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Limitations in and Solutions for Improving the Functionality of Picture Archiving and Communication System: an Exploratory Study of PACS Professionals' Perspectives

Mona Alhajeri[1,2] · Syed Ghulam Sarwar Shah[3]

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Abstract
Picture Archiving and Communication System (PACS) technology is evolving leading to improvements in the PACS functionality. However, the needs and expectations of PACS users are increasing to cope with the rising demands for improving the workflow and enhancing efficiency in healthcare. The aim was to study the limitations in the current generation of PACS and solutions for improving PACS functionality. This was a longitudinal online observational study of the perspectives of PACS professionals accessed through four online discussion groups on PACS using the LinkedIn network. In this exploratory study, the methodology involved a thematic analysis of qualitative data comprising 250 online posts/comments made by 124 unique PACS professionals collected between January 2014 and December 2015. Participants were mostly male ($n = 119$, 96%) from the North America ($n = 88$, 71%). Key themes on limitations in the current generation of PACS were image transmission problems, network and hardware issues, difficulties in changing specific settings, issues in hardcoded Digital Imaging and Communication in Medicine attributes, and problems in implementing open source PACS. Main themes on solutions for improving PACS functionality were the integration of multisite PACS, multimedia for PACS, web-based PACS, medical image viewer, open source PACS, PACS on mobile phones, vendor neutral archives for PACS, speech recognition and integration in PACS, PACS backup and recovery, and connecting PACS with other hospital systems. Despite ongoing technological developments, the current generation of PACS has limitations that affect PACS functionality leading to unmet needs and requirements of PACS users, which could impact workflow and efficiency in healthcare.

Keywords PACS technology · Digital medical imaging · Electronic images · Radiology workflow · Ubiquitous PACS · Online access

Introduction

Picture Archiving and Communication System (PACS) is a digital medical imaging management system [1], which is used in healthcare for acquiring, storing, transmitting, archiving, and accessing medical images electronically [2]. Using multimedia solutions, PACS can integrate healthcare data in different forms such as video recordings, text, voice, medical records, and wave images [3].

PACS was developed in Europe in the 1970s [4] and since then, PACS evolution has gone through different development stages [5]. The advancement in PACS focused on the development of imaging systems and integration in the late 1980s, integration of PACS with health information systems (HIS) and radiology information systems (RIS), and development of digital imaging and communication in medicine (DICOM) in the early 1990s, and development of PACS workflow and application servers, e.g. enterprise PACS and web-based PACS from late 1990s to 2010s ([6], p.17–18).

From the adoption perspective, practical implementation of PACS began in the USA in the early 1980s [4] albeit in very few selected hospitals [7]. Thereafter, PACS implementation rolled out in many hospitals mainly in developed countries in Europe [8], Asia [9], and North America [9]. Now, PACS is widely used in many countries including both the developed

✉ Syed Ghulam Sarwar Shah
Sarwar.Shah@gstt.nhs.uk

[1] Jaber Al Ahmad Center for Molecular Imaging, Ahmad Al Jaber Street, Shuwaikh, Sabah Area, 14113 Kuwait City, Kuwait

[2] Department of Computer Science, Brunel University London, Uxbridge, Middlesex UB8 3PH, UK

[3] Department of Occupational Health, Guy's and St. Thomas' NHS Foundation Trust, The Education Centre, St Thomas' Hospital, Westminster Bridge Road, London SE1 7EH, UK

and the developing countries [10]. In fact, PACS has become one of the most important digital imaging tools in the radiology landscape globally.

Adoption of PACS has not only made radiology practice filmless [11] but also has decreased material costs, physical storage space, and the manual labour of traditional film in radiology [12]. In addition, PACS as an enterprise-wide medical imaging IT system has improved radiology practice by enhancing workflow, efficiency, and productivity as well as time-saving leading to increased efficiency in healthcare delivery [3]. Besides radiology, PACS has also improved the productivity and efficiency of clinicians in other clinical disciplines [13, 14]. Moreover, the integration of PACS with other hospital systems has improved workflow and efficiency [15]. PACS can also help improve communication between radiologists and other clinicians [16]. More importantly, beyond the traditional hospital environment, PACS can play a significant role in healthcare delivery such as interventional radiology in the combat environment [17]. Thus, PACS provides a good return on investment [3].

However, despite above-stated benefits, PACS implementation is marred with many issues such as difficulties in integrating multiple PACS units both within and between hospitals and integrating PACS with other hospital systems [18], limited storage capacity, accesses issues, e.g. synchronous, multiple, and remote access, and solutions for backup and recovery, and problems in data migration [19]. In addition, there are challenges in enhancing radiology workflow, productivity, and efficiency [20] to keep the pace with rising calls for improvement in health care quality and delivery [21]. PACS users are thus calling for improvements in the PACS functionality [4] and developing new PACS functionalities [22]. Thus, PACS research and development must continue for meeting the needs and requirements of a wider community of PACS users who are not only radiologists but also clinicians of different medical specialities having diverse but interdisciplinary needs regarding PACS application in their clinical practices.

There is a limited research that provides answers to three important questions: What are the limitations in the current generation of PACS? What are the solutions for addressing limitations in PACS? How could PACS functionality be improved?

The aim of the present study was to identify limitations in PACS and identify solutions for improving the PACS functionality from the PACS professionals' perspectives.

Materials and Methods

Study Design

This is an online longitudinal observational study that involved collection and analysis of qualitative textual data comprising posts/comments made by PACS professionals engaged in four online discussion groups on PACS technology based on the LinkedIn—an online network for professionals.

Data Collection and Study Population

Online Discussion Groups

Online groups/forums are 'computer-supported communication technologies that facilitate virtual interaction on the Internet' comprising different discussion threads, i.e. conversations that start with the posting of a question, information, reply, or comment on a topic of interest to members of the discussion group [23]. As conversations continue on the topic, the number of threads adds up and the threads get stored and archived online in a descending order (the latest at the top and the oldest at the bottom) on the discussion group's webpage and they could be accessed and read online by other people, which might require authorised access privileges.

We captured and curated data comprising online conversations in four online discussion groups (ODGs) on PACS via the LinkedIn. LinkedIn is 'a business-oriented social networking site' that was launched on May 5, 2003, and its users are more than 562 million in more than 200 countries and territories globally [24]. LinkedIn is one of the most popular and a largest global online networking platform used by professionals of diverse backgrounds for professional networking, employment, and discussions on issues of common interest and exchanging knowledge and experiences in areas of expertise and technical topics and issues of mutual interest such as PACS technology. LinkedIn provides an online harbour to a large number of discussion forums and the unique feature of discussion forums on this online network is that the participants in each group are experts in their own fields. In addition, ODGs break geographical boundaries and allow stakeholders from different countries and territories to comment on topics of their expertise and interest. In ODGs, the participants have the opportunity to know about each other from the participant's personal profiles via a link that contains the participant's details such as the name, position, experience, and location. LinkedIn has thus been used as a tool for data collection for research studies [25].

We used the LinkedIn for accessing potential research participants and collecting data. LinkedIn provided access to the perspectives of a broader PACS community that included radiologists, clinicians, PACS administrators, engineers, managers, vensors and technologists from around the world.

For identifying the relevant ODGs on the LinkedIn, the first author (MA) created an account on the LinkedIn website. This was followed by searches for the relevant discussion groups using the 'search' menu by selecting the option of 'groups', the category of 'all', and the language as 'English',

which are provided in the search facility on the LinkedIn. The search terms used were picture archiving and communication system, PACS, radiology information system/systems, health information system/systems, radiologist, radiologists, radiographers, radiology technologists, PACS and medical imaging, and PACS and digital imaging.

Searches resulted in the identification of 159 discussion groups. We removed 13 groups that were duplicates. Thus, we identified 146 unique discussion groups. Applying selection criteria for shortlisting ODGs (Table 1), we excluded an additional 66 ODGs and retained 80 ODGs. Thereafter, we read the group profiles known as 'About This Group' of all retained ODGs ($n = 80$). Thereby, we identified 9 ODGs that were relevant to the objectives of our study. Thus, we shortlisted 9 ODGs for data collection.

We approached all short-listed ODGs ($n = 9$) through the 'Ask to Join' facility, available on the LinkedIn page of each ODG, for joining and accessing the groups. The first author (MA) sent an online request to the administrator of each shortlisted ODG for joining and shared with them her personal profile, which included the researcher's name, current position, and research speciality in the field of health information systems. Only four ODGs agreed and allowed the first author (MA) to join and access the group discussions while the remaining five ODGs denied permission to access to their groups.

After joining the four ODGs, the first author (MA) passively monitored discussions and read, captured, and harnessed online conversations including comments, opinions, questions, and answers on each of the short-listed ODGs. To avoid bias and influence on the group conversations, the first researcher (MA) did not take part in the group discussions but collected data as a passive observer by only observing and reading the conversations on the PACS in these ODGs.

Each of these four ODGs was accessed once every 3 months over a period of 2 years starting in January 2014 and finishing in December 2015. A 3-month gap in accessing and observing the ODGs allowed for the accumulation of new discussion threads/comments and topics discussed. Each of these four ODGs had a large membership (Table 2) and contained various discussion threads and participants' comments (posts) by members on PACS-related issues. We collected all posts/comments, relevant to the study objectives, which were available since January 2013. The process of capturing conversations continued until December 2015 when we stopped the data collection. Data collection in any threads was terminated where there were no new posts during the last 12 months from the date of access, which led to the conclusion that most of the interaction had been recorded [26]. Using the screen capture feature in the NVivo software version 10 for Windows [27], all comments/posts deemed relevant to the study were directly exported to a local database on a secure PC that was accessed by the first author (MA) only.

Ethical Issues

The Internet is considered to be an essential medium for retrieving and exchanging data due to its ease of use, ubiquitous access, and the richness of contents. However, there are both advantages and disadvantages of using the Internet-based ODGs as a source of data for research studies.

The advantages include access to a large amount of data that can be collected within a short time, a collection of information from people who have similar experiences and interests but are located in different and widespread geographical areas around the globe. This supports the research in the context and financially and the use of Internet removes the issues of in-person contact and provides an opportunity to the participants to present their opinions freely without feeling that they are being judged [28, 29].

The limitations in using the Internet as a medium for data collection include self-selecting participants, exclusion of some participants who might be very relevant to the study because they do not have an access to the Internet or they have no interest in using or participating in socio-technical media such as ODGs. Thus, these limitations of ODGs could introduce bias and limitations, which can be avoided with careful considerations in using online sources of data for research [28]. However, ODGs offer the advantages that overweigh the limitations; hence, ODGs are used in research studies [25].

From the ethical and privacy perspectives, using the Internet as a source of data and capturing conversations from ODGs is as important as any other means of data collection and the privacy and anonymity of both the participants and the ODGs is paramount. Therefore, it is imperative to be mindful and consider ethical issues in using online data and quoting and publishing opinions of online participants [30].

We obtained ethics approval from the research ethics committee at the first author's university. In addition, we obtained permission from administrators of all four ODGs for accessing their groups and harnessing participants' comments and posts and using them for the research purpose. We stored all data anonymously and securely on a password-protected computer that was accessed only by the first author (MA). We have analysed and reported all comments anonymously without mentioning the names of either the ODGs or the individuals making the comment(s) [31]. We cannot report the names of the participating ODGs due to the privacy reasons and our commitment to the moderators of the groups.

In addition, the role of the first researcher (MA) in accessing and collecting data from four ODGs was as a passive observer who only observed the discussions without any participation and interaction in the group discussions. Thus, we neither introduced any bias nor influenced participants' opinions/comments and the direction of the discussions.

Table 1 Criteria used for selection of online discussion groups

Relevance	Topic/comments/ posts relevant to the study aim and objectives and research questions
Language	English only
Group activity and membership	The group must be active and should have at least 10 members
Comments per thread	Minimum discussion comments on each discussion thread not less than 4 comments
Exclusions	Exclusion of comments deemed to be advertisements and sales

Data Analysis

We analysed qualitative textual data comprising 250 posts/ comments made by members of four ODGs on PACS using the NVivo software (Version 10 for Windows) [27]. We read verbatim all comments and created codes and nodes in the NVivo. We deleted duplicate codes and we combined nodes covering the same or very similar issues. We grouped similar nodes for creating sub-themes, which followed reviewing, developing, and finalising higher level themes using the thematic analysis process [32, 33].

Results

Four ODGs on PACS involved in this study varied from each other in terms of the number of members, the geographical location of members, and the participants' professional background, posts (comments), threads (discussion topics), and members making comments. The total number of members was 1739 in group 1, 5261 in group 2, 1833 in group 3, and 502 in group 4. The majority of participants in these ODGs was from the North America ($n = 88$, 71%) followed by Europe ($n = 16$, 13%) and Asia ($n = 6$, 5%) (Table 2). Participants' location by country showed that the maximum number of participants was from the USA ($n = 81$, 65%) followed by Canada ($n = 6$, 5%) and the UK ($n = 5$, 4%) (Table 2).

Information about the professional background of the participants showed that the most of them were engineers and manufacturing managers ($n = 33$, 26.6%) followed by IT and informatics consultants ($n = 30$, 24.2%) and PACS administrators and implementers ($n = 29$, 23.4%) (Table 3).

The total number of discussion threads (topics) observed per group was seven threads each in group 1 and group 2, four threads in group 3 and three threads in group 4 (Table 4). The number of members making comments (posts) per group also varied, i.e. 56 in group 1, 50 in group 2, 35 in group 3, and 17 in group 4 (Table 4). Some participants made comments more than once; hence, there were 124 unique participants (Tables 2 and 3). The number of total posts (comments) extracted per group also varied, i.e. 80 in group 1, 89 in group 2, 55 in group 3 and, 17 in group 4 (Table 4). Thus, in total, 250 posts (comments) from all four ODGs (Table 4) were collected and analysed.

Analysis of data from all four ODGs showed that the nature of discussion topics (threads) was different in each discussion group apart from one topic, i.e. medical image viewer, which was common between group 1 (discussion thread No. 2) and group 3 (discussion thread No. 3) (Table 4).

The thematic analysis of textual data comprising 250 posts (comments) led to the identification of two major themes, i.e. limitations in the current PACS and solutions for improving PACS functionality. Each of these themes comprised different sub-themes that are reported below.

Theme 1—Limitations in Current PACS

The theme of key limitations in the current generation of PACS comprised six sub-themes (Fig. 1), which are reported as follows.

Table 2 Participants' geographical location (country and number of participants)

North America		Europe		Asia		Latin America		Africa		Australia		Information not available
USA	81	UK	5	Pakistan	3	Venezuela	3	Botswana	1	Australia	1	1
Canada	6	Belgium	3	Saudi Arabia	3	Panama	1	Egypt	1			
Mexico	1	Spain	2	India	2	Peru	1					
		France	1	Kuwait	1							
		Germany	1	China	1							
		Malta	1	UAE	1							
		Netherlands	1									
		Norway	1									
		Switzerland	1									
Total	88		16		11		5		2		1	1

Table 3 Participants' professional background

Professional background	Count	%
Engineers and R&D managers	33	26.6
IT and informatics consultants	30	24.2
PACS administrators and implementers	29	23.4
Sales and Marketing consultants	6	4.8
Regulators	5	4.0
Chief Executive Officers (CEOs)	5	4.0
Radiologists	4	3.2
Technologists	3	2.4
Clinicians	2	1.6
Miscellaneous	7	5.6
Total	124	100

Problems in Viewing, Copying, and Importing Images and Data

Findings showed that PACS units supplied by different vendors lead to difficulties in viewing and importing images due to differences between PACS units such as not having DICOM directories or lack of supply of all necessary files in PACS CDs (compact disc)/DVDs (digital versatile disc, formerly digital video disc).

> A lot of the CDs from various vendors do not have the DICOM directory in the root directory of the CD/DVD. This causes a lot of issues. Options are to manually copy the DICOM files into the appropriate processing folder(s). Or to have the vendors re-burn the CD using strictly a DICOM format. A lot of vendors are using

Table 4 Discussion groups by threads, participants, and posts

Discussion groups and threads (discussion topics)	Participants		Posts (comments)
Thread ID and description	Total	Number that participated in other discussion groups and threads	Times comments made
Discussion group 1			
1. Future trends in PACS	11	7	16
2. Medical image viewer	4	2	4
3. PACS and the EMR/EHR	6	2	8
4. Critical problems and solution to consider while implementing open source PACS	5	3	8
5. A plea to PACS and modality implementation engineers, change the default AE title	18	5	28
6. Concerns about the way US modalities number images	7	2	12
7. DICOM for mobile devices	5	3	4
Discussion group 2			
1. EMR and imaging: interface designs to enable viewing of patient images in an EMR/API, URL, PDF, SC and How well did it work, any pros or cons to share?	8	1	8
2. How much should a PACS administrator know, do when it comes to (PACS) interfaces?	6	1	10
3. The quest for IT expertise to support healthcare technology	4	1	4
4. The RIS is dead	8	0	20
5. Tracking patient radiation dose reports in PACS	7	2	25
6. Full functional PACS using DCM4chee and e-film workstation with some difficulties	5	1	5
7. The problem in cardiology, the stress room when sending images to PACS it never goes on the first try, when sent a 2nd time it goes. Any thoughts why?	12	3	26
Discussion group 3			
1. 3D mammography: study storage	6	0	7
2. Scoping and planning for new PACS project at a referral hospital	8	1	13
3. Medical image viewer	7	2	14
4. Import/export DICOM on CD/DVD	14	1	21
Discussion group 4			
1. Do we need a PACS solution?	9	2	9
2. How to back-up EMR/PACS data, Tape, Optical Disk, or Hard Disk?	4	1	4
3. What's the average cost for cloud based pay per use PACS?	4	1	4

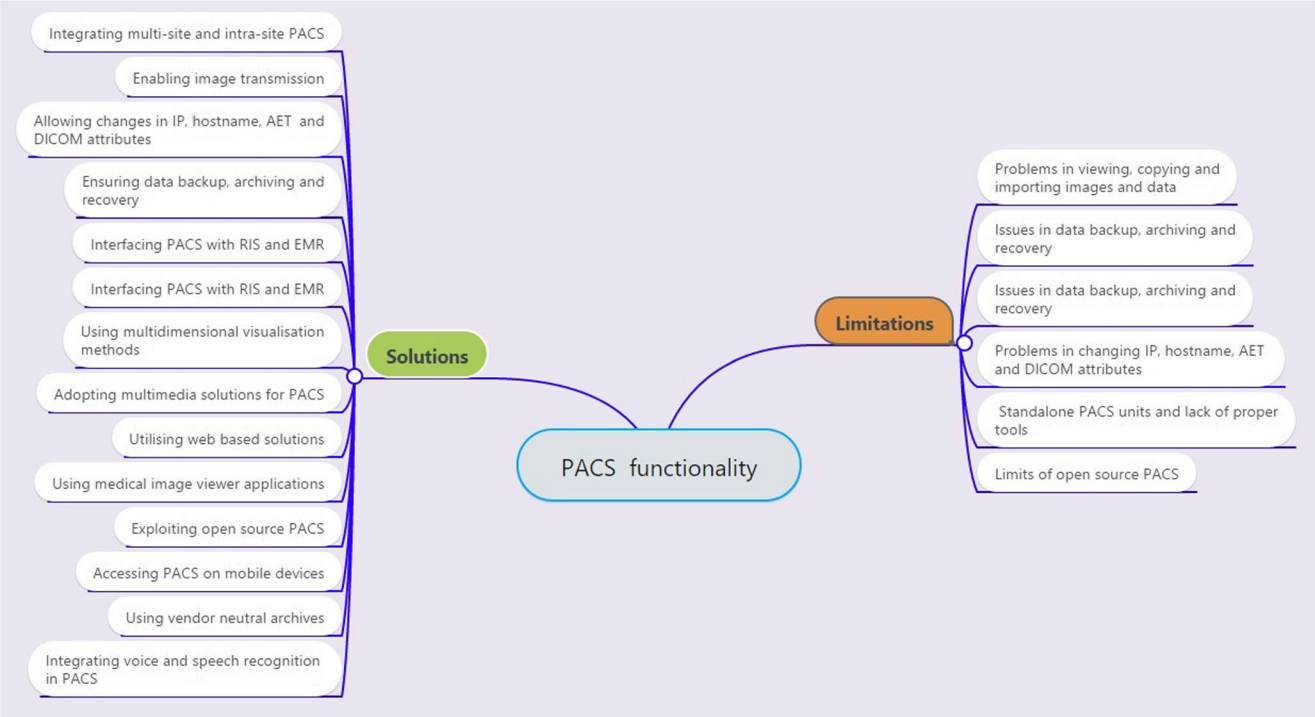

Fig. 1 Limitations in and solutions for enhancing PACS functionality

> their own viewers on the CDs that use jpegs. (Discussion group 3, Thread 4, Participant 11)
> I use a number of programs – send image… My biggest issue with CDs is that there are some vendors who don't send Part 10 files (of DICOM) in their CDs. (Discussion group 3, Thread 4, Participant 12)

It was also found that exchanging data via CDs/DVDs was not only a traditional way but also very time-consuming and expensive when all reports and images could be presented through the Internet to both the referring physician and the patient.

> Why are facilities still using CDs / DVDs when study/ report /views can be made available to patients and ref physicians via the internet? (It) seems really time-consuming and expensive. (Discussion group 3, Thread 4, Participant 13)

Issues in Data Backup, Archiving, and Recovery

The findings revealed that backup, archiving, and recovery were critical issues in PACS. The participants argued that the recovery system in PACS was not well developed and the PACS data could be lost in an accident. They suggested that due to accidents such as fire or water in the server room, there was a possibility of losing data if it was not backed up, and the recovery would not be a true recovery despite paying huge costs.

> One thing that enterprises both large and small need to realise is that Disaster Recovery is not back up.…True Disaster Recovery is a replica either online or offline of all your data in a different geographical location. That may be another rack in the server room or an offsite location. Just remember a fire in the server room or burst water main above the server room that fills the server room with water, and you still have no data. (Discussion group 1, Thread 4, Participant 3)

The findings showed that all necessary arrangements for disaster recovery were imperative; otherwise, the recovery would be very costly.

> Disaster recovery [DR], not many people see this important until you are hit with data-loss. I have seen hospitals don't invest on this, but spend thousands $$ when they get hit. Disaster recovery is not just storage - it includes Application and Database Servers. RAID [redundant array of inexpensive (independent) disks], Server virtualisations are some of the key features of DR (Discussion group 1, Thread 4, Participant 2)

Difficulties in Transmitting Images

The findings showed that some PACS users could face difficulties in transmitting images.

> We have a problem in Cardiology, the Stress room. When sending images to our PACS it never goes on the first try, when sent a 2nd time it goes. Any thoughts why anyone? Thanks (Discussion group 2, Thread 7, Participant 7).

The participants suggested that difficulties in transmitting images could be due to issues in the network and the hardware. These issues were more likely encountered in PACS units especially the PACS devices that were in operation for about 10 years or more. In addition, the Internet bandwidth and speed were also alleged to lead to difficulties in transmitting PACS images.

> Performance on the network is only as good as the weakest link. Any device that was put into place in the last 10 years is probably already at 100. Hard coding it can work for misbehaving devices, but this should not be necessary. Have your network person check the speed of the port that the device is connected to. (Discussion group 2, Thread 7, Participant 7).

Problems in Changing IP, Hostname, AET, and DICOM Attributes

The findings revealed that while using PACS, some participants encountered problems in changing some parameters such as the IP (internet protocol), hostname, AET (application entity title), and hardcoded DICOM attributes, e.g. data element.

> Using duplicate AET can also cause [a] big problem. Particularly with QR. (Discussion group 1, Thread 5, Participant 25)

Standalone PACS Units and Lack of Proper Tools

Some participants raised the issue of PACS units being standalone and a lack of supply of proper tools by PACS vendors.

> I do not feel that the PACS vendors are providing us the proper tools either. Most of our PACS vendors are still offering Silo'd systems, Radiology, Cardiology and some have meagre "othero logies" incorporated into their products. (Discussion group 2, Thread 4, Participant 2)

Limits of Open Source PACS

The findings showed that users of open source PACS could face a number of critical issues in regard to the workflow, security issues, and data storage, processing, and migration.

> Workflow, not all open sources provide the necessary workflow that fits your Radiology department, especially when it comes to Routing and Reporting. This needs additional software. …. Security and HIPAA [Health Insurance Portability and Accountability Act], simple HTTPs [hypertext transfer protocols] are beyond the scope of the software's alone, it needs [a] bit more than installing software. …. Last but the most basic stuff, is [a] plan for migration. This again first time PACS users will ignore and will realize the moment they are hit with bottlenecks like storage space. (Discussion group 1, Thread 4, Participant 3)

Theme 2—Solutions for Increasing PACS Functionality

The theme of solutions for increasing PACS functionality comprised 14 sub-themes (Fig. 1) that are presented below.

Integrating Multisite and Intrasite PACS

The findings showed that integrating PACS units within a hospital and between different hospitals would increase the functionality of PACS.

> … multi-site integration … and enterprise PACS. (Discussion group 1, Thread 6, Participant 7)

The participants suggested that multisite integration creating an enterprise-wide PACS would provide a single point of storing all medical images, which could reduce costs, minimise risks, and enhance efficiency across the users and the departments. Thus, the overall benefits of multisite integration of PACS would lead to consolidation of medical images; hence, delivering a better care via the patient-centred approach.

> …a single integration point for all medical imaging assets, lowering costs and risks through the UCP's [universal clinical platform] ability to work with different systems – enabling flexibility and efficiency across users and departments. ….a solution that … drives better care delivery through a patient-centric approach by consolidating medical images. …. (Discussion group 2, Thread 4, Participant 8)

However, participants suggested a need for an advanced level of integration of PACS systems between hospitals with a common data governance framework.

> Advanced level of Enterprise PACS integration (multiple sites with a common data governance). (Discussion group 1, Thread 6, Participant 13)

Enabling Image Transmission

Findings showed that for addressing the issue of difficulties encountered in transmitting images, PACS users can apply different solutions such as checking the local Internet network.

> If you have a laptop with DICOM software, try plugging the laptop into the network in the same area and see if the performance is any different. (Discussion group 2, Thread 7, Participant 7)

In addition, participants suggested to checking for any network hardware issues for solving problems in the transmission of digital medical images.

> Sounds like a network hardware issue. ... Some switches can take up to a minute or so to allow a network device back on the network due to STP [spanning tree protocol]... Additionally, it could be an ARP caching issue depending upon how the receiving device is configured. (Discussion group 2, Thread 7, Participant 7)

Allowing Changes in IP, Hostname, AET, and DICOM Attributes

For solving issues encountered in changing IP, hostname, AET, and DICOM attributes, participants suggested the involvement of PACS administrators and users in the early stages of PACS implementation so that they have sufficient information and directions from the installation engineers. The involvement of PACS administrators and users was also imperative to gain some experience in installation and implementation of PACS including how to change the naming structure and other things.

> The PACS Admin should be in control of AET naming structure.., the PACS Admin needs to be involved during planning stages of equipment installation. Having an open dialog with the installation engineer is crucial. Installation engineers (like most of us) are under time constraints. Sometimes it's difficult to get in contact with PACS Admins, so they might be forced to make up their own AET's. Not a good scenario!! (Discussion group 1, Thread 5, Participant 25)

Ensuring Data Backup, Archiving, and Recovery

The findings also revealed that ensuring backup, archiving, and recovery were critical issues for PACS users.

> Before you start backing up the data, you need to have restored plan. Since PACS data can grow to tens of terabytes within years, I feel, one should look for archive options and not backups for large discrete data sets. Also, synchronous replication of the storage can be a good option. (Discussion groups 4, Discussion thread 2, Participant 1)

In addition, participants suggested robust plans for data storage and migration very essential for addressing issues in PACS data backup, archiving, and recovery.

> Last but the most basic stuff is [a] plan for migration. This again first time PACS users will ignore and will realize the moment they are hit with bottlenecks like storage space. (Discussion group 1, Discussion thread 4, Participant 3)

The participants, however, emphasised upon the processes rather than the choices for the medium and tools of PACS data storage.

> Choice of storage media is not the priority. It is the process that needs to be automatic and completely reliable. (Discussion group 4, Thread 2, Participant 2)

Interfacing PACS with RIS and EMR

The participants suggested that PACS must be interfaced with other hospital systems especially with the RIS and EMR (electronic medical records). They also stressed for an expansion of PACS interfacing for meeting the needs of radiologists and improving radiology workflow. However, the participants warned that these changes in the interfacing could involve extra costs.

> I guess it depends on your vendor and if you interface your PACS with your RIS. Our vendor offers custom fields that we can name anything we want. The techs pull the dose info of the modality and enter this into a custom field in PACS. We have … mapped our custom field in PACS (using the OBR segment to map) to insert the information into our final report in our RIS and

ultimately our EMR. We are able to send dose info from our CT scanner directly to our PACS, but to have this information automatically inserted into the report costs more than we are willing to pay now. (Discussion group 2, Thread 5, Participant 1)

Applying Open Standards for Data Interoperability and System Integration

The findings showed that PACS functionality could be improved with the use of open standards for data interoperability and system integration and security and migration away from Windows XP.

Security and migration away from Windows XP. User names and passwords Access to only your patients HIPAA compliance is [the] key! (Discussion group 1, Thread 1, Participant 6)

Using Multidimensional Visualisation Methods

In regard to enhancing the functionality of PACS, the participants suggested that it could be enhanced with multiside visualisation methods with fast network access for accessing images such as through using mobile devices.

Fast multidimensional visualisation methods with parallel processing for rendering on the server side with fast network access from thin clients for display (mobile devices). (Discussion group 1, Thread 1, Participant 15)

Adopting Multimedia Solutions for PACS

Participants suggested that using multimedia solutions such as adoption of Halogenic PACS with 3D functionality would improve the functionality of PACS.

Hologic is a system that will produce 3D images and receiving/storage … PACS is able to store and display processed DICOM images, but … ultimate goal [is] to store entire study as well. ... Also, …found out … that …PACS is able to store BTO [Baytex Organix! 2001 Language] objects and Hologic is able to query/retrieve back. (Discussion group 3, Thread 1, Participant 4)

They also suggested that the functionality of PACS can also be improved by using multimedia archiving and communication systems (MACS).

There are "MACS"… We have good experiences with them. Agile, flexible, open... (Discussion group 1, Thread 3, Participant 7)

Utilising Web-Based Solutions

Findings showed that exploiting web-based solutions such as Web/HTTP and cloud for connecting multisite PACS and connecting PACS with other hospital systems, e.g. RIS, HIS, and EMR, could be helpful in enhancing PACS functionality. In this regard, participants suggested that some supporting technologies and solutions would be required such as QIDO-RS, WADO-RS and HL7 (explained in the following quote).

The Future PACS is all about Web/HTTP and should support. Layer between RIS and PACS will get depleted and unified. Reports and images all part of the same archive. Easy integration with EMR, HER [electronic healthcare records] and HIS using Rest API based standards…. Some HTTP technologies that would need to make this happen are: Query using QIDO-RS [Query based on ID (for DICOM Objects) by RESTful Services], Download (retrieve) using WADO-RS [Web Access to DICOM Objects by RESTful Service], Upload (store) via STOW-RS [STore Over the Web by RESTful Services], XDS-i (cross-document exchange for imaging will use above 3 services) [Cross Enterprise Document Sharing profile], next version of HL7 [Health Level-7, as International standard] some supporting links. (Discussion group 1, Thread 1, Participant 16)

Participants also suggested the use of the cloud for connecting multisite PACS and managing data backups and recovery with a potential for reducing capital costs.

The cloud is a wonderful place to store data to be used between sites, manage backup and disaster recovery, and reduce capital expenditure. (Discussion group 4, Discussion thread 3, Participant 4)
Multi-Tenant Primary workflow data on the Cloud at [the] enterprise level and the images on local VNA [vendor neutral archive] / PACS at Hospital level. (Discussion group 1, Thread 1, Participant 16)

Nevertheless, participants showed concerns about using the cloud-based solutions for PACS as follows.

However, with the cloud comes a new worry, the stability of the vendor as a developer and as a business. (Discussion group 4, Thread 3, Participant 4)

Using Medical Image Viewer Applications

The findings showed that PACS functionality could be enhanced with IT applications such as the medical image viewer, which will support presenting medical images on any computer installed with this application.

> A medical image viewer is just an application that doesn't need any installation to work. … Medical image viewer needs hardware (whatever it is) and a browser to work. (Discussion group 1, Thread 2, Participant 2)

Exploiting Open Source PACS

The findings revealed that open source PACS could be a solution for improving PACS functionality and lead to cost savings.

> Using Open source PACS at each site and a custom Radiology Workflow solution…solved with Virtual LAN [local area network] zone and …the MPLS [multiprotocol label switching] connection …. This is how we solved with a huge cost saving... (Discussion group 1, Thread 5, Participant 24)

Accessing PACS on Mobile Devices

Participants suggested that accessing PACS on mobile phones was a way forward to enhance the PACS functionality. Access to PACS on mobile devices could be realised by using the WG-27, i.e. Web technology for DICOM. In this regard, participants suggested the use of DICOM Web solutions for uploading DICOM images and using mobile devices as platforms for presenting DICOM images on mobile phones.

> … WG27 refer to these RESTful [representational state transfer] DICOM services as "DICOM Web". I … suggest we rally around it rather than invent a new one. FHIR [fast health interoperable resources] solves a different problem than DICOM Web, they are not in competition with one another. (Discussion group 1, Thread 7, Participant 3)

Using Vendor Neutral Archives

The findings revealed that the use of a vendor neutral archive (VNA)—a medical imaging technology, with multimodality platforms—would provide enterprise-wide solutions for storing, archiving, and multisharing of PACS images.

> VNA & Enterprise solution to accommodate ever other clinical documentation. MULTI modalities platform. Sharing images rather than store them. (Discussion group 1, Thread 1, Participant 8)

However, participants argued that sharing data between multiple sites and institutions could not be feasible due to clinical data governance and administrative reasons.

> The big issue is access to shared data from multiple patients' episodes since that data is owned by different facilities with different policies. It is more an administrative and data format issue than a technological. (Discussion group 1, Thread 3, Participant 4)

Integrating Voice and Speech Recognition in PACS

The findings showed another solution for enhancing PACS functionality would be integrating and using voice integration and speech recognition in PACS, which would improve radiologists' work such as expediting data search queries.

> We can also see a shift in how [the] demographics of the patient can be queried in the work list. It will be more of voice-based search thereby reducing the time of Technologist and Radiologist. (Discussion group 1, Thread 1, Participant 4)

Discussion

This exploratory study is based on the PACS professionals' perspectives on PACS, which were captured from four ODGs that were accessed via the LinkedIn, which is an online social network of professionals from diverse professions such as PACS users and vendors. We have identified a set of limitations in the current generation of PACS devices and a range of solutions for addressing the limitations identified in the current PACS technology. The limitations identified in PACS include problems associated with implementing open source PACS, image transmission issues, network hardware issues, and difficulties in changing specific settings such as IP, hostname, AET, and hardcoded DICOM attributes (data element).

Some of these limitations such as difficulties encountered in image transmission issues and changing specific settings such as IP, hostname, AET, and hardcoded DICOM attributes could be important issues for some users such as novice users because these are minor issues for the expert users. Thus, these issues do not warn much discussion from the perspectives of the wider community of PACS users and implementers. Nevertheless, issues such as difficulties encountered in

implementing an open source PACS can be an important issue from the perspectives of PACS users; hence, this issue is discussed below.

In addition, our study has identified a range of solutions that could help in improving the limitations in the functionality of the current generation of PACS. The solutions identified include multisite PACS integration, connecting PACS systems between different hospitals, adopting open source PACS, and using multimedia. Moreover, our study has revealed that using web-based solutions for PACS would help in connecting multihospital PACS and connecting PACS with other hospital systems such as RIS and HIS. More importantly, our findings suggest that PACS on mobile phones could be useful especially for transferring DICOM images to smart mobile phone [34, 35].

The major limitations in the current generation of PACS technology and their solutions are discussed here.

Open Source PACS

Adoption of open source technologies such as open source PACS in medical imaging is an important development in imaging informatics [36]. From the users' perspective, open source PACS is more appealing mainly because it is free of cost [37], which is the most important issue for many PACS users, especially in resource-poor developing countries [38], small organisations [39], and research institutions [40]. However, our findings show that open source PACS has many limitations such as problems in the workflow (e.g. routing and reporting), data storage limitations, processing and migration problems, and security concerns. These finding may suggest that users of open source PACS should not expect that the open source PACS would provide the same level of functionality, ease of use, and applications as that provided by a commercial vendor developed PACS. Nevertheless, the functionality of open source PACS is being improved through the addition of new applications and features [41] and more open source PACS are available and being used [42]. However, the adoption of open source PACS could be challenging due to higher costs associated with the installation, maintenance, and training as well as limited functionalities such as a limited storage and computational capacity [42]. PACS users, therefore, need to consider the opportunities and limitations of both the open source PACS and the vendor-driven commercial PACS.

Vendor Neutral Archive and Web-Based Solutions for PACS

Our findings show that vendor neutral archive (VNA) would provide solutions to the problems of combining radiological images and patient records under one system, which could be under one control [43]. The VNA could solve the issues with regard to the storage and viewing of medical images and it would probably replace most of the medical image systems including PACS in the near future [44]. However, there are several issues associated with the VNA. For example, the definition of VNA standards, features, specifications, neutrality, interoperability, and conformance to open standards, and costs are some of the key factors that could be significant barriers to the adoption and implementation of VNA [45]. It is therefore argued that addressing the key issues such as the time, money, and expertise are essential before the VNA technology is widely adopted and implemented by healthcare establishments. In addition, VNA adoption has been criticised for binding the users in a contract with vendors of VNA, thus, nullifying the neutrality issue central to the VNA [46]. It is therefore not unlikely that instead of VNA, some healthcare organisations might opt for using virtual archives such as Cloud PACS through cloud computing services for processing, storing, exchanging, and using large volumes of clinical data including medical images and because the cloud computing is associated with several advantages such as ubiquitous access and cheaper rates, and lower maintenance and management overhead [47]. However, cloud-based PACS and other services are not free from limitations and challenges mainly the data security and privacy [47, 48], which could be addressed through different means and mechanisms [49]. However, in some countries such as the UK, health and care data only be hoisted on the cloud services in countries, such as the USA, the UK, and other countries in Europe, where there is a privacy shield [50].

Voice Recognition in PACS

Our findings have revealed that full integration of voice recognition in PACS would support radiologists by saving their time. For example, the radiologist can use voice-based searches of image databases on PACS, which could save their time in writing queries or searching through database indices. The importance of voice recognition in PACS has been described as the 'third hand of the radiologist' (personal communication by a senior radiologist and expert in PACS at the SPIE conference 2015 on the future of the PACS). In addition, the integration of voice recognition in PACS has been used as one of the important features for selecting the best PACS by radiologists [51] and PACS administrators [52]. Given these advantages of the voice recognition, adoption of PACS with voice recognition has begun in many hospitals, especially in the developed countries such as the USA [53].

Nevertheless, the use of voice recognition is associated with a number of drawbacks such as errors in voice recognition transcriptions, the distraction of the user and slowing down of the radiologists' productivity [54, 55]. In addition, the use of voice recognition in PACS in hospitals in many developing countries could be more challenging [56] for a

number of reasons such as lack of the informatics infrastructure and systems and costs, which could favour adoption of open source PACS and associated tools [38]. More importantly, certain types of medical devices despite being available are not used by healthcare professionals due to a variety of reasons such as personal choice and experience of the user [57, 58]. It is therefore likely that the voice recognition tool in PACS might not be easily adopted and used despite it being available in radiology departments due to radiologists' personal choice and lack of training and encouragement.

Backup Solutions for PACS

Backup for PACS data is an important issue because the existing backup solutions for PACS are inadequate, infallible, costly, and time-consuming [59], especially because the PACS data are growing at a very fast rate by both the volume and the time ([60], p., 369). Thus, backup solutions for PACS are critical especially to secure PACS data [61] and to avoid risks to patient care due to the loss of data [62], which could occur in an unforeseen data disaster incidences such as fire in a server room [63] or any malign hacking activity involving health data and healthcare organisations [64]. It must also be emphasised that the post-disaster data recovery would not be the actual recovery and the full backup. Thus, data backup in PACS is an important feature in the selection of PACS from the perspectives of radiologists and PACS administrators [51, 52]. These findings suggest that PACS developers need to develop, and PACS implementers need to adopt, backup systems and solutions for the PACS that are robust and effective [65].

Implications of the Findings

The findings of this study have implications for both the PACS technology developers and PACS implementers and users as follows.

PACS Technology Developers (Vendors) Our findings have revealed a number of limitations in the current generation of PACS technology. These limitations include limited storage, limited windows in the PACS workstation, and standalone PACS units from different vendors that do not integrate with each other. Therefore, PACS developers need to address these issues in the next generation of PACS.

In addition, our study has shown that there are a number of barriers in improving PACS functionality, integration, and accessibility, and there are high costs associated with adoption of the latest solutions for improving the PACS functionality. The PACS vendors could develop and provide affordable solutions for improving PACS functionality.

PACS Implementers and Users We have identified a number of limitations in using and accessing PACS including issues in integrating PACS such as integrating PACS developed by different vendors, integration of PACS between hospitals, and integration of PACS with other hospital systems. Other issues encountered by some users include challenges in remote access to PACS beyond the daily workplace. Hospital managers and PACS managers therefore need to adopt the latest solutions that can help in improving the functionality, integration, and access to PACS.

In addition, our study has shown that there are issues around the PACS training to various types of PACS users. Therefore, hospital managers in charge of education and training need to develop programmes for training on PACS including the latest PACS applications. Moreover, some of the potential users of PACS might have reservations for using the PACS; therefore, there is a need to involve and consult with these potential users of PACS prior to PACS implementation in healthcare organisations.

More importantly, adopting the latest solutions for PACS based on the information and communication technologies such as web-based PACS could have implications for data security and data loss [66, 67]. Therefore, the PACS users, implementers, and hospital managers need to ensure adoption of appropriate measures to ensure data security [66, 67] and backup solutions for PACS [68] that are essential to address the issues of potential breaches and losses of PACS data [67].

Strengths and Limitations of the Study

Strengths of this study include the collection and analysis of rich qualitative data from a range of PACS professionals involved in the development, evaluation, applications, and implementation of PACS. The perspectives of these professionals were captured through unobtrusive measures, i.e. online observations of 5 ODGs with their membership devoid of any geographic limitations, which will not be possible with either face to face, telephone interviews, or online surveys.

The limitations of this study include access to only four ODGs via LinkedIn. There could be many more ODGs that could have provided further insights relevant to the objective of our study. Future research involving online data may take a note of these limitations.

Conclusions

The functionality of the current generation of PACS is limited due to a number of different factors but there are various technological solutions to address these limitations in PACS as identified in this study. Some of the solutions identified in this study could be a technological push from the vendors' perspectives. These solutions need to be evaluated on several

aspects such as the cost, implementation, management, effectiveness, and security, which are imperative from the perspectives of PACS users. Thus, both the limitations in the current generations of PACS and the solutions for enhancing the PACS functionality identified in our study have implications for both the PACS developers, users, and implementers as discussed in this paper.

Capturing online conversations for research provide many insights on the topic of research enquiry; however, these insights are random and lack the depth and supporting evidence. Thus, online conversations via discussion forums and groups are more useful only for exploratory studies. Findings of research studies based on online data need to be confirmed through scientific enquiry using other means of data collection from the population of interest.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

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References

1. Law MY, Zhou Z: New direction in PACS education and training. Comput Med Imaging Graph 27:147–156, 2003
2. Arora D, Mehta Y: Use of picture archiving and communication system for imaging of radiological films in cardiac surgical intensive care unit. J Anaesthesiol Clin Pharmacol 30:447–448, 2014
3. Liu BJ, Huang HK: PACS and Medical Imaging Informatics for Filmless Hospitals. Amsterdam: Academic Press, 2008
4. Top M: Physicians' views and assessments on Picture Archiving and Communication Systems (PACS) in two Turkish public hospitals. J Med Syst 36:3555–3562, 2012
5. van de Wetering R, Batenburg R: Towards a theory of PACS deployment: an integrative PACS maturity framework. J Digit Imaging 27:337–350, 2014
6. Huang HK: PACS and Imaging Informatics: Basic Principles and Applications. Hoboken: Wiley-Blackwell, 2010
7. Duerinckx AJ: Introduction to two PACS' 82 Panel Discussions edited by André J. Duerinckx "Equipment Manufacturers' View on PACS" and "The Medical Community's View on PACS". J Digit Imaging 16:29–31, 2003
8. Inamura K, Kousaka S, Yamamoto Y, Sukenobu Y, Okura Y, Matsumura Y, Takeda H: PACS development in Asia. Comput Med Imaging Graph 27:121–128, 2003
9. Huang HK: Short history of PACS. Part I: USA. Eur J Radiol 78: 163–176, 2011
10. Mendel JB, Schweitzer AL: PACS for the developing world. J Glob Radiol 1:5, 2015
11. Strickland NH: PACS (picture archiving and communication systems): filmless radiology. Arch Dis Child 83:82–86, 2000
12. Xue Y, Liang H: Understanding PACS development in context: the case of China. IEEE Trans Inf Technol Biomed 11:14–16, 2007
13. Mackinnon A, Billington R, Adam E, Dundas D, Patel U: Picture archiving and communication systems lead to sustained improvements in reporting times and productivity: results of a 5-year audit. Clin Radiol 63:796–804, 2008
14. Schooley B, Hikmet N, Atilgan E: Health IT Maturity and Hospital Quality: Effects of PACS Automation and Integration Levels on US Hospital Performance. Proc. The 2016 International Conference on Computational Science and Computational Intelligence (CSCI 2016) Las Vegas, Nevada, USA, Dec 15–17, 2016 Year
15. Sevenster M, Travis AR, Ganesh RK, Liu P, Kose U, Peters J, Chang PJ: Improved Efficiency in Clinical Workflow of Reporting Measured Oncology Lesions Via PACS-Integrated Lesion Tracking Tool. Am J Roentgenol 204:576–583, 2015
16. Matta EJ, Nunez-Atahualpa L, West OC: Use of a PACS-Based Tool for Improving Communications With Referring Physicians. J Am Coll Radiol 14:1455–1458, 2017
17. Mendoza J, Mallari-Ramos P, Thoren K, Kitley C: Interventional Radiology in the Combat Environment. Curr Trauma Rep 3:249–256, 2017
18. Godinho TM, Almeida E, Silva LAB, Costa C: Integrating multiple data sources in a cardiology imaging laboratory. Proc. e-Health Networking, Applications and Services (Healthcom), 2016 IEEE 18th International Conference on: Munich, Germany
19. Sarkar AK, Khan R, Pandey C: Challenges in Data Migration in Super Speciality Tertiary Care Hospital: A case study. Int J Adv Res Comp Sci 8, 2017
20. Reiner BI: The challenges, opportunities, and imperative of structured reporting in medical imaging. J Digit Imaging 22:562–568, 2009
21. Graban M: Lean Hospitals: Improving Quality, Patient Safety, and Employee Engagement. Boca Raton: CRC Press, 2016
22. Zheng K, Padman R, Johnson MP, Diamond HS: An interface-driven analysis of user interactions with an electronic health records system. J Am Med Inform Assoc 16:228–237, 2009
23. Da Cunha JV, Orlikowski WJ: Performing catharsis: the use of online discussion forums in organizational change. Info Organ 18: 132–156, 2008
24. LinkedIn Corporation About LinkedIn. Available at https://press.linkedin.com/about-linkedin. Accessed 2nd August 2018.
25. Grajales, III FJ, Sheps S, Ho K, Novak-Lauscher H, Eysenbach G: Social media: a review and tutorial of applications in medicine and health care. J Med Internet Res 16:e13, 2014
26. Barley SR: Images of imaging: notes on doing longitudinal field work. Organ Sci 1:220–247, 1990
27. QSR International Pty Ltd: NVivo qualitative data analysis Software, 2012
28. Seale C, Charteris-Black J, MacFarlane A, McPherson A: Interviews and internet forums: a comparison of two sources of qualitative data. Qual Health Res 20:595–606, 2010
29. Adair CE, Marcoux G, Williams A, Reimer M: The Internet as a source of data to support the development of a quality-of-life measure for eating disorders. Qual Health Res 16:538–546, 2006

30. Sixsmith J, Murray CD: Ethical issues in the documentary data analysis of internet posts and archives. Qual Health Res 11:423–432, 2001
31. Eysenbach G, Till JE: Ethical issues in qualitative research on internet communities. BMJ 323:1103–1105, 2001
32. Braun V, Clarke V: Using thematic analysis in psychology. Qual Res Psychol 3:77–101, 2006
33. Braun V, Clarke V: Successful Qualitative Research: A Practical Guide for Beginners. London: Sage, 2013
34. Matar R, Renapurkar R, Obuchowski N, Menon V, Piraino D, Schoenhagen P: Utility of hand-held devices in diagnosis and triage of cardiovascular emergencies. Observations during implementation of a PACS-based system in an acute aortic syndrome (AAS) network. J Cardiovasc Comput Tomogr 9:524–533, 2015
35. Choudhri AF, Norton PT, Carr TM, Stone JR, Hagspiel KD, Dake MD: Diagnosis and treatment planning of acute aortic emergencies using a handheld DICOM viewer. Emerg Radiol 20:267–272, 2013
36. Nagy P: Open Source in Imaging Informatics. J Digit Imaging 20: 1–10, 2007
37. Ratib O, Rosset A, Heuberger J: Open Source software and social networks: disruptive alternatives for medical imaging. Eur J Radiol 78:259–265, 2011
38. Ratib O, Roduit N, Nidup D, De Geer G, Rosset A, Geissbuhler A: PACS for Bhutan: a cost effective open source architecture for emerging countries. Insights Imaging 7:747–753, 2016
39. Valente F, Silva LAB, Godinho TM, Costa C: Anatomy of an Extensible Open Source PACS. J Digit Imaging 29:284–296, 2016
40. Valeri G, Zuccaccia M, Badaloni A, Ciriaci D, la Riccia L, Mazzoni G, Maggi S, Giovagnoni A: Implementation, reliability, and feasibility test of an Open-Source PACS. La Radiologia Medica 120: 1138–1145, 2015
41. Costa C, Ferreira C, Bastiao L, Ribeiro L, Silva A, Oliveira JL: Dicoogle - an open source peer-to-peer PACS. J Digit Imaging 24:848–856, 2011
42. Kagadis GC, Alexakos C, Langer SG, French T: Using an open-source PACS virtual machine for a digital angiography unit: methods and initial impressions. J Digit Imaging 25:81–90, 2012
43. Gray M: ACS Paradigm Shift: Moving control of the data from display applications to an enterprise access infrastructure. Context Magazine:1–16, 2014
44. Dennison D: PACS in 2018: an autopsy. J Digit Imaging 27:7–11, 2014
45. Cook R: Is VNA the future of image delivery? A platform independent archival system has strong appeal. Healthcare IT News, 2014
46. Digital Health Intelligence Limited Special Report: VNA and Data Storage. Available at https://www.digitalhealth.net/2016/11/special-report-vendor-neutral-archiving/. Accessed 2nd August 2018.
47. Kagadis GC et al.: Cloud computing in medical imaging. Med Phys 070901:40, 2013
48. Sun Y, Zhang J, Xiong Y, Zhu G: Data Security and Privacy in Cloud Computing. Int J Distrib Sens Netw 10:190903, 2014
49. Hamrioui S et al.: A Systematic Review of Security Mechanisms for Big Data in Health and New Alternatives for Hospitals. Wirel Commun Mob Comput 2017:6, 2017
50. NHS Digital NHS Digital publishes guidance on data off-shoring and cloud computing for health and social care. Available at https://digital.nhs.uk/news-and-events/latest-news/nhs-digital-publishes-guidance-on-data-off-shoring-and-cloud-computing-for-health-and-social-care. Accessed 2nd August 2018.
51. Joshi V, Lee K, Melson D, Narra VR: Empirical investigation of radiologists' priorities for PACS selection: an analytical hierarchy process approach. J Digit Imaging 24:700–708, 2011
52. Joshi V, Narra VR, Joshi K, Lee K, Melson D: PACS administrators' and radiologists' perspective on the importance of features for PACS selection. J Digit Imaging 27:486–495, 2014
53. Torrieri M: Talk vs. Type: Taking Another Look at Voice Recognition. Physicians Practice 21, 2011
54. Fox MA, Aschkenasi CJ, Kalyanpur A: Voice recognition is here comma like it or not period. Indian J Radiol Imaging 23:191, 2013
55. Hayt DB, Alexander S: The pros and cons of implementing PACS and speech recognition systems. J Digit Imaging 14:149–157, 2001
56. Hwang I-C, Lee KW, Park SS, Chanthanoulay S, Sisavanh M, Rajpho V, Kim M, Billamay S, Phangmanixay S, Oudavong B: The first picture archiving and communication system in Lao People's Democratic Republic: Changes in the utilization rate of imaging tests in the first year after implementation. Int J Med Inform 94:31–38, 2016
57. Shah SGS, Farrow A: Trends in the availability and usage of electrophysical agents in physiotherapy practices from 1990 to 2010: a review. Phys Ther Rev 17:207–226, 2012
58. Shah SGS, Farrow A, Esnouf A: Availability and use of electrotherapy devices: a survey. Int J Ther Rehabil 14:260–264, 2007
59. Faggioni L, Neri E, Castellana C, Caramella D, Bartolozzi C: The future of PACS in healthcare enterprises. Eur J Radiol 78:253–258, 2011
60. Chunn T, Honeyman J: Chapter 9. Storage and Database. Bellingham: Spie Press, 2000
61. Gutiérrez-Martínez J, Núñez-Gaona MA, Aguirre-Meneses H: Business Model for the Security of a Large-Scale PACS, Compliance with ISO/27002:2013 Standard. J Digit Imaging 28: 481–491, 2015
62. Mansoori B, Rosipko B, Erhard KK, Sunshine JL: Design and Implementation of Disaster Recovery and Business Continuity Solution for Radiology PACS. J Digit Imaging 27:19–25, 2014
63. Thurston S: ASP Configuration Handbook. A Guide for ISPs. Syngress: Rockland, 2001
64. Martin G, Ghafur S, Kinross J, Hankin C, Darzi A: WannaCry—a year on. BMJ 361, 2018
65. Kun W, Rui-dan S, Zeng-Xin L, Zhen C, Li-Hua Z: Robust disaster recovery system model. Wuhan Uni J Nat Sci 11:170–174, 2006
66. Anonymous: Lack of confidentiality with the Picture Archiving and Communication System (PACS). J R Soc Med 97:455–455, 2004
67. Mahlaola TB, van Dyk B: Reasons for Picture Archiving and Communication System (PACS) data security breaches: intentional versus non-intentional breaches. Health SA Gesondheid 21:271–279, 2016
68. Alhajeri M, Aldosari H, Aldosari B: Evaluating latest developments in PACS and their impact on radiology practices: a systematic literature review. Informatics Medicine Unlocked 9:181–190, 2017