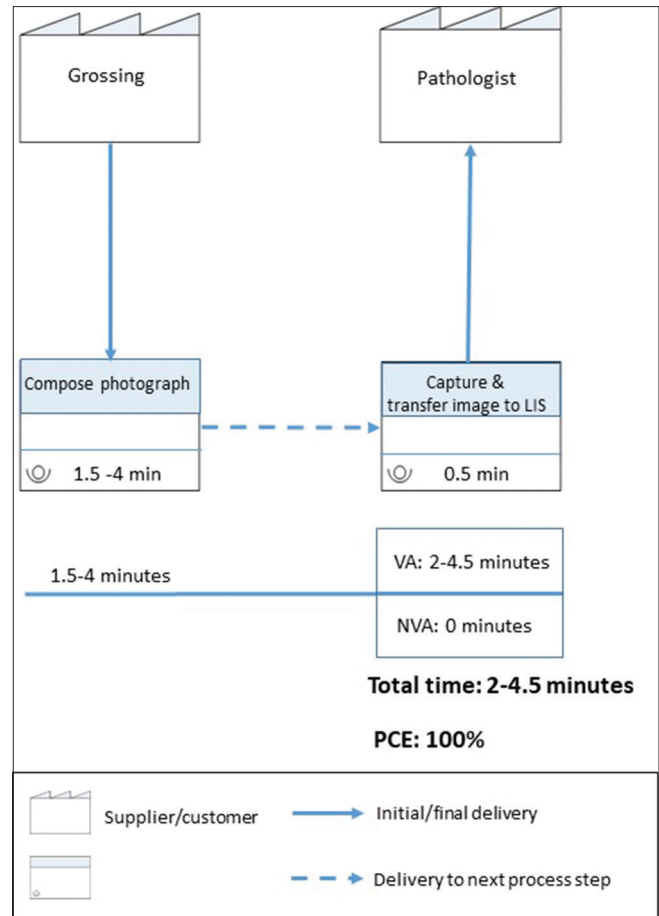

Figure 6: LED ring light and Logitech BRIO web camera positioned such that both components move together after simple adjustment of the flexible arm and the ring light may eliminate shadows from ceiling lights by providing a constant light source from behind the web camera. VA: Value-added activities, NVA: Nonvalue-added activities, PCE: Process cycle efficiency

produce quantitative improvements in specimen processing workflow. Our study implemented UniTwain software in combination with a high-resolution webcam to improve productivity and cut costs and, to the authors' knowledge, is the first of its kind. In this study, we aimed to define value in gross specimen photography and demonstrate the application of VSM in maximizing quality, time, and cost performance of photography workflow. These are essential steps for obtaining leadership approval and getting end-user buy-in for any new process. Our primary goal was to deploy a cost-effective alternative to commercial medical imaging systems that would provide the similar functionality and comparable performance.

The common trends in gross digital photography include commercial medical imaging systems, homegrown automatic imaging systems, flatbed scanners, and consumer-type cameras with manual archiving. [12] Table 4 illustrates the advantages/disadvantages of different imaging systems present in the market.

We believe that our proposed solution of implementing a high-resolution webcam in combination with UniTwain

Table 4: Comparison of different features of common gross pathology imaging devices

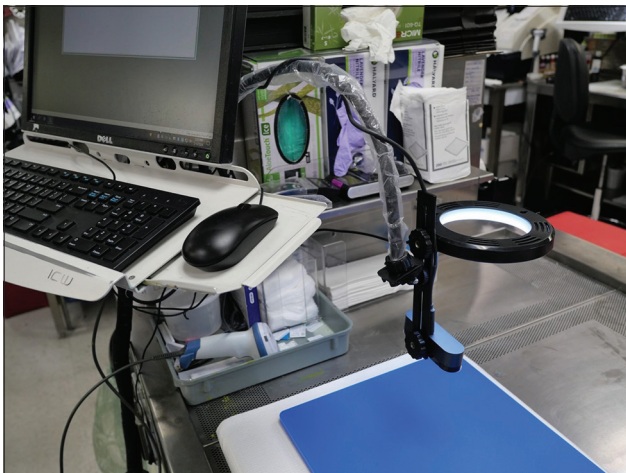|	Medical imaging system	Home-grown imaging system	Scanner or consumer camera
Image resolution	13-20 MP	5-50 MP	5-50MP
Capturing feasibility	++++	++++	++
Archiving feasibility	++++	++++	+
Scalability	++++	++	++
Durability	++++	++	++
Cost	++++	+++/++++	+/++

Figure 7: Value-stream map of improved process. The new process has a total time of 2-4.5 minutes with zero to minimal non-value-added time. VA indicates value-added activities; NVA: non-value-added activities; PCE: process-cycle efficiency

software could provide a viable, cost-effective alternative to a commercial imaging system. This solution provides archiving feasibility and high scalability, comparable to commercial imaging systems, for a much lower price. The full implementation of webcams cost $167,000 to $189,000 less compared to commercial pathology gross specimen imaging devices. This solution also requires minimal human and technical resources for maintaining hardware and software. UniTwain is automatically upgraded online each year and does not require validation of the software following each LIS upgrade. The webcam is easy to use and provides instant integration of images into the corresponding case in the LIS, which can be easily retrieved at the time of sign-out with the minimal manual effort. The new solution also eliminates the mislabeling errors associated with our previous manual process, which could result in pathologist review of wrong images during case finalization.

With the implementation of our webcam-to-AP-LIS interface, we could increase our process cycle efficiency to 100% and decrease the process time by 99.7%. This approach also eliminates the labor-intensive and mind-numbing daily tasks of manual transferring and archiving images, which results in increased satisfaction among our education staff. Our software solution, UniTwain, would allow prosectors to save and annotate gross images as part of their natural dictation process

for each case and diagnosticians to reference and include these images instantaneously while reviewing cases.

As most high-end business and medical software tends to rely only on the TWAIN protocol for image importation, UniTwain is also a great tool to expand and allow the use of many other devices for capturing images and documents such as laboratory requisition. Its most significant advantage is in bringing other options, such as webcams or mobile phones, to the table when it comes to scanning and image acquisition without the need to heavily invest in hardware. The software can also be configured to match the requirements of a specialized device and its manufacturer's needs.

We believe that the combination of UniTwain software and a high-resolution webcam is an ideal solution for capturing on-demand images for smaller laboratories not willing to invest heavily in commercial imaging devices. This design is also suitable for transient workstations, which are not equipped with a mounted camera, such as frozen section grossing stations.

The main limitations of this solution are lower image resolution relative to more expensive enthusiast digital cameras and commercial imaging station and still requiring users to manually manipulate the webcam for image capture in the laboratory environment. The resolution of gross images is a significant factor in proper gross diagnosis and sampling of the specimen.[3] The sensor resolution of current high definition webcams available in the market ranges from 8 to 15 MPs, which is lower than the 20 MPs offered by most commercial medical imaging systems. The high-resolution sensors better enable users to enlarge digital images without losing image details and quality. Increasing the sensor resolution by a factor of 4 would allow users to view an image at twice its size, at the same PPI, without loss of detail. For example, enlarging a photo captured with a 12.1 MP camera to twice its size without any loss of detail requires capturing that same image using a 48.4 MP (12.1 MP x 4) camera. In other words, a medical imaging device with 20 MP would allow users to enlarge photos 1.2 times larger than an image taken by our selected webcam (8 MP), without loss of image quality.[15] However, we find it questionable whether this difference in resolution would make a significant impact in our ability to interpret a gross image.[9]At absolute best, the human eye can distinguish objects 0.04 mm wide. Enlarging an image 1.2 times translates into being able to see an object 0.03 mm wide with the naked eye (0.04/1.2 = 0.03 mm).[10,16] We concluded that sacrificing a

0.01 mm difference has minimal effect on the interpretation of most gross pathologic details. Furthermore, the high definition webcam we selected provides the required 300 dpi quality for most scientific journals and high-quality printed reports.

The other disadvantage with our solution is the complexity of the image capturing process in the laboratory environment. The webcam employs digital zoom, which essentially uses a computation method to crop and enlarge the pixels of the captured digital image, resulting in loss of resolution with each level of zoom. The laboratory personnel must point and adjust the webcam manually to bring the lens closer or farther from the specimen to zoom, which requires changing gloves, and interrupting the specimen dissection workflow, which is not ideal. The Nikon Coolpix W100 employs optical zoom, which manipulates light physically to enlarge an image without loss of resolution, and thus requires slightly less manual manipulation. Most medical imaging devices can be operated hands-free either using the keyboard and mouse or foot pedals. Moreover, these medical imaging systems include measuring functions that allow users to digitally measure specimen dimensions and perform calculations, which is not currently capable with our system.[17] This also raises the issue of device durability in a laboratory environment, with frequent exposure to harsh solutions such as formalin and biohazardous fluids such as blood. Most medical imaging devices are installed within a metal case and mounted above the workstation, which protects the camera from exposure to blood or other chemical spatters. We decided to cover the webcam in disposable plastic sleeves to keep the device clean. However, the front of the webcam, which holds the lens, cannot be wrapped.

Finally, a concern that may arise when implementing any new workflow based on lean principles is possible job loss. In our case, the complete elimination of the manual image labeling and archiving steps, at first, raised concerns about the future role of the media manager. However, while interviewing him, we learned that the proposed future workflow would allow him to redirect his time toward other more meaningful activities. After implementation of the future state workflow, our media manager welcomed the change, as he was able to focus more on various other projects ranging from academic support to electronic resident education initiatives.

Despite these disadvantages, the combination of cost-effective photography equipment and practical software that maximized the functionality of our existing AP-LIS proved to be a simple solution to address issues brought to light by the application of lean production principles and quantitated by VSM.

Conclusions

We have demonstrated the implementation of a novel low-cost webcam combined with UniTwain software at our institution that is low in overhead to implement and maintain but maximizes the efficiency. Moreover, existing infrastructure within the LIS and intranet was used to implement the archival system in a manner that is scalable and not cost prohibitive. Although the webcam is not hands-free and does not provide the highest resolution in the market, it represents an advancement in image management practices stated in the literature and can be applied to other institutions.

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Conflicts of interest
There are no conflicts of interest.

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