In: Telemedicine
Editor: Haider Khaleel Raad
ISBN: 978-1-63483-435-3

Chapter 3

AN ANALYSIS OF DICOM AND ITS USE FOR IMAGE MANAGEMENT AND COMMUNICATION IN STORE-AND-FORWARD TELEHEALTH

Liam Caffery
Centre for Online Health, The University of Queensland,
Brisbane, Queensland, Australia

ABSTRACT

DICOM is an international information technology standard used for the encoding and communication of digital medical images. DICOM was originally developed for radiology and is considered a key determinant in the success of teleradiology. There is an increasing move and policy consensus to use DICOM as the standard image management and communication protocol for all medical images including images acquired for the purpose of store-and-forward telehealth services. Standardized image management would allow the efficient integration of all imaging into a patient's electronic medical records and also allow a single Picture Archiving and Communication (PACS) to be used across an enterprise.

In this chapter the actual or intended application of DICOM for image management in store-and forward telehealth was investigated. It was found that DICOM allows alternative image encoding by acquisition modalities. These encodings include: Secondary Capture, Visible Light and Ophthalmic Photography. Different metadata in the DICOM header of these DICOM files is the predominant differences between encodings.

Ophthalmic imaging would appear to be the most mature non-radiological applications of DICOM and the Ophthalmic Photography IODs and related Service Object Pair (SOP) classes are intended for use with ophthalmic imaging systems, for example, microscopes, ophthalmoscope, fundus camera, slit lamp imaging systems and external cameras. These information objects contain rich patient, clinical, examination, and equipment metadata. Visible Light IODs (and related SOP classes) are intended for use with endoscopes, colposcopes and digital cameras. Hence, it would be suitable for use in teledermatology, telecolposcopy, telewoundcare, teleotolaryngology and numerous other clinical specialty services that use a simple digital camera to obtain clinical images. The inclusion of Secondary Capture support by acquisition modalities would appear to be only for interoperability with devices that do not support either Ophthalmic Photography or Visible Light SOP classes.

The wide spread use of DICOM Modality Worklist to improve workflow management in a telehealth imaging network was observed during this investigation. Similarly, the wide spread support of image communication services like electronic image storage from acquisition device to PACS was also seen. However, compliance of these network services is not mandatory and the device's DICOM conformance statement should be used to identify what information objects and network services are actually provided by a device.

Keywords: Telehealth, telemedicine, DICOM, store-and-forward

INTRODUCTION

Digital Imaging and Communication in Medicine (DICOM) is an international information technology standard for the encoding and exchange of digital clinical images. The DICOM standard has defined a file format for clinical images. DICOM has also defined network services used to exchange clinical images between devices on an imaging network. DICOM was originally developed to transfer radiological images between imaging modalities, image archives and display stations. Although the use of DICOM is voluntary, it is almost universally adopted by vendors of radiological imaging equipment. Hence, nearly all teleradiology uses a DICOM file format and DICOM network services to exchange images. The use of DICOM led to the widespread adoption of the telemedicine approach to the delivery radiology services [1]. Today, teleradiology is regarded as the most successful telehealth application and DICOM is considered to be a key determinant of that success [2].

To emulate the success of teleradiology, DICOM has expanded into other image producing clinical specialties. Hence, DICOM is used for the encoding and exchange of non-radiological clinical imaging e.g., ophthalmic or dermatological images in telehealth services. The application of DICOM in telehealth is less widespread than in radiology and may be responsible for the slower uptake of telehealth into mainstream practice [3]. However, there is increasing promotion for DICOM to be used in telehealth. For example, the American Telemedicine Association (ATA) has published practice guidelines advocating the use of DICOM compliant systems for teledermatology and diabetic retinopathy screening [4, 5]. The US Department for Veteran's Affairs and the US Department of Defense have mandated DICOM compliant imaging modalities for all purchases of radiology, dental, ophthalmology and optometry, cardiology, pathology, endoscopy, dermatology digital acquisition modalities and related equipment [6]. The principle goal of DICOM is to facilitate interoperability between different medical imaging devices (e.g., acquisition and storage devices) from different manufacturers. Standardization of image management based on DICOM would allow a single Picture Archiving and Communication System (PACS) to manage all clinical imaging (radiological and non-radiological) within the organization [7]. Similarly, efficient integration of imaging into electronic medical records (EMR) can be achieved using DICOM as the standard for medical image management and communication [8].

The use of DICOM for telehealth is not rigidly defined. Hence, it is possible for a clinical image to be encapsulated in different file formats all of which are DICOM compliant. Further, there is no device that has a holistic support of the entire DICOM standard; instead a device will normally comply with only a subset of file formats or network services. Consequently, some PACS developed for radiology may not be compatible with parts of the DICOM standard developed for non-radiology applications [7]. Therefore, it is necessary to investigate how the optional parts of DICOM can be best applied to telehealth. The aims of this study are to: i) identify what DICOM file types are used in the practice of store-and-forward telehealth; ii) analyze the differences between the file types; iii) identify the effect file type has on interoperability between a telehealth applications and existing DICOM and/or PACS infrastructure; and iv) identify DICOM network services necessary for efficient workflow in a telehealth service.

BACKGROUND

This section provides contextual information on the DICOM standard and store-and-forward telehealth.

Digital Imaging and Communication in Medicine (DICOM)

The DICOM standard is a document which contains definitions for file formats and network services used to transfer a DICOM file from one DICOM-compliant device to another. DICOM also defines an additional set of workflow services to allow patient and / or study metadata to be transferred between DICOM-compliant devices. The DICOM standard document is used by imaging equipment manufacturers to implement a consistent way of creating and exchanging DICOM files in their software. The most recent version was released in 2014 and has 18 base parts (**Table 1**) (Parts 9 and 13 have been retired).

Table 1. Parts of the DICOM base standard

1 Introduction and Overview
2 Conformance
3 Information Object Definitions
4 Service Class Specifications
5 Data Structures and Encoding
6 Data Dictionary
7 Message Exchange
8 Network Communication Support for Message Exchange
10 Media Storage and File Format for Data Interchange
11 Media Storage Application Profiles
12 Media Formats and Physical Media for Data Interchange
14 Greyscale Standard Display Function
15 Security Profiles
16 Content Mapping Resource
17 Explanatory Information
18 Web Access to DICOM Persistent Objects (WADO)
19 Application Hosting
20 Transformation of DICOM to and from HL7 Standards

The first version of DICOM was released in 1985. It was jointly developed by the American College of Radiologist (ACR) and the National Electrical Manufacturers Association (NEMA). Prior to the release of the standard, images were stored in proprietary formats. Transmission of images was not electronic. Images were copied to removable media and physically transported to another imaging device. DICOM has realized its objective of network transfer. DICOM applications are designed to work over a standard TCP/IP network.

DICOM Working Groups

The development and maintenance of the DICOM standards is managed by the DICOM Standards Committee. The committee co-ordinate the effort of working groups who advance categories of work. The current working groups are listed in Table 2. Non-radiological working groups include: WG-09 Ophthalmology, WG-19 Dermatologic Standards, WG-22 Dentistry, WG-24 Surgery and WG-26 Pathology.

Table 2. DICOM Standards Committee Working Groups (WG)

WG-01: Cardiac and Vascular Information	WG-15: Digital Mammography and CAD
WG-02: Projection Radiography and Angiography	WG-16: Magnetic Resonance
WG-03: Nuclear Medicine	WG-17: 3D
WG-04: Compression	WG-18: Clinical Trials and Education
WG-05: Exchange Media	WG-19: Dermatologic Standards
WG-06: Base Standard	WG-20: Integration of Imaging and Information Systems
WG-07: Radiotherapy	WG-21: Computed Tomography
WG-08: Structured Reporting	WG-22: Dentistry
WG-09: Ophthalmology	WG-23: Application Hosting
WG-10: Strategic Advisory	WG-24: Surgery
WG-11: Display Function Standard	WG-25: Veterinary Medicine
WG-12: Ultrasound	WG-26: Pathology
WG-13: Visible Light	WG-27: Web Technology for DICOM
WG-14: Security	WG-28: Physics
	WG-29: Education, Communication and Outreach

DICOM File Format

DICOM defines a file format which has two parts. The first is text-based metadata which describes patient, study, series and image entities. The second is the pixel data of the image which can be in any standard image file formats, for example, JPEG. The two parts are melded into a single file. A DICOM file is often referred to as a DICOM object.

DICOM Information Model

An Information Object Definition (IOD) is an object-oriented, abstract data model used to specify metadata about a DICOM object or image. Each type of DICOM image e.g., CT

Image, MR Image, Visible Light Image, Ophthalmic Photograph Image has a different IOD. Whilst each of these image types may have common attributes e.g., patient name or acquisition date they also have unique attributes.

Table 3. Common DICOM Value Representations

VR Name	VR Pneumonic	Description
Age string	AS	Three numbers followed by D for Days, W for Weeks, M for Months or Y for Years
Code String	CS	A string of characters. Gender is a codes string with M for Male, F for Female or U for Unknown
Decimal String	DS	A string of characters representing a fixed point or floating point number.
Date	DA	A string of characters in the format YYYYMMDD
Date Time	DT	A string of characters in the format YYYYMMDDHHMMSS
Integer String	IS	A string of characters representing a decimal with an optional leading *+ or -*
Long String	LS	A string of up to 64 characters
Long Text	LT	A string of characters up to 10,240 characters which may contain one or more paragraphs
Person Name	PN	A string of characters made up of five components separated by the ^ symbol. The five components are: family name, given name, middle name, title, suffix
Short String	SS	A string of up to 16 characters
Short Text	ST	A string of characters up to 1024 characters which may contain one or more paragraphs
Time	TM	A string of characters in the format HHMMSS.FFFF where FFFF is a fraction of a second
Unique Identifier	UI	A series of numbers separated by a full stop that is used to uniquely identify something.

For example, gantry tilt and pitch are attributes unique to a CT image; whereas patient eye movement is unique to an ophthalmic photography. An IOD is a hierarchical structure of information entities, modules and attributes. Information entities e.g., patient, study, series and image are made up of one or more modules e.g., patient, general image, image pixel, CT image, VL image. Each module is made up of a number of DICOM elements. A DICOM element is the most atomic item in the information hierarchy and describes a single attribute e.g., patient name or acquisition time in a name value pair. DICOM logically groups and orders these attributes and also specifies which are mandatory and which are optional. A DICOM element is referenced by a unique attribute tag in the format of (group, element). All patient data are in Group 10 with the attribute tag (0010, 0010) for Patient Name, (0010,0020) for Patient ID, (0010,0030) for Patient Date of Birth and (0010,0040) for Patient Gender. For each element DICOM also defines a data type which DICOM refers to as the Value Representation (VR). Common VRs are listed in Table 3.

DICOM Network Services

DICOM network services involve transmitting a DICOM object (image file) from one medical imaging device to another for various purposes, for example, storing the file from an acquisition modality to a data storage device e.g., a PACS, printing the image to a networked

DICOM printer or querying the PACS for a particular image and retrieving it to a workstation for viewing. These transactions occur between two DICOM-compliant devices that are connected on a TCP/IP network. DICOM network services are based on a client / server architecture. In DICOM, the server is referred to the Service Class Provide (SCP) and the client the Service Class User (SCU). DICOM network services improve the efficiency of imaging network by allowing the electronic transfer of images between acquisition, storage and review nodes on an imaging network.

DICOM defines a service class for each of the network services. For the above examples, Storage Service Class, the Query Retrieve Service Class and the Print Management Class are used. For each service class there is a defined set of messages and responses. DICOM messages are described in Table 4. These messages and responses are exchanged between two DICOM-compliant devices and are used to negotiate an association between the devices, transfer the DICOM object and close the connection between devices. The two communicating devices must agree on parameters such as role (SCP or SCU), the image type and format of the pixel data before an association is established.

Table 4. Composite DICOM messages

DICOM message	Function
C-STORE	Used to store a DICOM object. This command is often called a *DICOM push.*
C-FIND	Used to query a DICOM-compliant device. The C-FIND request command contains items to constrain the query, for example, constrain to an individual patient identifier, modality or date. The C-FIND response contains a list of DICOM objects that match the query. C-FIND can be used to query/retrieve DICOM images from an image archive or by the DICOM Modality Worklist to query for patient and/or study demographics.
C-MOVE	Used to request one DICOM-compliant device to transfer (move) DICOM objects to another DICOM-compliant device. The C-MOVE command can constrain the DICOM objects to be moved to an individual identifier. C-MOVE is used in conjunction with a C-FIND for the query / retrieve of DICOM objects. The C-MOVE command may involve three actors. The command can be issued from one DICOM-compliant device, the source of the DICOM objects can be a second DICOM-compliant device and the destination of the images can be a third DICOM-compliant device. The DICOM-compliant device issuing the C-MOVE may be the same as the destination device.
C-GET	Similar to a C-MOVE however the DICOM-compliant device issuing the command is the destination of the requested DICOM objects.
C-ECHO	Used to establish a DICOM connection between DICOM-compliant devices most often for the purpose of troubleshooting. This command is often called a *DICOM ping*.

SOP Class

There is a functional relationship between the service class and the DICOM object known as the Service Object Pair (SOP) class. As the name implies, the SOP class is a combination of service and the DICOM object. For example, in the SOP class *Visible Light Image Storage,* a visible light image is the object and storage is the service class. For digital images to be transferred from one device to another, the communicating devices must both support (use) the same SOP class with one device as a SCU and the other as a SCP. A DICOM device will optionally support a SOP class. Supported SOP classes for a device are listed in a document called a DICOM conformance statement (DCS). A DCS is self-published by the device's vendor.

Work Flow Management in DICOM

DICOM defines methods workflow management, for example, how to transfer patient demographics from one device to another. One such service is the DICOM Modality Worklist (DMWL). The DMWL transfers patient demographics from an orders or scheduling information system to the image acquisition modality. This avoids the need for manual entry of patient and study demographics which results in both workflow efficiency and improved accuracy of metadata. Another DICOM workflow management service is Modality Performed Procedure Step (MPPS) which allows an acquisition modality to report the status of examination (in progress, completed, cancelled) to another DICOM-compliant device. A further DICOM workflow management service is Storage Commitment (SC). SC verifies that files intended for storage have actually been stored by the destination device.

DICOM Web Services

DICOM has more recently introduced three web services to allow the storage, retrieval and querying of DICOM objects using web services. Web services, when compared to the traditional client / server architecture used by DICOM, improve accessibility to DICOM-compliant devices by using the Internet. The DICOM web services include: Storage over web (STOW), Query based on ID for DICOM objects (QIDO) and web access to DICOM objects (WADO). Hypertext transfer protocol (HTTP) requests from these web services are translated into composite DICOM messages (C-STORE, C-FIND, C-MOVE) by the HTTP server allowing co-existence of web services and the traditional client / server devices on the same medical imaging network [9].

DICOM Summary

DICOM is a broad standard. It has defined a file format which includes both pixel data and metadata incorporated into a single file. The metadata is a standardized list of text fields describing the patient, study, equipment and image. Secondly, DICOM defines network services which are used to transmit a DICOM file from one device to another. These network services include procedures for storing DICOM files, retrieving DICOM files from data storage devices so they can be viewed by a clinician.

Thirdly, DICOM has defined work flow management processes aimed at improving the efficiency of the image acquisition, storage and retrieval processes. One example of workflow management is the transfer of patient and examination demographics from a scheduling system to an acquisition modality to avoid re-keying data and improving accuracy of metadata using the DICOM modality worklists.

Store-and-Forward Telehealth

Telehealth refers to the practice of health consultation at a distance via the exchange of electronic information [10]. The aim of telehealth is to improve access to clinical services that would otherwise be unavailable, prohibitively expensive, inconvenient or impossible for patients and providers to use [11].

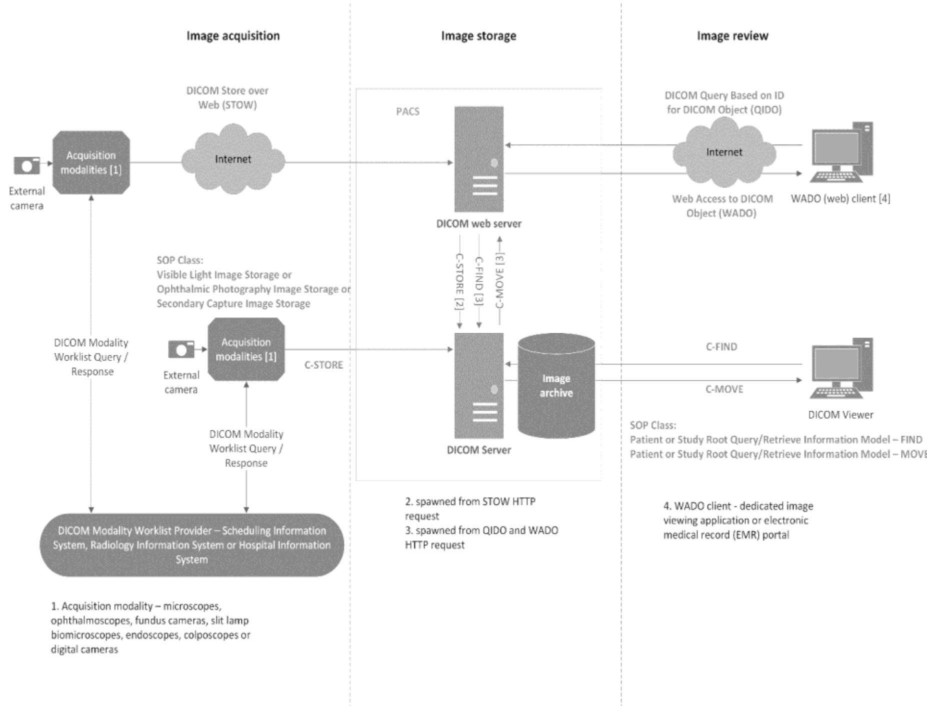

Figure 1. DICOM architecture for telehealth imaging network.

Store-and-forward is one of the two principal modalities of telehealth (the other being real-time video conferencing). The name store-and-forward comes from the steps involved in the communication process. Some type of clinical information – for example, still images, video images, text, recorded sound are initially stored by the sender and subsequently sent (forwarded) to the recipient. Asynchronous, pre-recorded and store-and-forward are all synonymous terms for this type of telehealth consultation. Store-and-forward telemedicine is practiced in a large number of medical specialties and settings. There are a number of niche applications namely image-oriented specialties, for example dermatology, pathology, wound care, plastic surgery and ophthalmology [12]. It is these services that can potentially use DICOM to standardize image management and communication.

METHODS

For this study, multiple information sources were used to identify the actual or intended use of DICOM for image management and communication in telehealth. These sources include: peer-reviewed literature, the DICOM standard, documentation produced by DICOM working groups and the DICOM conformance statements from telehealth image acquisition devices, secondary capture devices and specialty telehealth PACS applications. These sources were examined for supported SOP classes and DICOM network services. DICOM IODs were also identified. The identified IODs were categorized into medical specialty to identify different ways the same clinical image could be encoded according to the DICOM standard. The DICOM standard was used to *decode* the identified object and lists of the mandatory modules and in turn, the DICOM elements used to describe each of the objects was generated. Analysis was performed to identify gaps in metadata resulting from alternative image encodings.

RESULTS

Three IODS Secondary Capture, Visible Light and Ophthalmic Photography have been identified as possible image encodings on DICOM-compliant acquisition devices used for store-and-forward telehealth. The DICOM standards committee (http://dicom.nema.org/) definition for these IODs is shown in Table 5.

Table 5. DICOM IODs used for non-radiological image definition

IOD	Description
Secondary Capture	The Secondary Capture (SC) Image Information Object Definition (IOD) specifies single-frame images that are converted from a non-DICOM format to a modality independent DICOM format, without any constraints on pixel data format.
Visible Light	The Visible Light (VL) Image Information Object Definition (IOD) specifies images that are acquired by means of a camera or other sensors (endoscopy, colposcopy, ophthalmology, digital cameras) that are sensitive to visible or near-visible light.
Ophthalmic Photography	There are two Ophthalmic Photography IODs namely an 8 bit and 16 bit. Ophthalmic Photography 8 bit or 16 bit Image Information Object Definitions defines an information object to be used with several types of ophthalmic photographic imaging devices including fundus cameras, slit lamp biomicroscope, scanning laser devices, stereoscopic cameras, video equipment and digital photographic equipment.

Most modern ophthalmic image acquisition devices, for example, fundus cameras can natively acquire in DICOM format and will most often support more than one of these DICOM IODs. Image specific storage SOP classes (indicating the devices support of electronic image communication) are also supported in most ophthalmic image acquisition devices, for example, Ophthalmic Photography 8 bit / 16 bit Image Storage, Visible Light (VL) Photographic Image Storage and Secondary Capture Image Storage.

Digital imaging for dermatology, dentistry and wound management is frequently acquired using either: a consumer digital camera; a consumer digital camera with clinical attachment, e.g., a cross-polarization filter for dental photography; a dedicated imaging device coupled with a consumer digital camera e.g., slit-lamp imaging system or a microscope imaging system; or a dedicated clinical camera e.g., dermatoscope. Some of these devices will support native DICOM acquisition producing both VL Photographic Image and / or Secondary Capture Images. However, the output of most devices is a standard image file formats such as joint photographic experts group (JPEG) or tagged image file format (TIFF). These images can be converted to DICOM by means of a secondary capture relay station, a print-to-PACS virtual printer driver or direct import as a function of a PACS workstation. Whilst some of the metadata contained in the DICOM header is machine generated, for example, unique identifiers, a user interface is needed to capture data elements, i.e., patient demographics which will go on to form the metadata in the DICOM header. Metadata is melded with the image file to produce a DICOM file. This type of conversion produces VL Photographic Images or SC Images.

Dedicated microscopic devices e.g., endoscopes or colposcopes can acquire in either standard image file format or DICOM file formats (VL Endoscopic or VL Microscopic Images).

The mandatory modules for each of the DICOM IODs are listed in Table 6. The *Patient, General Equipment, General Study, General Series, General Image* and *SOP Common* are modules common to all IODs. Mandatory data attributes for these modules are listed in Table 7. There are also optional data attributes that have not been listed.

Table 6. Mandatory modules for IODs used in telehealth applications

	Secondary Capture Image IOD	Ophthalmic Photography (8 Bit and 16 Bit) Image IOD	Visible Light (Photography, Microscopic and Endoscopic) Image IOD
Information Entities	*Compulsory Modules*		
Patient	Patient	Patient	Patient
Study	General Study	General Study	General Study
Series	General Series	General Series Ophthalmic Photography Series	General Series
Equipment	General Equipment SC Equipment	General Equipment	General Equipment
Image	General Image	General Image	General Image
	SC Image	Ophthalmic Photography Image Ocular Region Imaged Ophthalmic Photography Acquisition Parameters Ophthalmic Photographic Parameters	VL Image Specimen*
	SOP Common	SOP Common	SOP Common

* Required if imaging subject if a specimen.

Modules specific to the Ophthalmic Photography IODs include: Ophthalmic Photography Series (Table 8), Ophthalmic Photography Image (Table 9), Ocular Region Imaged (Table 10), Ophthalmic Photography Acquisition Parameters (Table 11), Ophthalmic Photographic Parameters (Table 12). Modules specific to Secondary Capture IODs include: SC Image and SC Equipment (Table 13). There is only one module specific to Visible Light IODs namely VL Image (Table 14).

Table 7. Data attributes for modules common to Secondary Capture, Ophthalmic Photography and Visible Light IODs

Patient Module	
Attribute	*Description*
Patient's Name	Patient's full name
Patient ID	Identification number or code issues by the hospital or medical service to uniquely identify the patient
Patient's Birth Date	Named patients date of birth
Patient's Sex	Named patients gender
General Study Module	
Study Instance UID	Globally unique identifier for the study
Study Date	Date the study was started.
Study Time	Time the study was started.
Referring Physician's Name	Name of the patient's referring physician
Study ID	Equipment generated study identifier
Accession Number	A computer generated number that identifies the order for the study. Can be generated by order entry information system (radiology, pathology) or a scheduling information system (ophthalmology, dermatology)
General Series Module	
Modality	Type of equipment that originally acquired the images e.g., CT (computerized tomography), XC (external camera), ES (endoscopy) etc.
Series Instance UID	Globally unique identifier for this series
Series Number	Equipment generated series identifier
Laterality	Left or Right of (paired) body part examined
General Image Module	
Instance Number	A number that identifies this image
Content Date	The date the image pixel data creation started
Content Time	The time the image pixel data creation started
SOP Common	
SOP Class UID	Unique identifier for SOP class
SOP Instance UID	Unique identifier for this DICOM image file

Table 8. Ophthalmic Photography Series Module

DICOM Element	Description
Modality	Modality of equipment that sourced the image for Ophthalmic Photography this is always OP

Table 9. Ophthalmic Photography Image Module

DICOM Element	Description
Image Type	Multi-value field with values separated by "\" character in the format PIXEL DATA CHARACTERISTICS\ PATIENT EXAMINATION CHARACTERISTICS\MODALTY SPECIFIC CHARACTERISTICS\IMPLEMENTATION SPECIFIC IDENTIFIERS Options for PIXEL DATA CHARACTERISTICS are ORIGINAL (an image whose pixel values are based on original or source data) or DERIVED (an image whose pixel values have been derived in some manner from the pixel value of one or more other images). Options for PATIENT EXAMINATION are PRIMARY (image created as a direct result of the patient examination) or SECONDARY (image created after the initial patient examination). Options for MODALTY SPECIFIC CHARACTERISTICS A Montage Image is MONTAGE which is only used for DERIVED images i.e., DERIVED\PRIMARY\MONTAGE A MONTAGE is constructed out of several individual images, which also can be exchanged separately.

Table 9. (Continued)

DICOM Element	Description
	IMPLEMENTATION SPECIFIC IDENTIFIERS is optional and may contain COLOR (a picture taken at white light), REDFREE (a picture taken at green illumination light), RED (a picture taken at red illumination light), BLUE (a picture taken at blue illumination light), FA (a picture taken at fluorescein exciting illumination light) or ICG (a picture taken at Indocyanine green exciting illumination light).
Instance Number	A number that identifies this image
Samples per Pixel	Number of samples (planes) in this image, each plane typically represents a colour.
Samples per Pixel Used	The number of samples (planes) containing information.
Photometric Interpretation	Specifies the intended interpretation of the pixel data. Options are MONOCHROME2 (a greyscale image), RGB (an uncompressed colour image constructed of red, green blue planes image), YBR_FULL_422, YBR_PARTIAL_420 and YBR_ICT, YBR_RCT (encoding of RGB images used in JPEG compression based on YCbCr colour space. YCbCR colour space is three channels where Y represents luminance Cb [blue difference], Cr [red difference]).
Pixel Representation	Options are 0 (pixel values are always positive e.g., a 256-bit image has pixel values from 0 to 255) or 1 (pixel values may be represented by a negative number e.g., a 256-bit image has values (-127 to 128).
Planar Configuration	Options are 0 (the colour channels are interlaced e.g., RGBRGBRGB…..) or 1 (the colour channels are separated e.g., RRRRBBBBBGGGG)
Pixel Spacing	The physical distance between adjacent pixels in an image. Pixel spacing contains two measurement separated by the "\." The first is the distance from centre of one pixel to the centre of adjacent pixel on the same row and the second is the distance from centre of one pixel to the centre of adjacent pixel on the adjacent column i.e., adjacent row spacing \ adjacent column spacing, in mm.
Content Time	The time the image pixel data creation started.
Content Date	The date the image pixel data creation started.
Acquisition Date time	The date and time that the acquisition of data started.
Source Image Sequence	A Sequence that identifies the images that were used to derive this image. Required if Image Type is DERIVED.
Lossy Image Compression	Flag to specify whether an image has undergone lossy compression. Options are 0 (no lossy compression) or 1 (lossy compression).
Lossy Image Compression Ratio	Describes the lossy compression ratio(s) that have been applied to this image e.g., 5:1 to indicate the image is one-fifth the size of an uncompressed image.
Lossy Image Compression Method	The compression algorithm used on the image. Options are JPEG Lossy Compression, JPEG-LS Near-lossless Compression or JPEG 2000 Irreversible Compression.
Presentation LUT Shape	The shape of the look-up table (LUT) used to transform an actual pixel value to the presentation value used by the display device. Only required if Photometric Interpretation is MONOCHROME.
Calibration Image	Indicates whether a reference object (phantom) of known size is present in the image and was used for calibration.
Burned In Annotation	Indicates whether or not image contains sufficient burned in annotation to identify the patient and date the image was acquired.
Recognizable Visual Features	Indicates whether or not the image contains sufficiently recognizable visual features e.g., photograph of the patient's face to allow the image or a reconstruction from a set of images to identify the patient

Table 10. Ocular Region Imaged Module

DICOM Element	Description
Image Laterality	Laterality of object imaged. Values: R = right eye L = left eye B = both left and right eye
Anatomical Region Sequenced	Values: ANTERIOR CHAMBER OF EYE, BOTH EYES ,CHOROID OF EYE CILIARY BODY, CONJUNCTIVA, CORNEA, EYE, EYELID, FOVEA CENTRALIS, IRIS, LACRIMAL CARUNCLE, LACRIMAL GLAND, LACRIMAL SAC, LENS, LOWER EYELID, OPHTHALMIC ARTERY, OPTIC NERVE HEAD, RETINA, SCLERA, UPPER EYELID

DICOM Element	Description
Position of image on retina	This field maps the image to a protocol. Diabetic Retinopathy Study field 1 Diabetic Retinopathy Study field 2 Diabetic Retinopathy Study field 3 Diabetic Retinopathy Study field 4 Diabetic Retinopathy Study field 5 Diabetic Retinopathy Study field 6 Diabetic Retinopathy Study field 7 Field 1 for Joslin3 field Field 2 for Joslin 3 field Field 3 for Joslin 3 field Macula centred Disc centred Lesion centred Disc-macula centred Mid-peripheral-superior Mid-peripheral-superior temporal Mid-peripheral-temporal

Table 11. Ophthalmic Photography Acquisition Parameters Module

DICOM Element	Description
Patient Eye Movement Commanded	Did the examiner give instructions to the patient to gaze in a particular direction? Values: YES or NO
Patient eye Movement Command Sequence	Values: Upward gaze Left upgaze Left gaze Left downgaze Downgaze Right downgaze Right gaze Right upgaze Convergent gaze
Refractive State Sequence	Refractive state of the eye at the time of imaging. Contains three measurements: Spherical Lens Power, Cylinder Lens Power and Cylinder Axis
Intra Ocular Pressure	The pressure of fluid inside the eye. Measure by tonometry in mmHG.
Horizontal Field of View	User defined.
Pupil Dilated	Values: Yes or No
Mydriatic Agent	Values: Atropine, Homatropine, Cyclopentolate, Phenylephrine or Tropicamide
Degree of dilation	User defined

Table 12. Ophthalmic Photographic Parameters Module

DICOM Element	Description
Acquisition Device Type	Describes the type of acquisition device. Options are: Operating Microscope Scanning Laser Ophthalmoscope Indirect Ophthalmoscope Direct Ophthalmoscope Ophthalmic Endoscope Keratoscope Pupillograph Fundus Camera Slit Lamp Biomicroscope External Camera Specular Microscope
Illumination	Describes the illumination. Options are: Indirect retroillumination from the iris Indirect retroillumination from the retina Indirect iris transillumination diffuse direct illumination Scotopic light Mesopic light Photopic light Dual diffuse direct illumination Fine slit beam direct illumination Broad tangential direct illumination Indirect sclerotic scatter illumination Dynamic light
Light Path Filter Type	Filters used in the light source path. Options are: Green optical filter Red optical filter Blue optical filter Yellow-green optical filter Blue-green optical filter Infrared optical filter Polarizing optical filter No filter
Light Path Filter Pass-Through Wavelength	Wavelength of light in nanometres.
Image Path Filter Type	Filters used in the image path. Options are: Green optical filter Red optical filter Blue optical filter Yellow-green optical filter Blue-green optical filter Infrared optical filter Polarizing optical filter No filter
Detector Type	CCD = Charge Coupled Devices CMOS = Complementary Metal Oxide Semiconductor

For Ophthalmic Photography 8 bit/16 bit images: Bits Allocated is always 8 or 16, Bits Stored is always 8 or 16 and High Bit is always 7 or 15.

Table 13. Secondary Capture Equipment Module

DICOM Element	Description
Conversion Type	The process for converting the non-DICOM format to DICOM. Defined Terms: DV = Digitized Video, DI = Digital Interface, DF = Digitized Film, WSD = Workstation, SD = Scanned Document, SI = Scanned Image, DRW = Drawing SYN = Synthetic Image

Table 14. Visible Light Image Module

DICOM Element	Description
Image Type	Multi-value field with values separated by "\" character in the format PIXEL DATA CHARACTERISTICS\ PATIENT EXAMINATION CHARACTERISTICS\MODALTY SPECIFIC CHARACTERISTICS\IMPLEMENTATION SPECIFIC IDENTIFIERS Options for PIXEL DATA CHARACTERISTICS are ORIGINAL (an image whose pixel values are based on original or source data) or DERIVED (an image whose pixel values have been derived in some manner from the pixel value of one or more other images). Options for PATIENT EXAMINATION are PRIMARY (image created as a direct result of the patient examination) or SECONDARY (image created after the initial patient examination). Options for MODALITY SPECIFIC CHARACTERISTICS are STEREO L (image is the left image of a stereo pair acquisition) or STEREO R (image is the left image of a stereo pair acquisition)
Photometric Interpretation	Same as in Ophthalmic Photography Image Module
Bits Allocated	Number of bits allocated for each pixel sample. This value is normally in multiples of eight e.g., 8 bit, 16 bit or 24 bit because computer storage is organized in 8-bit / 1 byte units. The more bits allocated the greater the number of colours (or shades of grey) that a pixel can represent.
Bits Stored	Number of bits stored for each pixel sample. An image does not have to use all of the bits allocated. For example, an image may be 12-bit hence requires 12 bits to be stored but would need to have 16 bits allocated.
High Bit	The most significant bit.
Pixel Representation	Same as in Ophthalmic Photography Image Module
Samples per Pixel	Same as in Ophthalmic Photography Image Module
Planar Configuration	Same as in Ophthalmic Photography Image Module
Content Time	Same as in Ophthalmic Photography Image Module
Lossy Image Compression	Same as in Ophthalmic Photography Image Module
Referenced Image Sequence	A sequence that references other images significantly related to this image e.g., reference to the STEREO L from a STEREO R image.
Window Centre / Width	Transforms an actual pixel value to the presentation value used by the display device used when the transformation is linear (LUT are used for non-linear transformations). Only required if Photometric Interpretation is MONOCHROME
Anatomic Region Sequence	A sequence that identifies the anatomic region of interest in this image
Pixel Spacing	Same as in Ophthalmic Photography Image Module

DISCUSSION

Image Acquisition

It is the file structure that makes the practice of telehealth using DICOM particularly advantageous. Firstly there will be a standardized set of metadata elements used, and secondly enhance safety resulting from no risk of separation of the image and the patient demographics [3].

Telehealth services allow today's ophthalmic clinicians to remotely diagnose, manage and monitor several ophthalmic conditions from a distance [13]. Ophthalmic imaging would appear to be the most mature non-radiological applications of DICOM. Ophthalmology has an active DICOM working group (WG-09) which was responsible for authoring DICOM Supplement 91 Ophthalmic Photography Image SOP Classes. Supplement 91 was released in 2004 and updated in 2009.

Diabetic retinopathy (DR) screening is the predominant application of store-and-forward teleophthalmology consistent with increasing prevalence of diabetes. There are several large scale DR screening programs reported in the literature. For example, the UK's National Health Service Diabetic Retinopathy Screening Program is a national program with 2.3 million enrolled patients [14] and the Joslin Vision Network, a collaboration between the US Department of Defense, Veterans Health Administration and Joslin Diabetes Centre [15]. DR screening uses fundus or retinal cameras to visualize vasculature in the fundal or posterior eye. Hemorrhage or aneurysms are characteristics of retinopathy and identification of either of these abnormalities on retinal images may indicate the presence of disease. In addition to DR screening, store-and-forward teleophthalmology can also be used for the diagnosis and management of glaucoma [16, 17], traumatic eye injuries [18], strabismus [19] and corneal disease [20]. In addition to fundal or retinal imaging, commercial digital cameras with macro lenses are used to image the external eye and eyelids; hence, are used for teleophthalmology applications related to trauma of the external eye or strabismus. Slit-lamp examinations demonstrate the anterior structures of the eye; hence, are used in glaucoma, corneal disease and trauma involving anterior structures of the eye. A number of teleophthalmology programs report using DICOM for their service [16, 21]. However, no details regarding which DICOM information objects are reported by any of these authors. Similarly no detail on network services (SOP classes) is described.

The Ophthalmic Photography Image IODs provides benefit over using other IODs for ophthalmic imaging because of the rich metadata. For example, ophthalmic photographic imaging may incorporate magnification, dyes and colour filters and stereoscopic photography. Ophthalmic photographic imaging requires very specific and detailed identification of equipment and related acquisition attributes for proper interpretation of the images [22]. Further, different retinal imaging protocols — for example, Joslin 3 Field or Diabetic Retinopathy Study Field can be employed for DR screening. The appropriate position of image on retina can be recorded and stored in the DICOM metadata when using a retinal camera that uses the Ophthalmic Photography IODs. Examination parameter including the whether the pupil was pharmalogically dilated and the mydriatic agent used for dilation have DICOM field elements. Similarly, ancillary ophthalmic measurements such as intraocular pressure (IOP) can also be stored as discrete data fields. Access to metadata may provide important opportunities for computer-based clinical decision support and clinical research [23]. It is also interesting to note the *identifiable features* and *burned in annotations* flag included in Ophthalmic Photography information objects. These flags are set to true if the patient's identity is recognizable from the photograph or annotations on the images. The flag should then be used to exclude the image from teaching or research purposes.

Visible Light Images have application for telehealth imaging in a range of clinical specialties. VL is intended encoding for use in teledermatology (dermatoscope and simple digital camera imaging) [24], burns [25], trauma [26], dentistry [27], otolaryngology [28] and colposcopy [29]. The VL IOD does not have the extensive examination, equipment, protocol or ancillary clinical information metadata that the Ophthalmic Imaging Modules have. Hence, Visible Light images have application to a wide range of medical specialties. A number of DICOM committee working groups have contributed to the Visible Light development. These include WG-15 Visible Light, WG-19 Dermatology and WG-22 Dentistry. WG-19 Dermatology is currently not active. WG-22 is currently working and Visible Light supplement for dentistry.

As previously noted most acquisition devices support one or more IODs including the Secondary Capture IOD. The choice of which information object should be used to encapsulate acquired images is user configurable when commissioning the acquisition device. The Secondary Capture IOD is the most basic DICOM file encapsulation and contains no specific information on examination or medical specialty. Further, there are no constraints on pixel data. For example, unlike the other IODs Secondary Capture does not have a metadata flag indication the use of lossy compression in the pixel data of the image. Further, other metadata fields such as *referenced image sequence* (indicating an image is one a sequence of images) which can improve diagnostic processes are also absent from the IOD. For these reasons, Secondary Capture has been deprecated in favour of Ophthalmic Image or Visible Light Image IODs and their associated SOP classes. The retention of the Secondary Capture IOD by acquisition devices is most likely to allow interoperability with legacy PACS that do not support Ophthalmic Image or Visible Light Storage SOP classes.

Network Services

A DICOM *push* enabling storage from a remote image acquisition device or alternatively a remote clinician access via query / retrieve may constitute the transmission component of a telehealth exchange [30]. During this study some acquisition devices were identified that will acquire images and store them on the local device in DICOM file format. However, the device may not support network services such as image storage. Devices that do not support DICOM network services often require the images to be transferred from acquisition device to the storage device via removable media and hence require a manual work around for image communication.

There is widespread support of DICOM modality worklists (DMWL) by acquisition devices; however support is not holistic. The application of DICOM to non-radiology clinical specialties does require some workflow redesign especially for specialties that do not have an information system equivalent of a Radiology Information System (RIS) for scheduling imaging examinations [7]. As a work around some use the RIS to schedule all radiological and non-radiological imaging examination whilst others use the hospital information system (HIS) as a DICOM modality worklist provider [31].

Limitations

There is a paucity of DICOM technical information, for example, SOP class and information objects used by a service and published in the peer-reviewed literature. However, this is the primary place of publication for articles that describe store-and-forward telehealth services. Hence, it is difficult to get an indication of exactly how DICOM is being applied to store-and-forward telehealth. The scope of discussion of this chapter has been the use of DICOM for image management and communication and for workflow management. DICOM does also have application for diagnostic reports in the form of encapsulated portable document files (PDFs) or DICOM structured reports (SR) which could be used for reporting functions of telehealth services, for example, a dermatologist's diagnostic report on a skin lesion. To obtain a complete view of the application of DICOM to telehealth would also require investigation of DICOM reporting methods.

CONCLUSION

This study has consolidated and critically analyzed information from multiple sources regarding actual or intended use of DICOM for image management and communication in telehealth. There is an increasing move and policy consensus to use DICOM as the standard image management and communication protocol for all medical imaging including images acquired for the purpose of store-and-forward telehealth services. The use of DICOM is considered best practice [32] because it allows a rich and consistent source of metadata and enhances safety by not separating patient demographics from the image. A standardized image management protocol facilitates integration of imaging from multiple specialties into a patient's electronic medical records giving clinicians a comprehensive, patient-centric view of imaging. This improves both the accuracy and efficiency of patient management [33]. The use of DICOM allows telehealth services to leverage existing radiology PACS infrastructure and support services as in storage or distribution of images, technical support and interoperability with EMR.

During this study three DICOM IODs were identified for use in telehealth, namely, Secondary Capture, Visible Light, and Ophthalmic Photography. These formats are used by acquisition devices that acquire in a native DICOM format or devices that convert standard image file formats (JPG, TIFF, BMP) into a DICOM format. It is common for an acquisition device to support multiple IODs. The format to be used by the device is user configurable. Ophthalmic Photography IODs and related SOP classes are intended for use with ophthalmic imaging systems (microscopes, ophthalmoscope, fundus camera, slit lamp biomicroscopes and external cameras). These IODS contain rich patient, clinical, examination, and equipment metadata. Visible Light IODS (and related SOP classes) are intended for used with endoscopes, colposcopes and digital cameras. Hence, would be the intended IOD for teledermatology, telecolposcopy, telewoundcare, teleotolaryngology and numerous other medical specialty services that use a simple digital camera to obtain clinical images. Visible Light IODs are more generic metadata than the Ophthalmic Photography IODs. Secondary Capture is the most basic DICOM format. Secondary Capture IODs are still supported by most acquisition devices but would logically only be used when communicating peers, for example, PACS did not support either Ophthalmic Photography or Visible Light SOP classes. When configuring an acquisition modality it is important to use the DICOM conformance statement of communicating devices to determine support of the SOP class. For example, before choosing Ophthalmic Photography SOP class when configuring a fundus camera it is important to ensure the PACS where images will be stored, also supports Ophthalmic Photography Storage SOP class. If the PACS does not support Ophthalmic Photography Storage SOP class an alternative supported SOP class must be configured on the acquisition device but there will be loss of metadata using IODs associated with alternate SOP classes.

Wide spread support of DICOM modality worklists (DMWL) by acquisition modalities was observed during this study. A DMWL will query a departmental scheduling information system for patient and examination demographics. The use of DMWLs increases the accuracy and completeness of metadata by eliminating the need to manually re-enter data at the modality. This also increases the efficiency of examination.

The DICOM compliance of devices used for telehealth image management and communication need to be verified as there is no single, holistic support of all parts of the DICOM standard. The initial verification can be done via the device's DICOM conformance statement and should include supported information objects, network services for image management and communication and network services for workflow management. A device may acquire images in a DICOM format and it was observed that most acquisition devices will support multiple formats. The most appropriate format needs to be configured with reference to both i) consistent support of related SOP classes by peer devices the acquisition devices will communicate with and ii) the metadata contained in the information model. Similarly, support of network services e.g., image storage or worklists needs to be validated both on the devices and on peers the device will be communication with on an imaging network.

Further Reading

Caffery LJ. Teledermatology PACS. In: Soyer HP BM, Smith AC, Wurm EMT, eds. Telemedicine in Dermatology. Heidelberg: Springer; 2012. p. 133-42.

References

[1] Garritano FG, Goldenberg D. Successful Telemedicine Programs in Otolaryngology. *Otolaryngologic Clinics of North America*. 2011 Dec; 44(6):1259-1274.

[2] Bashshur RL, Shannon G, Krupinski EA, Sustaining and Realizing the Promise of Telemedicine. *Telemed J. E-Health*. 2013 May;19(5):339-345.

[3] Hofer B, Scheibbock C, Binder M. Quality Assurance and Risk Management. In: Soyer HP BM, Smith AC, Wurm EMT, editor. Telemedicine in Dermatology. Heidelberg: Springer; 2012. p. 187-195.

[4] American Telemedicine Association. Telehealth Practice Recommendations for Diabetic Retinopathy, 2011.

[5] Krupinski E, Burdick A, Pak H, American Telemedicine Association's Practice Guidelines for Teledermatology. *Telemed J. E-Health*. 2008 Apr;14(3):289-302.

[6] Joint VA / DoD DICOM Conformance Requirements for Digital Acquisition Modalities. Department of Veterans Affairs Department of Defense; 2005.

[7] Bandon D, Lovis C, Geissbuhler A, Enterprise-Wide PACS: Beyond Radiology, an Architecture to Manage All Medical Images. *Acad. Radiol*. 2005 Aug;12(8):1000-1009.

[8] Yogesan K. Teleophthalmology. Berlin; New York: Springer; 2006.

[9] Wu HQ, Lv ZM, Geng XY, Interoperative Fundus Image and Report Sharing in Compliance with Integrating the Healthcare Enterprise Conformance and Web Access to Digital Imaging and Communication in Medicine Persistent Objects Protocol. *International Journal of Ophthalmology*. 2013;6(6):879-883.

[10] What Is Telemedicine? American Telemedicine Association; 2012.

[11] Armfield NR, Edirippulige SK, Bradford N, Telemedicine--Is the Cart Being Put before the Horse? *The Medical Journal of Australia*. 2014 May 19;200(9):530-533.
[12] Caffery LJ, Smith AC. A Literature Review of Email-Based Telemedicine. *Studies in Health Technology and Informatics*. 2010;161:20-34.
[13] Strouthidis NG, Chandrasekharan G, Diamond JP, Teleglaucoma: Ready to Go? *The British Journal of Ophthalmology*. 2014 Apr 10.
[14] Scanlon P. The Systematic DR Screening in England for Two Million People with Diabetes. In: Yogesan K, Goldschmidt LP, Cuadros J, editors. Digital Teleretinal Screening: Teleophthalmology in Practice. Berlin: Springer; 2012.
[15] Sanchez CR, Silva PS, Cavallerano JD, Ocular Telemedicine for Diabetic Retinopathy and the Joslin Vision Network. *Seminars in Ophthalmology*. 2010 Sep-Nov;25(5-6):218-224.
[16] Khouri AS, Szirth BC, Salti HI, DICOM Transmission of Simultaneous Stereoscopic Images of the Optic Nerve in Patients with Glaucoma. *Journal of Telemedicine and Telecare*. 2007;13(7):337-340.
[17] Kiage D, Kherani IN, Gichuhi S, The Muranga Teleophthalmology Study: Comparison of Virtual (Teleglaucoma) with in-Person Clinical Assessment to Diagnose Glaucoma. *Middle East African Journal of Ophthalmology*. 2013 Apr-Jun;20(2):150-157.
[18] Kumar S, Yogesan K, Hudson B, Emergency Eye Care in Rural Australia: Role of Internet. *Eye*. 2006 Dec;20(12):1342-1344.
[19] Helveston EM, Neely DE, Cherwek DH, Diagnosis and Management of Strabismus Using Telemedicine. *Telemed J E-Health* 2008 Aug;14(6):531-538.
[20] Peeler CE, Dhakhwa K, Mian SI, Telemedicine for Corneal Disease in Rural Nepal. *Journal of Telemedicine and Telecare*. 2014 Jun 6;20(5):263-266.
[21] Murthy KR, Murthy PR, Kapur A, Mobile Diabetes Eye Care: Experience in Developing Countries. *Diabetes Research and Clinical practice*. 2012 Sep;97(3):343-349.
[22] DICOM Supplement 91 Ophthalmic Photographic Image SOP Classes. 2003.
[23] Chiang MF, Boland MV, Brewer A, Special Requirements for Electronic Health Record Systems in Ophthalmology. *Ophthalmology*. 2011 Aug;118(8):1681-1687.
[24] Muir J, Xu C, Paul S, Incorporating Teledermatology into Emergency Medicine. *Emerg Med. Australas*. 2011 Oct;23(5):562-568.
[25] Warner PM, Coffee TL, Yowler CJ. Outpatient Burn Management. *The Surgical Clinics of North America*. 2014 Aug;94(4):879-892.
[26] Smock ED, Wek CD, Milroy CD. Plastic Surgery Trauma - Setting up a Telemedicine Service at a Major London Trauma Centre. *Plastic and Reconstructive Surgery*. 2014 Oct;134(4 Suppl 1):47.
[27] Chen RS, Chen SK. Teledentistry Using Videoconferencing and a DICOM Image Management System. *Journal of Telemedicine and Telecare*. 2002;8(4):244-246.
[28] Smith AC, Armfield NR, Wu WI, A Mobile Telemedicine-Enabled Ear Screening Service for Indigenous Children in Queensland: Activity and Outcomes in the First Three Years. *Journal of Telemedicine and Telecare*. 2012 Dec;18(8):485-489.
[29] Hitt WC, Low G, Mac Bird T, Telemedical Cervical Cancer Screening to Bridge Medicaid Service Care Gap for Rural Women. *Telemed E-Health*. 2013 May;19(5):403-408.

[30] Caffery LJ. Teledermatology PACS. In: Soyer HP BM, Smith AC, Wurm EMT, editor. Telemedicine in Dermatology. Heidelberg: Springer; 2012. p. 133-142.

[31] Kuzmak PM, Dayhoff RE. The Department of Veterans Affairs Integration of Imaging into the Healthcare Enterprise Using the Vista Hospital Information System and Digital Imaging and Communication in Medicine. *J Digit Imaging*. 1998 May;11(2):53-64.

[32] Bedini R, Belardinelli A, Giansanti D, Quality Assessment and Cataloguing of Telemedicine Applications. *Journal of Telemedicine and Telecare*. 2006;12(4):189-193.

[33] Ratib O, Swiernik M, McCoy JM. From PACS to Integrated EMR. *Computerized Medical Imaging and Graphics* 2003;27(2-3):207-215.