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GLOBAL VISION

PACS for the Developing World

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Introduction

DIGITAL imaging is now firmly ensconced in the developed world. Its widespread adoption has enabled instant access to images, remote viewing, remote consultation, and the end of lost or misplaced film. Unfortunately, the current paradigm of Picture Archiving and Communication System (PACS), with advanced technology inseparable from high complexity, high purchase costs, and high maintenance costs, is not suited for the low-income developing world. Like the simple, easy to repair, 1950's American cars still running on the streets of Havana, the developing world requires a PACS (DW-PACS) that can perform basic functions and survive in a limited-resource environment. The purpose of this article is to more fully describe this concept and to present a blueprint for PACS tailored to the needs and resources of the developing world. This framework should assist both users looking for a vendor-supplied or open-source solutions and developers seeking to address the needs of this emerging market.

The term PACS was coined in 1982 at the First International Conference and Workshop on Picture Archiving and Communication Systems (1). Many factors spurred the growth of PACS in the higher-income or developed world in the 1980s and 1990s. The most notable factors were support and interest from venture capital, the IT industry serving research laboratories, US government agencies such as the Department of Defense hospitals and the Department of Veterans Affairs Medical Center Enterprise, major imaging equipment manufacturers and small, innovative IT companies entering the field (1). The simultaneous growth of digital imaging and computational capability created the PACS currently used in the developed world, and occurred contemporaneously with an era of explosive growth in radiology services. For example, from 1980-2006, the volume of CT scans performed in the Unites States is estimated to have increased from 3 million to 62 million (2). This dramatic growth fueled a concomitant growth of budgetary resources of hospitals and imaging centers, which promoted the expansion of PACS capability and functionality.

The creation of DW-PACS will occur in a different time and place. Developing countries have significant shortages of both financial resources and trained IT personnel (3). Well beyond the scope of this article is a discussion of the political, social and many other challenges faced by countries in the developing world. DW-PACS will benefit, however, from extensive existing PACS technology.

Defining objectives for DW-PACS

Before delving into our specific recommendations for DW-PACS, it is important to clearly define both the initial and long-term objectives. Key drivers for the implementation of PACS in the developing world will differ to some extent from those in the developed world. The following list of five key drivers for DW-PACS is based on the assumption of deployment primarily in small clinics and regional medical facilities.

1) Enabling remote interpretation for either primary interpretation or consultation is often a key driver for DW-PACS. This can be due to an absolute shortage of radiologists in a specific country, or the relative absence of radiologists in remote settings. In many developing-world settings, particularly at small and/or remote sites, clinicians often have to interpret their own patients' radiography and ultrasound exams. DW-PACS will enable sites to secure radiologist interpretations for both complex and routine cases. Remote viewing will also enable off-site specialists to view imaging studies and consult with local clinicians about treatment options.

2) The acquisition of new digital equipment, and thus the decision to implement DW-PACS, is fueled by antiquated analog equipment, the difficulty in maintaining film chemistry in the absence of climate control, and/or hazards associated with disposal of used chemistry.

3) The acquisition of digital technology in a location without a local radiologist would drive the acquisition of DW-PACS, as this would facilitate creation of a complete radiology medical record by allowing clinicians to access images within their setting (intranet) and record their interpretations of these studies.

4) While the desire to reduce film-related cost may be a significant driver, it is difficult to determine if implementation of DW-PACS would produce

cost savings. To the authors' knowledge, there have been no cost-benefit analyses on the deployment of digital imaging and PACS in the developing world. One recent study in the developed world found that the direct cost per study was 24% higher with digital imaging and PACS compared to the existing analog systems when implemented using currently available developed world hardware and software in a location with a preexisting, efficient film environment (4). As with numerous other studies, the authors emphasized that the indirect benefits of a digital environment to patient care may well outweigh the penalty in direct costs. The use of telemedicine in the developing world has similarly been posited to have a significant positive effect on healthcare services and outcomes (3). It has certainly been the authors' experience that the implementation of PACS in the developing world can have a dramatic positive impact on patient care.

5) For those sites that have added or are planning to add a CT or MR scanner to their radiology department, that scanner would be a driver for DW-PACS. We saw a similar occurrence in the developing world in the 1980s, when cross-sectional imaging was a key driver in the introduction of both mini-PACS and, ultimately, department-wide PACS. PACS has proven advantages in productivity (5) and accuracy (6) over interpreting CT scans using printed film. In the authors' experience, there are similar advantages when compared to the interpretation of CT scans on the dedicated workstations typically provided with CT or MR scanners. A scanner would virtually mandate the use of remote interpretation performed either by paid off-site radiologists or by a network of volunteer radiologists, at sites that do not have a local radiologist capable of interpreting these modalities. Even in those facilities that have an onsite radiologist, DW-PACS would enable consultation with sub-specialty radiologists both regionally and internationally.

The primary drivers at any one site will determine that site's initial requirements, and DW-PACS must have the flexibility to handle these varied configurations. Once there is an installed base, experience in the field and the scale of demand from larger institutions will be valuable drivers for defining the future objectives and scalability of DW-PACS. Public Private Partnership (PPP) initiatives by non-governmental organizations and national regulatory bodies are supporting telemedicine and teleradiology programs, and running Proof of Concept exercises. The results of these programs will aid in the development of regional standards and, ultimately, regional delivery systems.

Challenges for PACS for the developing world

Technical infrastructure

In any setting in the developing world, the reliability and quality of electrical power, climate control and Internet access will often be inconsistent (7,8). In addition, many sites lack both a robust local area network (LAN) within the facility (wired or Wi-Fi) and deployment of computers in patient areas.

- **Power**

  To deal with electrical power issues, many sites use radiographic equipment that can continue to operate on battery power when external power is not available. One such example is the WHIS-RAD radiographic unit, conceptualized by World Health Organization (WHO). Given the DW-PACS' critical clinical function, it should also be equipped with a battery backup system when integrated with battery-powered acquisition devices. This backup system should ideally be able to automatically fail over and sustain basic functionality on battery power for at least one and a half times longer than the amount of time associated radiography or ultrasound equipment can function off the grid. This would allow sufficient time to register, process and distribute images from the acquisition units without interrupting patient flow or adversely affecting acute patient care.

- **Climate control**

  Computer hardware for DW-PACS is often deployed in locations that do not have the climate control typical of hospitals in the developed world. The environmental specifications for potential computer hardware ideally would be equal to that of the digital imaging equipment commonly used in the developing world. This would ensure that the imaging chain remains intact at sites that experience relatively high heat and humidity. In the authors' experience, many standard ultrasound and digital radiography units have environmental tolerances well beyond the narrow temperature confines of a typical hospital in the developed world (9). It is noteworthy that many digital devices targeted for the developed world have broad environment tolerances, which should be matched by the associated PACS hardware.

- **Internet**

  Internet connectivity is an additional environmental challenge. Connectivity is expanding worldwide but remains both patchwork and unreliable (8). In much of the developing world, cellular networks are the only means available for connecting to the Internet. Fortunately, developing countries now account for two-thirds of all cellular phone subscriptions and have a correspondingly large penetration rate (10). Like other methods for connecting to the Internet in the developing world, cellular networks suffer from frequent outages and bandwidth restrictions, but coverage is rapidly expanding.

- **Intranet**

  Many developing-world healthcare settings, especially older facilities, lack even a basic LAN. Whether wired or wireless, if a LAN does exist it frequently does not extend into critical patient care areas, such as the operating suite, in which clinicians need access to imaging studies. In addition, unless the facility has an existing electronic medical record (EMR), it is unlikely that there are PCs deployed in patient care areas. Unless serious consideration is given to printing imaging studies on film or paper, widely available clinician viewing is essential to DW-PACS. There are myriad combinations of wired or wireless LAN with fixed computers, laptops or tablets. It is also possible to envision that, given increasing cellular access and speed, clinician viewing in the developing world might come to rely entirely on mobile devices and cellular networks. Whichever method is used, clinician viewing is critical for patient care, interpretation of studies, and moving away from the need to print imaging studies on film or paper.

- **Data security**

  The introduction of DW-PACS and the associated components of an EMR and radiology information system (RIS) creates the potential for both remote theft and destruction of digital medical data. Consideration of basic data safety policies and procedures, along with care in employing cloud-based systems, should be part of any initial DW-PACS deployment. Of particular concern should be the physical access to the hospital intranet. Destructive viruses are particularly prevalent in Internet cafes and personal computers in the developing world. One source estimates that 80% of personal computers in Africa are infected (11). Furthermore, virtually all PACS are Windows-based, as are virtually all computer viruses. Network design in the developing world should be predicated on the assumption that any computer connected to the network is likely to be infected. This level of security should specifically include the computers used by technicians who service digital imaging equipment.

Software costs

Costs are clearly a challenge in the developing world, and many of the larger, more established PACS vendors do not have products or pricing structures that can scale down very effectively. There are, however, many viable “second-tier” PACS vendors with more cost-effective solutions that might work in a developing-world setting. Many of these leverage technology in an attempt to minimize costs for smaller sites by sharing resources (e.g. data center, servers, storage systems) among sites. Unless located in regions in which Internet access is highly reliable, cloud-based software solutions will likely be restricted to platform as a service (PaaS) models. PaaS retains software on the local hardware and is thus tolerant of local Internet outages (12).

There are also several open-source PACS archive and PACS workstation software (OSS) options available that make it tempting to minimize costs by implementing an open-source option. However, in considering OSS, the typically lower (or even negligible) initial software purchase cost must be weighed against the availability and cost of support resources. One article describes a large scale OSS deployment at a developed-world hospital that had a robust and dedicated in-house IT staff. Their report cautions that support was the key issue in this deployment, and that while overall project costs were substantially reduced by the use of OSS, the support costs for OSS were similar to those for commercially available software. They also found that Internet access was a critical source of information for the IT team (13). Sites that have the both the need and the resources to adopt and subsequently modify the base OSS for their local use would likely have adequate IT support resources to maintain an open-source PACS. However, most sites would rely on some type of remote support structure. Despite the likelihood that volunteers might be willing to donate their time in supporting this software, for a project on this scale to be sustainable, long-term reliance on volunteer support is impractical. The goal should be to choose software that can be supported by a viable business entity, whether non-profit or for-profit, that can employ and sustain a staff to provide timely support, maintenance, and software upgrades over the long term. Regional support entities might be especially effective and necessary if the open-source graphical user interface (GUI) were to be customized for each region and language. Thoughtful design and implementation can mitigate some support issues, but long-term success requires long-term support.

Hardware costs

- **Computers**

  Installing multiple software applications on the same computer can sometimes minimize hardware costs. For example, smaller sites might install the PACS archive and the PACS viewing software together on one server or computer. Digital imaging modalities such as CR, US, or CT typically include a console or QA station. Since most of these systems run Windows, other applications (e.g. PACS viewer, teleradiology gateway) might be installed on this hardware system. However, most imaging modality vendors consider their hardware to be dedicated and will not guarantee operational reliability or even warrantee the basic imaging acquisition function if other software is installed. In addition, any “extraneous” software applications might be deleted or disrupted when the modality vendor performs troubleshooting or software upgrades. Both the risk of the added (PACS) application interfering with the primary acquisition software and the difficulty in restoring the added application if it is inadvertently or intentionally deleted can be somewhat mitigated by running it under a virtual machine (e.g. Oracle™ VM VirtualBox™). However, this strategy remains fraught with potential problems and operational issues that would likely not justify the potential hardware cost savings. If this strategy is employed, it should be with the formal agreement from the vendor or regional distributor that is supplying and supporting the digital imaging device.

- **Monitors**

  The presumption for this proposal is that radiography would be the most common use for a PACS workstation at developing-world sites, with cross-sectional imaging limited to ultrasound, except when the system is deployed at larger hospitals. In the interpretation of radiographs, the critical specification for a diagnostic monitor is delivering and maintaining high luminance over its useful lifetime. A luminance of 400-600 cd/m2 is considered standard for medical-grade monitors (14) and, while not essential in the interpretation of non-radiographic studies, it is critical to the detection of subtle findings, such as small nodules and pneumothoraces, on radiographs. While some commercial off-the-shelf (COTS) monitors are capable of medical-grade luminance initially, this high level of luminance is not maintained and falls off rapidly over time. Unlike medical-grade monitors that have at least one built-in rear sensor to measure the actual light output and maintain luminance, COTS monitors have no built-in mechanism for maintaining a constant level of luminance. Most high-end medical-grade monitors also have a front sensor that allows the monitor to automatically calibrate and maintain the DICOM grayscale standard display function (GSDF). For those medical monitors without a front sensor, and for all COTS monitors, maintenance of GSDF requires the use of a ‘puck’ or external sensor in concert with a suitable software package. The latter system is not autonomous, as it relies on trained personnel to regularly confirm accurate calibration. Such a software package does have the small advantage of being able to calibrate multiple monitors. A more detailed discussion of monitor specifications for PACS is available from several sources (15,16).

  From a cost point of view, buying and replacing high-luminance COTS monitors on a regular basis, likely every 1-2 years, would be somewhat less expensive than using medical grade monitors (17), and does offer the potential for both a lower initial investment and the ability to more easily repurpose those monitors for non-radiographic interpretation uses. However, the cost of medical-grade monitors can be minimized by the use of 2MP rather than 3MP monitors and the purchase of models that have a rear sensor (luminance) but no front sensor (GSDF). If there is no local regulatory mandate to maintain GSDF, one has the choice to consider foregoing a front sensor and automated DICOM calibration. In a low-volume setting in which a single acquisition device is attached to a PACS server/viewer, the use of a single medical-grade monitor would suffice. Many sites would require a COTS monitor proximate to the digital acquisition device, for the technologist, as well as a separate high-luminance monitor on a PACS workstation(s) for the clinicians or radiologist to review and report the imaging studies. The use of a single medical-grade monitor for both radiography and cross-sectional imaging, such as ultrasound, is becoming easier because of the gradual shift from grayscale to color for many medical-grade monitors. The latest color medical-grade monitors do not compromise display quality for radiography and also allow a better (color) user interface. Lastly, when they can no longer maintain the high luminance required for radiologic interpretation, color monitors are easier to repurpose than grayscale monitors.

Hardware support

Support for any medical device in the developing world is challenging. WHO reports that 70% of donated equipment in some regions is nonfunctional because of service and support problems (18). Access to technical support resources can be the greatest challenge for many sites. As suggested in much of the prior discussion, developing, funding, and executing a viable plan for providing both remote and onsite support is as critical for hardware as it is for software. Again, there are significant advantages to the use of a virtualized environment when repair or replacement of hardware is required.

Digital modalities

Many sites in the developing world are lacking in the fundamental prerequisite technology that enables digital imaging and DW-PACS, as they often have analog X-ray (or analog X-ray and ultrasound) as their only imaging modality. It is outside the scope of this paper to provide guidance for the acquisition of the enabling technology for digital X-ray. In the authors' experience, Computed Radiography (CR), rather than Direct Radiography (DR), is most often the primary initial technology deployed in the developing world when sites convert from analog to digital X-ray. The current driving factors appear to be lower initial cost and lack of reliance on a single costly component (digital radiography detector). Regardless of the type of digital X-ray system, the ability to support a DICOM modality worklist should be a key requirement if the unit is to be installed with DW-PACS.

HIS/RIS/EMR

The authors acknowledge the importance of a HIS (hospital information system), RIS, and EMR in optimizing the delivery of healthcare in the modern world. In much of the developed world, the implementation of HIS has preceded the introduction of PACS. While it is the authors' opinion that introducing a PACS before the foundation of a HIS and RIS is in place may not be optimal, the potential of PACS to enable remote interpretation of imaging studies provides obvious benefits. Its introduction into a healthcare environment with minimal information technology infrastructure may act as a primary driver for the adoption of these information technologies.

Healthcare delivery infrastructure

In many countries in the developing world, the healthcare system is highly non-uniform and disjointed, with particular disjunction between government and private sector delivery systems. This represents a unique challenge even in environments where the technical infrastructure required to support DW-PACS is readily available.

Training

Education and training of clinicians, technologists, technical support personnel, and other related personnel in the use and support of digital imaging and PACS pose additional, major challenges in the developing world. In many cases, these personnel lack even basic computer skills. Any initiative that aims to introduce these new technologies must incorporate the necessary training programs and associated resources into the implementation plan. In addition, the identification and training of onsite operational support personnel to provide both user training and guidance for DW-PACS is crucial to the success of the new digital imaging technologies. Relying solely on remote access for maintenance and support is difficult in regions without robust Internet connectivity. Transferring operational and support knowledge to local PACS administrators will help to mitigate the challenges of reliance on remote support.

Functional requirements

- **Data transfer**

  Whether for remote interpretation, archiving, or software support, data transfer must satisfy several requirements:

  1) The method of data transfer must tolerate both qualitative (e.g. packet loss) and quantitative (bandwidth) restrictions.

  2) Given the larger file size for radiographic studies compared to the alphanumeric data produced by electronic medical records, DW-PACS should be able to perform image compression. There is well-established evidence that moderate levels of irreversible ('lossy') compression can be applied to all types of radiologic imaging without significant visual quality loss or image degradation (19,20). DW-PACS should therefore be capable of supporting both reversible ('lossless') and, more importantly, irreversible data compression.

  3) Data transfer should allow for planned time-shifting. In an environment in which limited Internet bandwidth is frequently in demand for multiple uses, such as email, Internet searches, telemedicine/teleconferencing, and non-radiological data transfer, the ability to schedule and automate data-heavy tasks (e.g. archiving during off-hours) allows for maximum utilization of this limited resource.

  4) DW-PACS should be able to utilize multiple methods to access the Internet, including the use of cellular networks. Ideally, this capability should be highly adaptive to available resources.

  5) DICOM Store and DICOM storage commitment services were designed in the early 1990s, when all radiologic data were being transferred over LANs with little worry about the quality of the network. When used as a method for transfer of images over the Internet, especially when there is marked packet loss and/or limited bandwidth, DICOM data transmission can easily fail. DW-PACS should therefore be expected to support fault-tolerant transmission protocols, such as HTTPS, SFTP, or ideally, Store over the Web by Restful Services (STOW-RS), the newest standard for medical image data transfer over the Internet. A detailed description of this new standard, also referred to as DICOM-RS or DICOMweb™, is beyond the scope of this article but is available on the DICOM website (21). This standard, which grew out of the Medical Image Network Transport (MINT) protocol, offers the potential to provide improved image data transfer over suboptimal Internet connections, without the need to use non-DICOM-based medical image transfer software. Some might question the inclusion of such a 'cutting-edge' DICOM service in DW-PACS, but given the likely lead-time for developing and implementing DW-PACS coupled with the likelihood that it would be in use for many years, this seems a reasonable goal. In the interim, there are cloud-based services available, ranging from general consumer services like Dropbox™ to radiology-specific vendors that can enable transfer of DICOM data without relying on DICOM Store.

- **Cloud**

  The trend toward migration of medical imaging solutions to the cloud suggests that the use of the cloud as a service (CaaS) model might be well suited to the developing world. Cloud solutions are a particularly attractive option, given the lack of onsite IT support resources at many developing-world sites. CaaS should offer absolute costs savings over the traditional purchased hardware and software model (22). There is the further advantage of reduced upfront costs associated with PACS deployment (23). CaaS can support virtually all facets of a PACS deployment without the requirement for locally installed software. While this concept is very appealing, the importance of having critical functionality available during Internet outages can be easily appreciated by anyone who has attempted to use bundled office software solutions, such as Google Docs™, in locations with intermittent Internet access. Until Internet access is both ubiquitous and reliable in the developing world, we suggest that DW-PACS consider platform as a service (PaaS) for select applications, including archiving, disaster recovery, offsite hosting, remote software support and teleradiology for both primary interpretation and subspecialty review. Given the potential unreliability of the Internet, it appears clear that, as with electrical power, DW-PACS must be able to fully function for extended periods of time "off the grid." Given the ongoing concerns about the security of medical information storage in general, the choice of any CaaS vendor should include a thorough evaluation of the security of both their physical site and data transmission. Further discussion on the pros and cons of a cloud-based PACS can be found in the literature (12,24).

- **Viewing options**

PACS viewing functionality can range from the minimal but easy-to-use set of functions typically provided to clinicians on a CD/DVD to the extensive array of functionality incorporated into modern high-end PACS. Most of the more sophisticated functions will be required only for primary interpretation of cross-sectional imaging, such as CT or MRI. The choice to include display tools for modalities such as CT depends on how likely it is for DW-PACS to be deployed at larger centers that could potentially offer CT scanning. The availability of this viewing functionality will also depend on whether DW-PACS is developed de novo or adapted from existing PACS software. In the latter case, it is likely that minimal effort would be required to port cross-sectional display functions from the existing PACS to DW-PACS.

M-health, or the use of mobile computing devices for healthcare, has been proposed as a solution to improving healthcare in the developing world (3). While the use of smart phones and tablets for medical applications is still emerging in the developed world, their anticipated wide use in the developing world suggests that DW-PACS will need to be able to support the viewing and, possibly, the reporting of imaging studies on mobile devices.

- **User interface**

The use of English in the creation of DW-PACS has the advantage of universality and ease of support, but does not facilitate the creation and support of the local language GUIs. One can make a reasonable argument that English is the current 'universal' computer language, and having support and service functions in English maximizes the opportunities to create a robust support infrastructure. When it comes to the concept of a local language GUI, there are clear advantages to adopting a non-language based interface, especially in settings wherein users would not have a dominant primary language. A pictogram-based GUI works well for radiographic equipment but, given PACS' inherent complexity, its implementation for PACS will be more challenging. However, one could propose that DW-PACS could be sufficiently modular so that, in its basic form, it could handle registration and ordering, and also serve as a digital viewbox and film library. In this case, the GUI for those functions might be amenable to full iconographic representation as proposed in the IHE Basic Image Review (BIR) profile (25). It is important to bear in mind, however, that BIR specifically states that it is "not intended to be a reading workstation;" and innovative adaptations for reporting and other functionality would likely be required to fully implement an iconographic GUI.

- **Archive**

A functional film library, the standard in the developed world before PACS, is not ubiquitous in the developing world. Films are often poorly labeled and the images evanescent because of suboptimal chemistry. Storage is often not provided by the clinic and is the responsibility of the patient or their family. The elimination of film provides the opportunity to improve patient care by creating a permanent image repository in the form of a long-term archive. DW-PACS needs to support a flexible archiving strategy allowing for the incorporation of a combination of local and remote archiving. Unless onsite IT resources and environmental conditions are robust, most developing-world sites would be wise to consider remote long-term archiving/disaster recovery, using either CaaS or a regional archive for this function. This is recommended with the proviso that the DW-PACS should include local storage sufficient to accommodate no less than three months of image acquisition. In terms of CaaS being a potential source for cost savings, current evidence is limited to reports of CaaS being cost-competitive only for archiving in sites that require very large amounts (hundreds of Tb) of storage (12).

- **Teleradiology**

As described above, if the need for remote interpretation is a critical function for DW-PACS, teleradiology for both primary interpretation and subspecialty review is a requirement. If interpreters are in multiple locations, there are two available options: 1) Use a web-viewer hosted at a site with reliable Internet access (likely at the same location as a remote long-term archive); or 2) implement a cloud-based viewer to facilitate unlimited access via the web. It would be desirable for DW-PACS to have the capability of sending anonymized studies via email or text messaging to those clinicians lacking either the computer capability or Internet access to use a web-based viewer.

- **Remote support**

The vast majority of support for PACS can be provided remotely. All onsite equipment needs to be configured to provide remote access to enable vendors, distributors, and/or volunteers to provide remote support. As stated above, a virtualized environment would facilitate the remote restoration of PACS software in the event of catastrophic failure.

- **RIS functionality**

A modern RIS enables the flow of patients and their data through a busy department, and allows for higher-level management functions, including inventory, practice analytics, and billing. A DW-PACS needs to be able to provide basic RIS functionality in the absence of an RIS or EMR, and should be capable of interfacing with an existing RIS/EMR.

To function in the absence of an RIS, certain functionalities traditionally associated with RIS needs to be incorporated into DW-PACS. These minimal functionalities include the ability to register and manage patient data, create orders for studies in support of modality worklists, and to create, store, and distribute reports. Table 1 lists functions typically found in a developed-world RIS, with the minimum proposed functionality for DW-PACS highlighted in bold.

Table 1. Radiology information system functions

Patient registration
Order creation
Scheduling
Patient list management
Modality interface via DICOM worklist
Workflow management
Scanning and handling scanned documents
Resource (modality and materials) management
Patient tracking
Examination performance tracking
Standards-based structured reporting
Results distribution

The ability of DW-PACS to interface with an RIS or EMR is one of the more controversial requirements, given that the initial target for DW-PACS would be clinics and first-referral hospitals. However, two additional forces must be taken into consideration. First, as DW-PACS develops, there are also groups targeting the need for basic electronic medical information systems in the developing world (DW-EMR). Clinics and hospitals with a DW-EMR would use that system to, at a minimum, register and manage patient data. This would necessitate that DW-PACS be capable of interfacing with the DW-EMR to access necessary patient data. Second, despite the perceived target for DW-PACS, it is highly likely that, if successful, this technology will also be deployed in higher-level medical care facilities that would most likely have an existing EMR with RIS capability. It would thus be highly advantageous for DW-PACS to have the capability to interface using HL7 (Health Level-7) and eventually HL7 FHIR (Fast Healthcare Interoperability Resources).

- **Reporting**

  Radiology reports are one area in which iconographic functionality would by necessity be supplanted by the local language. There would be a substantial benefit to incorporating basic structured reporting terms, such as RadLex, as the underpinnings of any reporting system. The use of standardized reporting terms translated into equivalent structured terms in the local language would dramatically facilitate the process of obtaining consultations from non-native speakers. This would also allow non-native speaking radiologists to create reports in their native language, which the DW-PACS could easily translate into the language in use at the clinic level. To maintain interfacing standards, DW-PACS needs to be able to output radiology results via an HL7 interface to an RIS or EMR.

- **CD output and input**

  As is the case in the developed world for the foreseeable future, patients and clinicians will occasionally need copies of imaging studies on some type of transportable media, typically a CD or DVD. Therefore, DW-PACS should support output of imaging studies in DICOM Part 10 format to CD/DVD. Output of report text as both a text file and as a DICOM image (for ingestion into a repository that does not associate text-based reports) would be desirable. The CD/DVD should include a basic DICOM viewer that can also display the diagnostic report. This viewer should ideally function on both current and older versions of Windows. DW-PACS must also support input of imaging data from a CD/DVD.

- **Database: Access and query**

  DW-PACS should support database queries via Structured Query Language (SQL) for both quality assurance (QA) and research purposes. This would provide access to all of the common data elements associated with digital imaging, including body part, view, kVp, mAs, equipment information, patient demographics (sex, age), and, when available, exposure indices. In addition, diagnostic report structured fields and the free text in reports should be made available for the types of analyses that would be applied in both the QA and research settings. The adoption of standards will also allow sites to more easily migrate data as regional networks grow and Vendor Neutral Archive infrastructure becomes available.

- **Network**

  Given the lack of LAN or Internet infrastructure in many developing-world settings, it would be helpful for the DW-PACS vendor or distributor to work with local providers to ensure the necessary infrastructure is in place. This infrastructure may include routers (conventional, WiFi, and/or cellular data), wiring, cellular data modems, cellular data booster antennas, and/or satellite communications equipment. The DW-PACS vendor will typically be responsible for ensuring the DW-PACS works in concert with the networking equipment provided.

Conclusion

Virtually all the functionality described in this article is readily available from multiple commercial vendors. However, the financial, connectivity and technical support limitations in the developing world make their widespread deployment in this arena impractical. The final structure of the DW-PACS proposed in this article will evolve as ideas become actual software. Certain concepts are important regardless of the final structure. These include: modular design allowing for easy addition of functionality such as RIS and teleradiology; minimal use of language in the GUI; use of standards for communication and archiving; simplified software designed for ease of use, reliability and simple troubleshooting; simultaneous creation of a support enterprise; and adaptability as reliable cloud access increases over time. While the use of low-cost hardware would be ideal, standard computer hardware is available at nominal pricing and has been shown to function reasonably well in the developing world.

Our goal in writing this article was to a lay a foundation for feedback from the global radiology community regarding the creation and design of DW-PACS. Using the principles outlined above, we hope to create the information technology equivalent of the WHIS-RAD radiography unit. The final realization of a DW-PACS may well come when an article such as this one spurs not only the development of specifications, but also a partnership with a forward-thinking vendor or group who can build, support and deploy such a system. ❒

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Conflict of interest

The authors report no conflict of interest.

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