A preliminary comparison of using handheld devices in promoting the healthcare performance within a radiology department in terms of diagnostic accuracy and workflow efficiency

Abdullah O. Alamoudi*, Syed Haque, Shankar Srinivasan and Dinesh P. Mital

Department of Health Informatics,
School of Health Related Professions,
University of Medicine and Dentistry of New Jersey,
Newark, 07107-3001, New Jersey, USA
Fax: 973-972-8540
E-mail: alamouao@shrp.rutgers.edu
E-mail: haque@shrp.rutgers.edu
E-mail: srinivsh@shrp.rutgers.edu
E-mail: mitaldp@shrp.rutgers.edu
*Corresponding author

Abstract: A preliminary research was conducted to compare the merits of using smartphones, iPad, and other tablet handheld devices with traditional systems in enhancing performance and workflow of radiology department. Review of work done on the topic was used as the secondary research method. There were not many works directly related to the topic. Hence, other related works were also reviewed. Nevertheless, handheld devices have many applications in telemedicine. In radiology, it is useful to transmit data and images to healthcare professionals for information, diagnosis and consultation. Image quality, screen size, resolution, transmission and response times are important in this aspect. In fact, different devices could differ in these and other technical aspects. These characteristics determine the relative usability of any handheld device. Although investment cost is high, patients receive healthcare at lower cost. Low cost community healthcare is also possible. Workflow efficiency from imaging procedure to diagnostic stage and finally to treatment phase is increased and performance of radiology professionals and the department are enhanced when handheld devices are used.

Keywords: diagnostic accuracy; mobile applications; picture archiving and communication system; PACS; radiology workflow; teleradiology.

Reference to this paper should be made as follows: Alamoudi, A.O., Haque, S., Srinivasan, S. and Mital, D.P. (2014) 'A preliminary comparison of using handheld devices in promoting the healthcare performance within a radiology department in terms of diagnostic accuracy and workflow efficiency', *Int. J. Medical Engineering and Informatics*, Vol. 6, No. 4, pp.355–364.

Biographical notes: Abdullah O. Alamoudi is currently a PhD student in UMDNJ and Lecturer at Majmaah University in Saudi Arabia, His research interests are in the fields of medical imaging, imaging informatics and medical education.

Syed Haque is Professor and Chair of the Department of Health Informatics at UMDNJ. His interest areas include healthcare outcomes measurement and research and healthcare data mining. He has published extensively in journals and in several conferences and has also served as Chair in several international conferences.

Shankar Srinivasan is currently an Associate Professor in UMDNJ's Health Informatics Department and has taught in universities in Singapore and Australia. His research interests are mainly in the areas of healthcare data analysis, neuro-fuzzy systems and enterprise wide healthcare web services. He has published in various international conference proceedings and journals.

Dinesh P. Mital is a Professor in the Health Informatics Department at Rutgers, USA. His areas of research include biomedical signal and image processing, clinical decision support systems, neural and fuzzy logic based applications, and artificial intelligence. He has published over 250 technical papers in various international conferences and journals.

1 Introduction

The advancements in information and communication technologies have revolutionised the way health information is gathered, disseminated, and used by healthcare providers, patients, citizens, and mass media, leading to the emergence of a new area and new language known as 'e-health' (Viswanath and Kreuter, 2007). The e-health refers to internet-based healthcare delivery. In current era, this improvement in using information and communication technologies will play the main role in enhancing the healthcare performance. Moreover, it is a system that may take more responsibility to solve problem of decisions in health field. In this paper, we have looked into a specific information and communication technology within the domain of e-health. The specific technology is handheld devices and its role in promoting healthcare performance within radiology department has been examined.

2 Research questions

What is the effect of using the handheld device (such as smart phones, iPad, and tablets) in enhancing the diagnosis performance and workflow efficiency in medical imaging department?

3 Aim

The aim of this study is to provide a detailed comparison of the characteristics of handheld devices to other medical imaging platforms to determine if it meets the current industry standard, and also to improve the performance of radiologist and medical imaging technologist.

4 Objectives

The objectives of this research are to examine the relevant scientific literature associated with the various aspects of the use of hand held devoices in the healthcare industry, particularly in the field of radiology; to identify the various aspects relating to the use of hand held devices in radiology departments; and to relate the various aspects of the use of hand held devices in radiology departments to improve healthcare performance including efficiency.

5 What we want to compare

- smart phones
- iPad
- tablets.

6 What we are comparing

- display quality
- speed
- accessibility
- usability
- portability
- costs (purchasing/running).

In this paper, secondary research is used for dealing with the above aspects to solve the research question. As there are not many works specific to radiology department, other e-health aspects are also reviewed below. The general conclusions from them can be adapted to radiology cases also.

7 Review of literature

7.1 Information technology in healthcare

Available and emerging information technology and communication technology for medical applications were reviewed by Gallaher (2005). These include mobile technologies, smart cards, global positioning and radio frequency identity cards. They are used in administration, monitoring and delivery of healthcare. The advantages of accuracy, timeliness, reliability, performance monitoring and accountability of service provider are listed. However, they require high investment. Mobile devices include notebook computer, tablets, smartphones, and PDAs. These are categorised on the basis of operating systems: Palm OS, Windows, Symbian, Smartphones and

embedded Linux OS. These are available to meet specific requirements also. For instance, high storage and fast processing power, facility to connect to other devices using Bluetooth or expansion slots, chips, backup with PC facility are main features. The evidence of Telehealth can be clearly seen in the case of HealthNet Uganda (*HNU*) is shown as a successful example of using mobile technology in community healthcare.

Some applications of handheld devices in the 'Internet for eHealth seminar' were presented and summarised by Wac et al. (2012). Although advances in medicine and technology enables people to live longer, lifestyles increase the early incidence of chronic ailments in life. Health systems are playing a critical role and they are only designed for acute cases. This leads to increasing healthcare costs to chronic patients. Emergence of high bandwidth wireless and mobile devices has led to new mobile healthcare (*mHealth*) services. In addition, highly customised vital sign telemonitoring of chronically ill patients based on body area networks (BAN) can be provided. These enable live transmission of data to healthcare personnel and real-time feedback to patients, which the patient can use for self-management of the disease. For example, elderly people can be kept in continuous contact with healthcare persons with real-time data for timely interventions. Long run healthcare facilitation at low cost is this possible. Dia-Trace technology to transform a smartphone to a mobile assistant for physical activity and food assessment (obesity) is an interesting example.

In an extensive review, Mosa et al. (2012) classified smartphone-based healthcare technologies and evaluate their relative functionalities. Turning now to the result of the study, out of the total of 83 applications, 57 were related to various aspects of healthcare. Smartphones are useful for evidence-based healthcare at care point and in clinical communications, disease self-management, remote monitoring of patients and patient education.

7.2 PACS management issues

Workflow and patient data management have facilitated these developments. The picture archiving and communication system (PACS) investments are often difficult to justify due to immediate use and returns from other imaging technologies like MRI or CT scans. Low perception about organisational impact of PACS is changing with gradual increase in number of (ageing) population and decrease in related healthcare staff.

7.3 Teleradiology

Bava (2011) discussed ICT applications in telemedicine. Specific chapters were devoted to radiology. The relevant points are discussed in this paper.

7.4 Definition

Teleradiology was defined as electronic transmission of radiological images across different places for diagnosis or consultation. During the last decade increased focus was given on image quality, fast networks for transmission and better compression of image algorithms. Moreover, increased digitalisation and reduced network and communication costs were achieved.

7.5 Teleradiology project results

7.5.1 Issues in EU countries

Non-existence of uniform healthcare systems prevents adoption of teleradiology across EU. In contrast, Inadequacy of national and international standards, integration of different systems, integrity, security and privacy of information are still some major issues. Integration of clinical data with radiological images, image quality assurance during transmission, regulations of countries, payment mechanisms across different national health systems are some administrative problems. Some standards of data and image quality and security assurance exist. Security is related to data, information, net and operational aspects. Confidentiality, integrity and availability (*CIA* triad) need to be ensured when implementing controls and systems confidentialities. High security networks, encrypted communications, integrity using approved standards, authentication using strong user name and password are some solutions.

7.5.2 EU projects

In EU projects on teleradiology, consultation requests were sent along with electronic patient records (*EPR*) and the image to the mobile device which has a smaller version of hospital software. Web browser can be used for additional information from EPR. Picture quality was satisfactory (62%) for consultation but was low (38%) for diagnosis. Regarding to transmission and reading time, the result was ranged from 10–35 minutes for different types of images and good quality diagnosis was obtained. The study of EU project showed that with faster networks, transmission time could be reduced to 5–10 minutes. Significantly, use of wireless technology independent of physical stations was used in different mobile sets failed.

7.5.3 Canadian project

In a Canadian project, iPhones and Android new generation smartphones were used in client-server architecture for interactive viewing of 2D and 3D images. Image rendering was made on the server before sending to smartphone. Interpretations and their times were similar in direct reading at hospital and smartphones. Sensitivity, accuracy and specificity were above 90% for different diseases.

7.5.4 Italian project

Security vulnerabilities were classified as logical, infrastructural, services and organisational. Requirements and control measures to deal with these vulnerabilities were listed. In an Italian project, methods and applications for reporting and consultations using tablets, smartphones and netbooks were studied. Small matrix images were used to reduce artefacts and improve image quality and resolution matching with resolution capability of smartphones. These mini-PACS could be transmitted direct to the mobile devices. Nevertheless, the innovative use of smartphones or tablets equipped with the required software for real-time image viewing images was evaluated in another project. The images were identical to those used in hospitals. The Samsung Galaxy tablet as an example of mobile devices and applications for teleradiology are now subjected to compliance with international standards and regulations. Software for iPads and iPhones,

in one study, CT and MRI were selected due to their low matrix less than the display resolution limits of smartphones and tablets. Apple iPhone 3 and 4, iPad 1 and 2, Android Nexus 1 Asus Transformer were found to be comparable. IT security issues related to smartphones are: device control and data protection, secure platform foundation, secure network communication and data protection. In the present series, measurement protocols for mobile teleradiology were evaluated for Android and Apple tablets. Standard images were stacked a the workstation in the hospital and sent to aycan mobile application using a 3G or Wi-Fi connection and a server only as a connection between sender and receiver and not storing patient data. The most interesting finding was that, with repeatable and controlled illuminations and display luminance conditions, satisfactory results were obtained as per measurement protocols. Both iPad and Asus tablet showed good response to measurement protocols of geometric distortions, luminance uniformity, visual angles, spatial resolution and display noise. What is surprising is that, both had problems of diffuse and specular ambient reflection artefacts.

Variations in display characteristics are observed for the same image on different devices. Visual consistency need to be ensured between devices for obtaining uniform evaluation. Relationship between digital image values and displayed luminance is important in this regard. Operational uniformity is achieved when devices are calibrated using the same luminance response standard and have the same luminance ratios. It can therefore be assumed that the users of mobile devices should be warned of the limitations of image displays so that evaluations are done more precisely. Also, commercial tablets and smartphones need to be calibrated against standards.

7.6 Models of smartphone use in teleradiology-cost and quality

In this context, Faggioni et al. (2011) pointed out that the aim of teleradiology is to make imaging data accessible to anyone, anywhere at any time. The authors propose the model which PACS occupy the central position different types of implementation at three levels: intra-department, inter-department and cross-enterprise levels using holography, vertical and horizontal integration and GRID or virtual technologies respectively. Total operating cost is reduced and quality and efficiency of healthcare is increased. Remote use of images is a distinct advantage offered by this development.

7.7 Low cost community healthcare

Already advanced multimodality imaging is available in the case of MRI, CT and nuclear medicine. Portable ultrasound, scanning protocols, development of local expertise for scanning, customised clinical data, transmission capabilities, internet use for remote consulting improved pregnancy outcomes in an under-resourced Ugandan community. Complete system requirement of low cost healthcare was described by DeStigter et al. (2011).

7.8 Applications

The use of *PACS* is now a being extended to teleradiology (remote diagnosis or offsite interpretation of radiological images) and computer aided design (*CAD*). PACS as a work facilitator has been studied by several authors like (Fridell et al., 2009).

Applications of teleradiology include: second opinion on emergency diagnosis, use of subject expertise, humanitarian works, crossing geographical barriers and education. It can also be used to connect different hospitals in a region, country or different countries. Regional PACS can share costs and services.

Remote communication of radiological reports has advanced from initial verbal communication via telephone to transmittance of clinical photographs as downloadable file between computers of distant specialists by hospital staff, to transmittance of digital images via internet mail servers/personal digital assistant phones and finally to transmittance from one smartphone to another smartphone, as was traced by Hee Hwang and Mun (2012). The images captured in smartphone group chat are displayed. Apple iPhone and Samsung Galaxy S with Kakao Talk free mobile messenger application were used. Even handheld Doppler sounds can be uploaded and shared with others as an audio or video clip while hearing the sound at bedside. Many other applications while performing the operations are also possible.

7.9 Orthopaedic radiology-screen size

In a study, Toomey et al. (2010), using Dell Axim personal digital assistant and Apple iPod touch handheld devices offered promise in orthopaedic radiological emergency teleconsultation. In another orthopaedic comparison (Crockett et al., 2012), image quality and confidence of participants were more when seeing the images on a larger screen of digital monitor than on smartphone screen. Nevertheless, there was no difference in diagnostic accuracy. Management plan was same in both cases.

7.10 Sensitivity, positive predictive value, negative predictive value with smartphones in e-health

However, in dermatological applications, 30% of melanoma risk was wrongly assessed by three of the four smartphones tested. Another important finding was that, ranges of values for four tested applications were: sensitivity 6.8% to 98.1%, specificity 30.4% to 93.7%, positive predictive value 33.3% to 42.1% and negative predictive value 65.4% to 97.0%. Sending image directly to a certified dermatologist for analysis produced highest sensitivity and use of automated algorithms produced lowest sensitivity. Based on their findings (Wolf et al., 2013) were not in favour of using smartphones for such cases.

7.11 Accuracy, response time, diagnostic efficiency

In an earlier comparison study by Engel et al. (2011), although accuracy was better with in-person (98.7%) than with smartphone (94.2%), response time was much shorter for smartphones. Overall, the method preserves the accuracy, increases diagnostic efficiency and patient recovery due to better communication and comprehensive information exchange.

7.12 Other smartphone applications

7.12.1 Smartphones as monitoring instrument using physiological aspects

Bai et al. (2012) used smartphones as a monitoring instrument for accurate measurement of physiological signals of breathing when the patient is sleeping. Rates of breathing, heartbeats and blood oxygen levels are monitored continuously. The system uses smartphones at the point from detection of abnormality by the computer to transmitting the information to distant hospital and family.

For most smartphone integration of blood glucose monitors, blood sample is required although sending data to target recipients and alerting on danger signals are possible. When non-invasive method is used, their reliability and real life applications are suspect. Some side effects are possible in certain advanced models. These observations were reported by Ramchandani and Heptulla (2012).

Sensecam developed by Microsoft was found (Li et al., 2011) useful in detecting significant physical events of human movements. In another study by O'Brien (2009), health sensors were found compatible with most mid to high end handsets enabling adaptation to health monitoring systems. Protection of data path from sensor to database is essential. Bluetooth's new medical device profile can be used.

7.12.2 Document-based database

CouchDB, a document-based database in medical information system, was evaluated for various applications by Schmitt and Majchrzak (2012). CouchDB can be used in mobile devices like smartphones, iPads and tablets of fire fighters in emergencies and it enables unified development of front end and back end applications.

7.13 Physician needs

Information and communication needs of physician which can be addressed by mobile and wireless devices and the issues involved were discussed by Cocosila and Archer (2012).

7.14 Demographic aspects foe self-management

Older persons prefer to use handheld devices due to social pressure, but do not accept advanced functions, physical keyboard rather than on-screen touch is acceptable. They have shallow comprehension of menus. Also, navigation helps for contextual information is more helpful. In term of size and spacing of the set, they need adjustment for their characteristics. These observations on handset requirements of older persons in providing e-health were discussed by Zhoua et al. (2012).

Use of handheld device to collect self-monitored dietary and exercise data on middle school students was tested by Nathan (2010). Paper diaries and electronic calorie counter were compared. Significantly higher compliance was observed for paper diaries. Usability and portability were major barriers for adoption of electronic device. Smaller units with alarms were favoured by the trial participants.

8 Discussion/evaluation of review points

Many radiological and non-radiological applications of handheld devices were reported. The results of this review can be related to the research question and aims as given in Table 1.

Table 1 Relationship of review results with research question and aims/objectives

Item	*Result*	*Related questions/aims*
Applications	Patient monitoring, communication of diagnosis and test results to healthcare persons and institutions, response communications, remote consultancy, low cost community healthcare	Workflow efficiency and performance of radiologist and medical imaging technologist are enhanced
Types and specifications of devices and communication systems	iPads, iPhones, smartphones, tablets, exclusive or commercial software, exclusive or internet or web-based communication systems	Current industry standards are complied with, diagnostic performance improved
Image quality, size, resolution, transmission and response times,	Compliance with international standards and measurement protocols	Diagnostic performance and workflow efficiency are improved
Privacy and security issues at all levels	by following standard practices	Laws and regulations and current industry standards are complied with
Costs and benefits	High investment cost leading to low cost to patients	Rapid, efficient and low cost healthcare to patients

9 Conclusions

In this paper, we have looked into handheld devices and their role in promoting healthcare performance within radiology department. Through a review of relevant scientific literature in this field, we have identified some important aspects of the use of hand held devices in radiology departments. These aspects are the applications of handheld devices, the technical specifications of the hand held devices, the hardware and software specifications of the handheld devices, information privacy and security, and the costs and benefits involved in the use of hand held devices. All these aspects of handheld devices need to be considered and optimised to improve performance in healthcare.

References

Bai, Y-W., Tsai, C-L. and Wu, S-C. (2012) 'Design of a breath detection system with multiple remotely enhanced hand-computer interaction devices', Paper presented at the *2012 IEEE 16th International Symposium on Consumer Electronics (ISCE)*, Harrisburg, PA, pp.26–30.

Bava, M. (2011) *Innovative ICT Solutions in Telemedicine to Support Clinical Practice and Research in Hospitals*, Doctoral dissertation, Università Degli Studi Di Trieste [online] http://hdl.handle.net/10077/7437 (accessed 20 May 2013).

Cocosila, M. and Archer, N. (2012) 'Physician interaction with mobile and wireless handheld devices: data entry and retrieval challenges', *International Journal of Healthcare Technology and Management*, Vol. 7, Nos. 3–4, pp.233–251.

Crockett, M., Guerin, S. and McElwain, J. (2012) 'iTrauma – the use of smartphones in the assessment of trauma patients, an app for the future?', *Journal of Bone & Joint Surgery*, Vol. 94, No. 35, p.261, British.

DeStigter, K.K. et al. (2011) 'Low-cost teleradiology for rural ultrasound', *IEEE Global Humanitarian Technology Conference*, pp.290–295.

Engel, H. et al. (2011) 'Remote real-time monitoring of free flaps via smartphone photography and 3G wireless internet: a prospective study evidencing diagnostic accuracy', *Microsurgery*, November, Vol. 31, No. 8, pp.589–595.

Faggioni, L. et al. (2011) 'The future of PACS in healthcare enterprises', *European Journal of Radiology*, May, Vol. 78, No. 2, pp.253–258.

Fridell, K., Aspelin, P., Edgren, L. and Lindsköld, L. (2009) 'PACS influence the radiographer's work', *Radiography*, May, Vol. 15, No. 2, pp.121–133.

Gallaher, M. (2005) *A Technology White Paper on Improving the Efficiency of Social Safety Net Program Delivery in Low Income Countries An Introduction to Available and Emerging Mobile Technologies*, World Bank [online] http://econpapers.repec.org/paper/wbkhdnspu/32753.htm (accessed 25 May 2013).

Hee Hwang, J. and Mun, G-H. (2012) 'An evolution of communication in postoperative free flap monitoring: using a smartphone and mobile messenger application', *Plastic & Reconstructive Surgery*, July, Vol. 130, No. 1, pp.125–129.

Li, N., Crane, M. and Ruskin, H.J. (2011) 'Automatically detecting 'significant events' on SenseCam', *ERCIMNews*, p.87.

Mosa, A.S.M., Yoo, I. and Sheets, L.S. (2012) 'A systematic review of healthcare applications for smartphones', *BMC Medical Informatics and Decision Making*, Vol. 12, No. 67, p.31.

Nathan, T.M. (2010) *Feasibility of Using an Electronic Calorie Counter to Monitor Energy Intake and Expenditure Among Young Adolescents*, Electronic theses, Treatises and Dissertations.

O'Brien, H. (2009) *Smart Phone Support for Bluetooth Body Sensors*, University of Limerick, Program on Computer Engineering, Limerick, Ireland [online] http://hughobrien.ie/fyp.pdf (accessed 15 March 2013).

Ramchandani, N. and Heptulla, R.A. (2012) 'New technologies for diabetes: a review of the present and the future', *International Journal of Pediatric Endocrinology*, No. 1, p.28.

Schmitt, O. and Majchrzak, T.A. (2012) 'Using document-based databases for medical information systems in unreliable environments', *The 9th International ISCRAM Conference*, pp.1–10 [online] http://www.iscramlive.org/ISCRAM2012/proceedings/119.pdf (accessed 18 May 2013).

Toomey, R.J. et al. (2010) 'Diagnostic efficacy of handheld devices for emergency radiologic consultation', *American Journal of Roentgenology*, February, Vol. 194, No. 2, pp.469–474.

Viswanath, K. and Kreuter, M.W. (2007) 'Health disparities, communication inequalities, and e-health: a commentary', *American Journal of Preventive Medicine*, Vol. 32, No. 5, p.131.

Wac, K., Hausheer, D., Fiedler, M. and Bonato, P. (2012) *Future Internet for eHealth*, Vol. 2, pp.21–45, Report No. 12231, Dagstuhl, Germany [online] http://publik.tuwien.ac.at/files/PubDat_210335.pdf.

Wolf, J.A. et al. (2013) 'Diagnostic inaccuracy of smartphone applications', *JAMA Dermatology*, January, Vol. 149, No. 4, pp.422–426, Chicago.

Zhoua, J., Rau, P-L.P. and Salvendya, G. (2012) 'Use and design of handheld computers for older adults: a review and appraisal', *International Journal of Human-Computer Interaction*, Vol. 28, No. 12, pp.799–826.