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Diagnostic accuracy and reliability of smartphone captured radiologic images communicated via WhatsApp®

By

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Declaration

I, Dr. Unathi Ntja declare that the coursework Master's Degree mini-dissertation that I herewith submit in a publishable manuscript format for the Master's Degree qualification Clinical Imaging Sciences at the University of the Free State is my independent work and that I have not previously submitted it for a qualification at another institution of higher education.

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Abstract

Background: Sending radiographic images as instant messages have become a common means of communication between physicians, aiding in triaging and transfer decision-making in emergencies. While the use of technology is increasing, this is not the case for the underserved or rural areas of South Africa with no picture archiving and communications system (PACS) or advanced hardware in place. In these areas, however, the medical population tends to have nearly universal access to smartphones and would benefit from the ability to share images quickly and easily with trained radiologists. South African data on diagnostic reliability of smartphone radiology images is lacking.

Objectives: The objective of the study was to determine the accuracy and reliability of diagnoses made on radiologic images with a smartphone compared to radiologic images on PACS.

Method: This was a cross-sectional study. Radiographs from 1 June 2018 to 1 July 2019 were selected from the PACS system at a tertiary hospital in the east-central South Africa. The images were displayed on a PACS computer screen and captured by the researcher using a smartphone. Five radiology registrars received the images via WhatsApp® and reviewed them on their phones. After three weeks, the registrars viewed the images in random order on a PACS station. McNemar's test was used to compare the diagnostic accuracy of smartphone and PACS. Kappa values were calculated for agreement. Reliability was assessed by analyzing the results of different registrars and diagnoses separately.

Results: One hundred and thirty-five X-rays, representative of common emergency conditions, were selected. For all registrars, the PACS accuracy was generally higher than the smartphone accuracy. The Kappa values all indicated fair to moderate agreement between smartphone and PACS diagnosis.

Conclusion: Capturing radiographic images using at least a 12-megapixel smartphone and sharing them via WhatsApp® is a reliable method that can be used with a high degree of confidence in emergencies to aid clinical decision making. This method of viewing medical imaging is however not a substitution for images viewed on PACS.

Abbreviations

PACS: Picture Archiving and Communication System

DICOM: Digital Imaging and Communications in Medicine

CT: Computed Tomography

List of appendices

Chapter 1- Literature review

Smartphones are inexpensive, user-friendly, readily available and the camera quality has improved dramatically (1)(2). A smartphone is a mobile device that combined cellular and mobile computing functions into one unit. Smartphones are swiftly becoming an essential part of contemporary world, changing the portability of information with functionalities such as high-quality phone cameras, internet access and access to third-party services(3). They also have the potential to have a beneficial impact to healthcare with easier access to telemedicine(3). The invention of smartphones together with the improved connectivity have resulted in an effortless communication compared to a few years ago (4). Smartphones have the potential to change the availability and access to specialist healthcare, especially in rural and remote communities(3)(5). The smartphone cameras have drastically improved over the past few years, from more lenses to more megapixels, improved software, better zoom, great low light performance and many more features. Features of the new era smartphone cameras are tabulated in table 1. Among doctors, the utilisation of smartphones is common, with studies reporting 74-85% of doctors using a smartphone(4). Nowadays, smartphones are favoured and generally more utilised than the previous hospital pager systems which are not deemed useful anymore (4). There are, however some disadvantages in using smartphones for clinical communication including unprofessional behaviour, network signal problems, amongst others(6)(4). However, having a very accessible way of communication can easily result in prolonged use of the smartphone, therefore, resulting in recurrent interruptions and the possibility of an error occurring(4). Rivera-Rodriguez and Karsh in their review study gathered that, although there is an increase in frequent interruptions and probability of errors, not all interruptions had an adverse effect and may even be necessary for the practice of safe healthcare(7). Also in the case of viewing images on a smartphone, there are some known disadvantages that may hinder accurate interpretation of the images; the size of the screen, the image quality and resolution which are inferior to original images, inability to manipulate the image such as increasing or decreasing contrast(8)

	Camera set-up	Quad	Triple
Primary	sensor	48MP, 1/1.4-inch	50MP 1/1.28-inch
	lens	26mm, f/1.78, OIS	27mm, f/1.9, OIS
	AF	Full sensor omnidirectional PDAF	PDAF
Ultra-wide	Sensor	48MP, 1/2.0-inch	40MP, 1/1.54-inch
	lens	16mm, f/2.2	18mm, f/1.8
	AF	PDAF	PDAF
	video	2160/60FPS	2160p/60fps
	Flash	LED	LED
	Chipset	Snapdragon 865	Kirin 990
	Time of flight sensor	No	Yes
	Colour sensor	yes	Yes

Table 1: features of the recent smartphone cameras

Teleradiology is a branch of telemedicine where telecommunication systems are used for the transmission of radiological images from one location to another for the purpose of sharing studies with other healthcare professionals including radiologists or physicians. Historically, there were concerns that remote image interpretation by external radiology providers would have possible negative repercussion for the specialty as a whole in the way of commoditization, reduced imbursement, movement of radiology personnel from their hospital contracts, increased infiltration by non-radiology specialties and reduced quality(9). However, it has also been recognised that teleradiology is a valuable tool allowing broader geographic, after hours and multispecialty coverage and therefore achieving more powerful access to rural, critical access, or other underserved populations(9). Offsite interpretation also helps in the turnaround time(9). Teleradiology is a highly evaluated and widely used method although it is costly and technically complex(10). Teleradiology has been shown to significantly reduce the number of missed fractures especially in patients that are seen in

general practice and rural hospitals (8). Other advantages of teleradiology include a decrease in the number of referrals to tertiary institutions(11). Worldwide, teleradiology is increasingly recognized as an invaluable tool, due to the lack of adequate staff to provide radiological coverage and lack of expertise in the specialty(10). However, teleradiology has its limitations; for example, the system may require digital imaging and communications in medicine (DICOM) images to be transferred to a remote device for viewing and interpretation by an off-site radiologist and installation of appropriate hardware and software can be costly. The use of technology in radiology is on the increase, especially with the availability of the picture archiving and communications system (PACS). PACS is a subdivision of healthcare information system which has modified workflow in hospitals and increase efficiency between healthcare practitioners and patients. During the last decade or so, PACS technology has been embraced by many radiology departments within South Africa, both private and public but mostly by the private sector(12). The South African Department of Health recognized the potential benefits of PACS and approved its implementation in the South African public sector to benefit a wider population(13)(12). These benefits included(13):

1. Ineffective diagnosis techniques that were used at the time. The specialist radiologists were situated in the specialist hospitals, so patients were moved from the rural areas to the specialist hospitals for diagnosis.
2. Hard copy images can only be in one place at a time. In a case where a referring clinician would like to show a radiologist images and get an advice, they will both have to be in the same venue to view and discuss the imaging findings.
3. Not all images can be printed. An example in fluoroscopy and interventional radiology, most of the images will be available in the work station short term and in the long term only a few images are available; making comparison very difficult.
4. Lost information. It is difficult to back up and access hard-copy information, this can be sometimes due to human error aspects such as filing and information management. This leads to unnecessary repeat imaging, leading to increased radiation, resource wasting to mention a few.
5. Poor comparisons: For one to make comparisons, they need both current and previous imaging of good quality. It has been proven that with a film- based department, the radiologist refers to previous imaging examinations in only 56% of cases and in a digital department 86% of cases.

6. Limitations of film: the images obtained are not always adequately acquired the first time, leading to unusable under- or over exposed films.
7. Delayed clinical decision-making: the time between gathering patient information and getting radiologist opinion results in delay in clinical intervention.
8. Cost of storage: Physical storage is needed to store the printed films and multiple resources are required. These resources include; the filing room indexing system, the filing clerks and porters to transport images.
9. Cost of film: The cost of developing the film include: the cost of darkroom assistants, the chemicals used to develop the film, the cost of the film, the maintenance cost, and the cost of printing on the laser camera. Another issue is the time wasted by the radiographers, while they could be carrying out other examinations.

South Africa healthcare institutions have been implementing PACS for almost over two decades, with the aim of addressing the health needs of the rural patients who do not have access to specialised medical care(13). When compared to the private sector, the public sector is massive, treating about 90% of the population(12). Only a small number of PACS are fully operationing in the public sector especially, after several deployment efforts for PACS and support from the Department of Health(12). A South African study done in KZN and published in October 2019 looked at the challenges in the implementation of PACS in South Africa both in private practice and the public sector. They found that space and inappropriate furniture, insufficient infrastructure, hospital financial constraints, equipment protection, lack of information technology knowledge, resistance to change, image storage capacity, system software and hardware requirements and vendor-related concerns amongst others are the most pertinent challenges of PACS implementation in South Africa(12). Evaluating and understanding these challenges is very important especially in developing countries to prevent system failure(12). Summary of PACS implementation challenges and possible solutions (12) are illustrated in Table 2.

Challenge	Possible solution
Space and inappropriate furniture	Proper situational and needs assessment
Insufficient infrastructure	Government and private sector support
Equipment protection	Government and private sector support
Hospital financial constraints	Government and private sector support
Lack of IT knowledge	Staff training
Resistance to change	Proper change management process
Image storage capacity	Adequate needs assessment
System maturity	Regular maintenance and evaluation
Software and hardware requirements	Regular maintenance and evaluation
Maintaining the radiology workflow	Regular maintenance and evaluation
Vendor related concerns	Regular maintenance and evaluation

Table 2. summary of PACS implementation challenges

Due to the rapid increased need for PACS integration in South African hospitals, PACS vendors are using to their advantage the lack of key decision makers' technical knowledge in the public healthcare environment. Using this lack of technical knowledge, they are therefore persuading the public health institutions into complicated contracts to agree up to 5 year periods and the services are suboptimal(13).

While the use of technology in radiology is on the increase, especially with the availability of the PACS, this is not the case for the underserved or rural areas of South Africa with no PACS or advanced hardware in place. Rural radiology is defined as radiology services to communities, residing in areas very isolated from urban areas. In Sub-Saharan African countries, over 80% of the population is rural(14). The introduction of imaging services in the rural areas has resulted in increasing usage of these facilities and imaging has been shown to have a big impact in patient management and decision making. The key diagnostic imaging modalities for primary care and emergency services in rural areas are x-rays and ultrasound and these two together are able to meet significant amount of imaging needs of the population(15). Generally, most countries in Sub- Saharan Africa lack trained radiologists(12).

In some areas, in-service training is offered, which is short and cheaper especially in trainees who have basic medical science and clinical knowledge(14). The major disadvantages of this in-service training are: there are no new recruitments to increase the number of staff in that specific centre, so the health worker who has received in-service training will have to multitask and provide their daily clinical service and rural radiology services; the multi-tasking health worker may change his preference to the newly acquired imaging role, leading to staff shortage in the other areas of medical care(14). In most areas, particularly in rural areas of South Africa, there is no in-service training and the interpretation of radiology images depends on a clinician who might not have sufficient training for diagnostic interpretation(1). A study by Nyhsen et al demonstrated that the undergraduate trainees feel that the existing radiology teaching does not fully meet their learning needs and prepare them for clinical practice(16). In many medical schools, the amount of time granted to radiology is not more than an hour a week for a college year, supplemented with the examination of radiographs demonstrating medical and surgical cases assigned to the student(17). In rural hospitals of South Africa, the community service and junior medical officers are the ones who mostly run the day-to-day patient management. South Africa, a country with a population of approximately 59 million, there are only about 60 qualified radiologists according to the Radiology Society of South Africa in academic institutions while a large number of qualified radiologists are in the private sector. These are rough estimates because not all qualified radiologists are RSSA members. 90% of the South African population is managed in the public sector. In some areas the plain x-ray films are sent to the referral hospital via a weekly ambulance and the radiologist's report is later returned via ambulance(18). These barriers result in a lot of delay in patient's treatment, leading to increase in morbidity and mortality as well as increased cost(18)(15). In these underserved or rural areas, however, the medical population tends to have nearly general access to smartphones(1) and would benefit from the ability to quickly and easily share images with trained radiologists across the world especially when the diagnosis may be essential to altering patient management(1). Emergent and acute cases such as pneumomediastinum from an oesophageal tear and aortic dissection or were among the cases accurately diagnosed by smartphone capture. Without adequate access to radiologic proficiency, it is easy to miss these cases with resultant dire consequences(1). The ability to send high-quality radiology images is very important in these areas as adequate assessment and verbal description can be variable and inaccurate(19)(3)

The WhatsApp® application is a free multi-platform application that is available and downloadable in most smartphones and there is no additional equipment is necessary. WhatsApp® is an American freeware, cross platform centralized messaging and voice-over-IP service owned by Facebook, Inc and released in February 2009. Using this application, the user can exchange messages and images easily with a specific contact person or a certain group with the additional benefit of being notified if the message has been received and read, make voice and video calls, share documents, user location and other contents (4). The recent data demonstrates that is the WhatsApp® most popular messaging application used globally, there are 2 billion users around the globe. WhatsApp® is available in more than 180 countries and 60 different languages. From April 2016, the WhatsApp® company introduced end-to-end encryption, this simply means that, the images or any shared information is only available to the sender and the receiver and the third parties, including WhatsApp® itself, will not have access. Johnstone et al analysed over 1100 hours of communication amongst emergency surgical teams using WhatsApp® and concluded that it was a safe and efficient form of communication(20). The candidates in one study found WhatsApp® to be a structured and logical tool for decreasing communication difficulties between senior and junior colleagues(4). The junior interns felt they had support from their seniors with their clinical decision making and the registrars felt they were updated on their patients' progress(4). Wani et al. reported that the use of WhatsApp® resulted in an early start in the management of the patients in plastic and reconstructive surgery(21). Advantages of WhatsApp® usage in the medical field includes: improvement of communication, no computers required, time-saving, the possibility of an immediate response, improvement of surgery performance and reduction of consultation times, smoothing of hierarchy and encouragement of junior doctors to seek help and improve the team perception of effectiveness(22). Disadvantages of using this tool include increased workload; one might underestimate how urgent each case is; worsening professional relations and risk of unprofessionalism; one has to remain logged on to the internet round the clock; the fact that the conversation cannot form part of the medical record; difficulty in identifying patient chats and possible issues of data protection and privacy(22). It is clear that the use of WhatsApp® in health care is considered a case of 'back-door adoption' as there are no laws regarding its use and no formal approval or assessment from the managers. Smartphone use has not been recommended for radiograph interpretation. There is therefore an importance of managers, researchers and policy makers

working to regulate a phenomenon that, although WhatsApp® is being used and considered very useful and effective, its use is widespread without any shared rules(22). The managerial factors have no much effect on the use of WhatsApp® and that is suspected to be related to the lack of stipulated clear rules regarding professional usage(22). Management interventions must strive to attain rules and regulation of its use, and focus on training and information for doctors, nurses as well as patients regarding the risks and benefit of this tool, rather than forbidding its use(22).

Capturing radiographic scans and video clips from computer screens and sending them as instant messages have become a common means of communication between physicians, aiding in the triage and transfer decision-making in orthopaedic and neurosurgical emergencies(2). Images taken with a smartphone camera are subject to multitude of variables that include: focus; distance; angle; hand shake; lighting and image flicker(23). If the imager is not careful, these factors can all significantly distort the image.

Several studies, in various disciplines, have investigated the use of smartphones for medical image capture. A study published by Bullard in 2013, demonstrated that mobile-phone images of CT scans appear to provide adequate images for triaging patients and assist with transfer decisions of neurosurgical cases(2). Orthopaedic studies conducted by Giordano in 2015 found an excellent inter-and intra-observer agreement in the imaging assessment of tibia plateau fractures sent via WhatsApp® Messenger(24). In 2012, Padmasekara demonstrated that MMS with smartphones is a useful tool when assessing radiology images to work out management plans in distal radius fractures(3).

A Southern African study conducted in Botswana by Schwartz et al demonstrated non-inferiority of digital photographs of chest x-rays obtained with a mobile phone compared to plain film(18). In this study, the radiologists viewed 75 plain films on a lightbox and the same images were photographed using a smartphone and then reviewed by the participating radiologists from their smartphones(18). A paediatric study published by Westberg *et al.* in 2016 found that there were no noteworthy differences in the accuracy of diagnosing pneumothorax on a smartphone versus PACS(25). In this study, 40 paediatric chest x-rays were viewed by 20 participants; the accuracy on a smartphone was 81% and 80% on PACS.

However, no South African studies have been conducted on the diagnostic reliability of smartphone captured and viewed radiology images. With this in mind, the researchers set out to determine whether smartphone captured radiographs transmitted via WhatsApp® instant messenger can reliably be used to make an accurate and reliable diagnosis. The study aimed to evaluate the reliability of radiographs captured and viewed using a smartphone, compared to a full-featured diagnostic Picture Archiving and Communication System (PACS) station for diagnosis of emergency life-threatening conditions.

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Chapter 2- Publishable article

2.1 Title:

Diagnostic accuracy and reliability of smartphone captured radiologic images communicated via WhatsApp®

2.2 Abstract

Background: Sending radiographic images as instant messages have become a common means of communication between physicians, aiding in triaging and transfer decision-making in emergencies. While the use of technology is increasing, this is not the case for the underserved or rural areas of South Africa with no picture archiving and communications system (PACS) or advanced hardware in place. In these areas, however, the medical population tends to have nearly universal access to smartphones and would benefit from the ability to share images quickly and easily with trained radiologists. South African data on diagnostic reliability of smartphone radiology images is lacking.

Objectives: The objective of the study was to determine the accuracy and reliability of diagnoses made on radiologic images with a smartphone compared to radiologic images on PACS.

Method: This was a cross-sectional study. Radiographs from 1 June 2018 to 1 July 2019 were selected from the PACS system at a tertiary hospital in the east-central South Africa. The images were displayed on a PACS computer screen and captured by the researcher using a smartphone. Five radiology registrars received the images via WhatsApp® and reviewed them on their phones. After three weeks, the registrars viewed the images in random order on a PACS station. McNemar's test was used to compare the diagnostic accuracy of smartphone and PACS. Kappa values were calculated for agreement. Reliability was assessed by analyzing the results of different registrars and diagnoses separately.

Results: One hundred and thirty-five X-rays, representative of common emergency conditions, were selected. For all registrars, the PACS accuracy was generally higher than the

smartphone accuracy. The Kappa values all indicated fair to moderate agreement between smartphone and PACS diagnosis.

Conclusion: Capturing radiographic images using at least a 12-megapixel smartphone and sharing them via WhatsApp® is a reliable method that can be used with a high degree of confidence in emergencies to aid clinical decision making. This method of viewing medical imaging is however not a substitution for images viewed on PACS.

2.3 Introduction

Smartphones are inexpensive, user-friendly, readily available and the camera quality has improved dramatically(1)(2). Smartphones are rapidly becoming an essential part of modern society, changing the portability of information with functionalities such as high-quality phone cameras, internet access and access to third-party services(3). They also have the potential to positively impact healthcare with easier access to telemedicine(3). Smartphones have the potential to change the availability and access to specialist healthcare, especially in rural and remote communities(3)(5).

Teleradiology is a branch of telemedicine where telecommunication systems are used for the transmission of radiological images from one location to another for the purpose of sharing studies with other healthcare professionals including radiologists or physicians. Teleradiology is a highly evaluated and widely used method although it is costly and technically complex (10). Worldwide, teleradiology is increasingly recognized as an invaluable tool, due to the lack of adequate staff to provide radiological coverage and lack of expertise in the specialty(10). However, teleradiology has its limitations; for example, the system may require digital imaging and communications in medicine (DICOM) images to be transferred to a remote device for viewing before interpretation and installation of appropriate hardware and software can be costly. Space, insufficient infrastructure, hospital financial constraints, image storage capacity, system maturity and vendor-related concerns amongst others are the most pertinent challenges of PACS implementation in South Africa(12).

While the use of technology in radiology is on the increase, especially with the availability of the picture archiving and communications system (PACS), this is not the case for the

underserved or rural areas of South Africa with no PACS or advanced hardware in place. These areas also lack trained radiologists. South Africa, a country with a population of approximately 59 million, there are only about 60 qualified radiologists according to the Radiology Society of South Africa in academic institutions while a large number of qualified radiologists are in the private sector. These are rough estimates because not all qualified radiologists are RSSA members. The interpretation of images relies on the clinician who might not have sufficient training for diagnostic interpretation. In these underserved or rural areas, however, the medical population tends to have nearly general access to smartphones(1) and would benefit from the ability to quickly and easily share images with trained radiologists across the world especially when the diagnosis may be essential to altering patient management(1). The WhatsApp® application is a free multi-platform application that can be used in most smartphones and, as such, no additional equipment is needed. With this application, one can exchange messages easily with a specific team member or the entire group with the additional benefit of being notified if the message has been received and read(4). Capturing radiographic scans and video clips from computer screens and sending them as instant messages have become a common means of communication between physicians, aiding in the triage and transfer decision-making in orthopaedic and neurosurgical emergencies(2).

Several studies, in various disciplines, have investigated the use of smartphones for medical image capture. A study published by Bullard in 2013, demonstrated that mobile-phone images of CT scans appear to provide adequate images for triaging patients and assist with transfer decisions of neurosurgical cases[3]. Orthopaedic studies conducted by Giordano in 2015 found an excellent inter-and intra-observer agreement in the imaging assessment of tibia plateau fractures sent via WhatsApp® Messenger(24). In 2012, Padmasekara demonstrated that MMS with smartphones is a useful tool when assessing radiology images to work out management plans in distal radius fractures(3).

However, no South African studies have been conducted on the diagnostic reliability of smartphone captured and viewed radiology images. With this in mind, the researchers set out to determine whether smartphone captured radiographs transmitted via WhatsApp® instant messenger can reliably be used to make an accurate and reliable diagnosis. The study aimed to evaluate the reliability of radiographs captured and viewed using a smartphone,

compared to a full-featured diagnostic Picture Archiving and Communication System (PACS) station for diagnosis of emergency life-threatening conditions.

2.4 Research methods and design

Study design and setting

This was a cross-sectional study conducted at Pelonomi Tertiary Hospital, Bloemfontein, Free State. The radiology unit within Pelonomi Tertiary Hospital serves the population of the Free State province, as well as occasional out of province and private patients.

Study population and sampling strategy:

The study population consisted of radiographs obtained from Pelonomi Tertiary Hospital from 1 June 2018 to 1 July 2019. The principal investigator identified 135 plain radiographs from PACS, which are representative of emergency life-threatening conditions.

The cases were not selected randomly or as they occurred, but rather with the specific intent of developing a spectrum representative of conditions that require immediate intervention and/or referral to a senior hospital for further management and investigation. The researchers aimed at selecting common emergency conditions, with at least 20 radiographs per condition; this was achieved for all the identified medical conditions to be included in the study, with the exception of pneumomediastinum for which we were only able to acquire seven radiographs.

The selected medical conditions included pneumothorax, haemothorax, pneumomediastinum, pneumoperitoneum, bowel obstruction, spinal fractures and normal X-rays. The images were displayed on a 2-megapixel PACS computer screen and captured by the principal investigator using a 12-megapixel iPhone 7 camera, positioned 25cm from the screen. To simulate what would occur in an emergency department, the x-rays were captured without any additional settings or equipment. The camera has a resolution of 1334 x 750

pixels at 326 pixels per image according to product specifications. The captured images were subsequently sent to five radiology registrars via the WhatsApp® instant messaging application (version 2.12.5).

Data collection

Antero-posterior/posteroanterior and lateral views of chest, abdomen and musculoskeletal radiographs were selected. Additional views were also used when needed. The selected images were viewed by the principal investigator and a board-certified radiologist; this was deemed as the gold standard.

The participating registrars were not provided with any clinical history. To ensure confidentiality, each registrar was allocated an identification number to be used throughout the study. The participating registrars reviewed the images on their phones with minimal resolution requirements of at least 1334 x 750 pixels. They completed a data form, stating the location of pathology and final diagnosis.

A period of 3 weeks was allowed to limit the possible recall of the previous image. Thereafter the registrars viewed the exact same images, but in random order, on a departmental full-featured picture archiving and communication system (PACS) station; again, the location of the pathology and their final diagnosis was captured on a data form.

The registrars were required to delete the images from their phones within 2 weeks of receiving them. While it is not possible for the researchers to delete the images on the recipients' smartphones, WhatsApp® instant messenger uses end-to-end encryption for data protection. This means that only the sender and the recipients have access to the image, WhatsApp® and third parties do not have the means to decrypt the data and therefore cannot read the data.

Data analysis

The researchers coded the data and entered it into a Microsoft Excel spreadsheet. The data was analysed by the Department of Biostatistics at the University of the Free State. McNemar's test was used to compare the diagnostic accuracy of smartphone and PACS. Kappa values were calculated for agreement. Reliability was assessed by analysing the results of different registrars and diagnoses separately.

Ethical considerations

Ethical approval was obtained from the Health Sciences Research Ethics committee of the University of Free State (Ethical clearance number UFS-HSD2019/0236/3007). Permission to perform the study was obtained from the Free State Department of Health.

Personal information on images, including patient age, sex, and hospital number were hidden before the image transfer to protect patient confidentiality.

2.5 Results

A total of 135 radiographs were included in the study; five radiology registrars assisted with the interpretation of the images. One registrar had completed the final written fellowship examination, three registrars were in their 3rd year of residency and one registrar was in the second year of residency.

As indicated in Table 1, most images were of the chest (70/135 [51.9%] images), cervical spine (31/135 [23.0%] images) and abdomen (29/135 [21.5%] images). Image pathology were distributed amongst pneumothorax (24.2%), spinal fractures (20.5%), normal (18.0%), bowel obstruction (16.1%), pneumoperitoneum (15.4%) and pneumomediastinum (5.2%).

Table 1: Images per body part and pathology

	Frequency	Percentage (%)
Images per body part (N = 135)		
Abdomen	29	21.5
Cervical spine	31	23.0
Chest	70	51.9
Chest and abdomen	4	3.0
Lumbar spine	1	0.7
Images per pathology		
Pneumothorax	32	24.2
Spinal fractures	28	20.5
Normal	25	18.0
Bowel obstruction	22	16.1
Pneumoperitoneum	21	15.4
Pneumomediastinum	7	5.2

The overall diagnostic accuracy (percentage of diagnoses agreeing with gold standard diagnosis) of all registrars on smartphones vs PACS is presented in Table 2.

Table 2: Overall diagnostic accuracy on smartphone vs PACS

	Smartphone accuracy (%) (N = 135)		PACS accuracy (%) (N = 135)			
Registrar	**Frequency**	**Percentage (%)**	**Frequency**	**Percentage (%)**	**p-value**	**Kappa**
1	114	84.4	124	91.9	0.04	0.51
2	115	85.2	124	91.9	0.01	0.47
3	95	70.4	116	85.9	<0.01	0.37
4	96	71.1	118	87.4	<0.01	0.43
5	112	83.0	123	91.1	0.1	0.39

The diagnostic accuracy of all registrars using smartphones vs PACS, per image pathology, is presented in Table 3. For all registrars, the PACS accuracy was generally higher than the smartphone accuracy. The diagnostic accuracy for pneumothorax and pneumoperitoneum was high on smartphones and PACS, whilst spinal fractures had a low accuracy with an average of 63% on smartphones and 72% on PACS.

Table 3: Diagnostic accuracy per image pathology on smartphone vs PACS

	Smartphone accuracy (%)					PACS accuracy (%)				
Registrar:	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
Diagnosis										
Spinal fractures (n= 28)	78	71	61	42	64	75	71	75	64	75
Bowel obstruction (n=22)	86	90	81	86	95	86	100	95	95	95
Pneumoperitoneum (n= 21)	100	95	95	95	90	100	100	100	100	90
Pneumothorax (n= 32)	96	90	93	90	84	100	100	96	100	96
Pneumomediastinum (n=7)	85	100	100	85	85	100	100	100	85	100
Normal (n= 25)	72	84	56	44	96	100	96	72	76	100

2.6 Discussion

Capturing images with a smartphone and sharing them with colleagues via WhatsApp®, has become one of the main communication channels, especially among the on-call teams. In remote areas, where there are no PACS in place, this practice can assist in prompt diagnosis and timeous transfer of patients to tertiary institutions. It is known that WhatsApp® reduces the size of the image before sending it to the recipient and there is, therefore, a reduction in image quality and resolution compared to the original images. Other disadvantages include the inability to manipulate the image and viewing the medical images on a small smartphone screen(8).

This study was designed to evaluate the accuracy of smartphone captured radiographic images communicated via WhatsApp® and viewed on a smartphone in comparison to viewing images on a full-featured PACS system. The study sample comprised of radiographs representing common accident and emergency conditions. The majority of diagnoses were made without difficulty on PACS, while a higher number of diagnostic abnormalities were misdiagnosed on smart-phone captured images, as would be expected, given the greater degree of technical limitations.

This was however not the case with spinal fractures, where a higher number of fractures were missed on both PACS and smartphones. This may be due to the complexity of the fractures and the fact that clinical history and examination findings were withheld from the participating reviewers. Conditions such as pneumothorax, pneumomediastinum, and

pneumoperitoneum were included, which could potentially be missed with inadequate access to radiologic expertise.

The intraobserver variation is indicated in Table 2. To our knowledge, no tested method has achieved 100%. There was no significant falloff in the diagnostic accuracy of pneumothorax on a smartphone compared to PACS (90% accuracy on smartphone and 98% on PACS) and pneumoperitoneum (95% accuracy on smartphone and 98% on PACS). Although pneumomediastinum accuracy was also high (91% smartphone) these results cannot be conclusive because of the number of selected cases.

Our results are consistent with published literature that also showed good accuracy of smartphone captured images(26),(1),(23),(25). A non-radiology study by Handelman 2018 in concluded that chest x-ray transmission via WhatsApp® results in a comparable ability to identify clinical findings as viewing the same image on a workstation(23). A paediatric study published by Westberg *et al.* in 2016 found no significant differences in the accuracy of diagnosing pneumothorax on a smartphone versus PACS(25). In this study, 40 paediatric chest x-rays were viewed by 20 participants; the accuracy on a smartphone was 81% and 80% on PACS.

There are some limitations to this study that are worth mentioning. Recall bias is inevitable in intra-observer studies. The researchers tried to minimize this by waiting at least three weeks between evaluating the cases in both methods. Another limitation was the relatively small number of cases, due to lack of representative radiographs on PACS system as most patients arrive as referral cases from local hospitals with printed films. The duration of the study also contributed to this limitation. Further larger studies with more representative cases and reviewers are advised.

A final limitation is taking into account the differences in quality of smartphone screen characteristics, which may be pertinent to the variations in smartphone quality. We attempted to minimize this bias by utilizing minimal resolution requirements of at least 1334 x 750 pixels.

Our findings indicate that the use of smartphone-based WhatsApp® imaging for sending images can be used accurately and effectively for diagnosis, decision making and management, especially for the detection of pneumothorax and pneumoperitoneum (accuracy of 90% and 95% respectively on a smartphone). This will in turn reduce waiting times in the emergency department and prevent unnecessary interfacility transfers.

2.7 Conclusion

Overall, the findings suggest that identifying major diagnostic abnormalities on smartphone-captured images utilizing at least a 12-megapixel camera can be done with a high degree of confidence. This method, however, should only be used in emergency settings to aid in timeous patient management/ transfer to the next level of care. We do not recommend routine usage of smartphones as a substitute for PACS.

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Author contribution: U.N and J.V.R. conceptualized and designed the study. U.N. obtained ethical clearance from relevant ethical committees. U.N. captured the data. Data analysis performed by G.J. The article was drafted by U.N. after the input and approval by J.V.R and G.J

Disclaimer: The views and the opinions expressed in this article are those of the authors and do not necessarily reflect those of their affiliated institution.

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Appendices

Appendix A

1.TITLE

Diagnostic accuracy and reliability of smartphone camera captured radiologic images communicated via WhatsApp instant messaging.

2. RESEARCHERS

PRINCIPAL RESEARCHER: Dr Unathi Ntja

Registrar, Department of Clinical Imaging Sciences

University of Free State

STUDY LEADER: Dr Fekade Gebremariam

Head of Department of Clinical Imaging Sciences

University of Free State

3. INTRODUCTION

Teleradiology is a branch of telemedicine where telecommunication systems are used for transmission of radiological images from one location to another for the purpose of sharing studies with other radiologists or physicians. Teleradiology is a highly evaluated and widely used method despite its high costs and technical complexity(10). It has become increasingly recognized as an invaluable tool around the world because of a number of reasons:

- Lack of adequate staff to provide radiological coverage.
- Lack of expertise in the specialty.

Limitations of teleradiology:

- System may require the patient digital imaging and communications in Medicine (DICOM) images be transferred to a remote device for viewing before interpretation begin.

While technology in radiology is highly increasing, especially with the availability of picture archiving and communications system (PACS), this is not the case for the underserved or

rural areas of South Africa with no PACS or advanced hardware in place. These areas also lack trained radiologists and the interpretation of images relies on the clinician who might not have sufficient training for diagnostic interpretation. In these areas, population tends to have nearly universal access to smartphones and would benefit from the ability to quickly and easily share images with trained radiologist across the world especially when diagnosis may be vital to altering patient management(1). Capturing radiographic scans and video clips from computer screens and sending them as instant messages have become common means of communication between physicians, aiding in triaging and transfer decision-making in orthopaedic and neurosurgical emergencies(2).

Smartphones are inexpensive, user friendly, readily available and the camera quality has improved dramatically(1)(23). They are rapidly becoming an integral part of modern society, revolutionising the portability of information with functionalities such as high quality phone cameras, internet access and access to third party services(3). They also have the potential to positively impact healthcare with easier access to telemedicine(3). Smartphones will likely change the availability and access to specialist healthcare especially in rural and remote communities(3).

There have been studies regarding the use of smartphones for medical image capture by multiple disciplines.

Bullard TB et al. demonstrated that mobile-phone images of CT scans appear to provide adequate images for triaging patients and helping with transfer decisions of neurosurgical cases(2).

Orthopaedic studies conducted by Giodano V et al. found an excellent inter- and intra-observer agreement in the imaging assessment of tibial plateau fractures sent via WhatsApp Messenger(2) and Padmasekara et al. demonstrated that MMS with smartphones is a useful tool in assessing radiology images to formulate management plans in distal radius fractures(3).

According to our knowledge there are no studies on diagnostic reliability of smartphone captured and viewed radiology images in the country, which is a question worth answering because this happens on day to day basis more especially among the on-call teams.

4. RESEARCH QUESTION

Can smartphone captured radiographs transmitted via WhatsApp instant messenger be used to make accurate and reliable diagnosis?

AIM AND OBJECTIVE OF THE STUDY

The aim of the study is:

- To evaluate the reliability of radiographs captured and viewed using a smart-phone compared to full featured diagnostic picture archiving and communication system station for diagnosis of emergency life threatening conditions.

5. RESEARCH METHODOLOGY

5.1 Study design

This was a retrospective cross-sectional study involving radiographs obtained in Pelonomi Hospital, Bloemfontein.

5.2 Study sample

A total of 150 radiographs including chest, abdomen and musculoskeletal radiographs will selected. Antero-posterior/ postero-anterior views were used with or without additional views. The cases will not be selected randomly or as they occur, but rather with the intent of having a representative spectrum of pathology. We aiming at selecting common emergency conditions, at least 20 radiographs per condition.

5.2.1 Sample size

A total of 150 selected radiographs will obtained from Pelonomi Hospital PACS from

1 June 2018- 1 July 2019

5.3 MEASUREMENT

The principal investigator will identify 150 radiographs on the Picture archiving and communication system that will be representative of life-threatening conditions.

A 12-megapixel iPhone 7 camera will be used for digital capture. This camera has 1334 x 750 pixels resolution at 326 pixels per image according to product specifications.

To standardize image capture:

- The images will be acquired by the principal investigator at 20-30cm from a 2-megapixel computer screen at a neutral angle.
- The images will be stored as a joint photographic experts (JPEG) file.

The images will be reviewed by the principal investigator and a board-approved radiologist on both the smart-phone and the full featured diagnostic picture archiving and communication system station (2-megapixel screen) and the consensus will be deemed as gold standard.

The images will be distributed in a random order to 5 radiology registrars via WhatsApp instant messaging, who will be blinded to diagnosis and patients' identification data.

The reviewing registrars have at least 2 years' experience in the Radiology department.

Clinical history will be given to participating registrars. Each registrar will be allocated an identification number from 1-5 that they will use throughout the study to ensure confidentiality.

The participating registrars will review the images on their phones with minimal resolution requirements of at least 1334 x 750 pixels and give a final diagnosis.

The reviewers will then view the images in a random order from a departmental full featured picture archiving and communication system station after a cool off period of about 2 weeks to limit inter-observer variation.

The reviewers will be required to delete the images from the phones after at least 2 weeks of receiving them. While there is no way possible for the principal researcher to delete the images on the recipients' smartphones, WhatsApp instant messenger uses end-to end encryption for data protection. This means that only the sender and the recipients have access to the image, WhatsApp and third parties do not have means to decrypt the data, therefore they cannot read the data.

5.3.1 METHODOLOGICAL AND MEASUREMENT ERRORS

Errors may occur in different phases in the research project:

Errors during literature review where only significant results are published.

Registrars may refuse to participate in the study. The research proposal will be presented to the department and the benefits of the study explained.

Loss/ damage of smartphones during the period of the study. The images will be saved in the principal investigator's smartphone for the duration of the study, the images will be resent to that particular participant.

5.4 PILOT STUDY

A pilot study will be performed using 20 radiographs after ethics approval, to assess the feasibility of the study.

The results of the pilot study will be included in the main study if no changes are made in the methodology.

6. DATA ANALYSIS

When all the data has been collected, the information on the data forms will be verified and any errors corrected.

The coded data will be entered into Microsoft excel spreadsheet.

Data will be analysed by the department of Biostatistics.

Kappa values will be calculated for agreement and sensitivity and specificity for validity.

7. TIME SCHEDULE

The project will run over a period of 14 months

- Protocol presentation: January 2019
- Ethics committee submission: 6 February 2019
- Data collection: July 2019- October 2019
- Data processing: November 2019
- Data analysis: December 2019-February 2020
- Writing research report and presentation: March 2020

8. BUDGET

- Stationery R600.00
- Internet R400.00
- Total R1000

These costs will be covered by the principal investigator.

9. ETHICAL ASPECTS

All the patient data on the X-ray images will (patient's name, date of birth and the hospital number) will be blinded prior image capture.

None of the images will be shown to physicians outside the department of diagnostic radiology in our hospital.

After departmental approval the protocol will be submitted to:

- Health Science Research Ethics committee of the University of Free State
- Free State Health Department.

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Appendix B

UNIVERSITY OF THE FREE STATE
UNIVERSITEIT VAN DIE VRYSTAAT
YUNIVESITHI YA FREISTATA

UFS·UV
HEALTH SCIENCES
GESONDHEIDSWETENSKAPPE

Health Sciences Research Ethics Committee

22-Jul-2019

Dear **Dr Unathi Ntja**

Ethics Clearance: **Diagnostic accuracy and reliability of smartphone camera captured radiologic images communicated via WhatsApp instant messaging**

Principal Investigator: **Dr Unathi Ntja**

Department: **Clinical Imaging Sciences Department (Bloemfontein Campus)**

APPLICATION APPROVED

Please ensure that you read the whole document

With reference to your application for ethical clearance with the Faculty of Health Sciences, I am pleased to inform you on behalf of the Health Sciences Research Ethics Committee that you have been granted ethical clearance for your project.

Your ethical clearance number, to be used in all correspondence is:**UFS-HSD2019/0236/3007**

The ethical clearance number is valid for research conducted for one year from issuance. Should you require more time to complete this research, please apply for an extension.

We request that any changes that may take place during the course of your research project be submitted to the HSREC for approval to ensure we are kept up to date with your progress and any ethical implications that may arise. This includes any serious adverse events and/or termination of the study.

A progress report should be submitted within one year of approval, and annually for long term studies. A final report should be submitted at the completion of the study.

The HSREC functions in compliance with, but not limited to, the following documents and guidelines: The SA National Health Act. No. 61 of 2003; Ethics in Health Research: Principles, Structures and Processes (2015); SA GCP(2006); Declaration of Helsinki; The Belmont Report; The US Office of Human Research Protections 45 CFR 461 (for non-exempt research with human participants conducted or supported by the US Department of Health and Human Services- (HHS), 21 CFR 50, 21 CFR 56; CIOMS; ICH-GCP-E6 Sections 1-4; The International Conference on Harmonization and Technical Requirements for Registration of Pharmaceuticals for Human Use (ICH Tripartite), Guidelines of the SA Medicines Control Council as well as Laws and Regulations with regard to the Control of Medicines, Constitution of the HSREC of the Faculty of Health Sciences.

For any questions or concerns, please feel free to contact HSREC Administration: 051-4017794/5 or email EthicsFHS@ufs.ac.za.

Thank you for submitting this proposal for ethical clearance and we wish you every success with your research.

Yours Sincerely

Dr. SM Le Grange
Chair : Health Sciences Research Ethics Committee

Health Sciences Research Ethics Committee
Office of the Dean: Health Sciences
T: +27 (0)51 401 7795/7794 | E: ethicsfhs@ufs.ac.za
IRB 00006240; REC 230408-011; IORG0005187; FWA00012784
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UNIVERSITY OF THE FREE STATE
UNIVERSITEIT VAN DIE VRYSTAAT
YUNIVESITHI YA FREISTATA

UFS·UV
HEALTH SCIENCES
GESONDHEIDSWETENSKAPPE

Health Sciences Research Ethics Committee

19-Feb-2021

Dear **Dr Unathi Ntja**

Ethics Number: UFS-HSD2019/0236/3007-0001

Ethics Clearance: **Diagnostic accuracy and reliability of smartphone camera captured radiologic images communicated via WhatsApp instant messaging**

Principal Investigator: **Dr Unathi Ntja**

Department: **Clinical Imaging Sciences Department (Bloemfontein Campus)**

Submission Page

SUBSEQUENT SUBMISSION APPROVED

With reference to your recent submission for ethical clearance from the Health Sciences Research Ethics Committee. I am pleased to inform you on behalf of the HSREC that you have been granted ethical clearance for your request as stipulated below:

- I would like to change my supervisor to the current head of department Dr J Van Rensburg as my previous supervisor is no longer in the department.

The HSREC functions in compliance with, but not limited to, the following documents and guidelines: The SA National Health Act. No. 61 of 2003; Ethics in Health Research: Principles, Structures and Processes (2015); SA GCP(2006); Declaration of Helsinki; The Belmont Report; The US Office of Human Research Protections 45 CFR 461 (for non-exempt research with human participants conducted or supported by the US Department of Health and Human Services- (HHS), 21 CFR 50, 21 CFR 56; CIOMS; ICH-GCP-E6 Sections 1-4; The International Conference on Harmonization and Technical Requirements for Registration of Pharmaceuticals for Human Use (ICH Tripartite), Guidelines of the SA Medicines Control Council as well as Laws and Regulations with regard to the Control of Medicines, Constitution of the HSREC of the Faculty of Health Sciences.

For any questions or concerns, please feel free to contact HSREC Administration: 051-4017794/5 or email EthicsFHS@ufs.ac.za.

Thank you for submitting this request for ethical clearance and we wish you continued success with your research.

Yours Sincerely

Prof. A. Sherriff
Chairperson : Health Sciences Research Ethics Committee

Health Sciences Research Ethics Committee
Office of the Dean: Health Sciences
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Appendix C

health
Department of Health
FREE STATE PROVINCE

09 April 2019

Dr U Ntja
Dept. of Clinical Imaging Science
UFS

Dear Dr U Ntja

Subject: Diagnostics accuracy and reliability of smartphone camera captured radiologic images communicated via WhatsApp instant messaging.

- Please ensure that you read the whole document, Permission is hereby granted for the above – mentioned research on the following conditions:
- Serious Adverse events to be reported to the Free State department of health and/ or termination of the study
- Ascertain that your data collection exercise neither interferes with the day to day running of Pelonomi Hospital nor the performance of duties by the respondents or health care workers.
- Confidentiality of information will be ensured and please do not obtain information regarding the identity of the participants.
- **Research results and a complete report should be made available to the Free State Department of Health on completion of the study (a hard copy plus a soft copy).**
- Progress report must be presented not later than one year after approval of the project to the Ethics Committee of the University of the Free State and to Free State Department of Health.
- Any amendments, extension or other modifications to the protocol or investigators must be submitted to the Ethics Committee of the University of the Free State and to Free State Department of Health.
- **Conditions stated in your Ethical Approval letter should be adhered to and a final copy of the Ethics Clearance Certificate should be submitted to** sebeelatso@fshealth.gov.za / Hlokomao@fshealth.gov.za **before you commence with the study**
- No financial liability will be placed on the Free State Department of Health
- **Please discuss your study with Pelonomi Hospitals CEO's on commencement for logistical arrangements see 2nd page for contact details.**
- Department of Health to be fully indemnified from any harm that participants and staff experiences in the study
- Researchers will be required to enter in to a formal agreement with the Free State department of health regulating and formalizing the research relationship (document will follow)
- You are encouraged to present your study findings/results at the Free State Provincial health research day
- Future research will only be granted permission if correct procedures are followed see http://nhrd.hst.org.za

Trust you find the above in order.

Kind Regards

Dr D Motau
HEAD: HEALTH
Date: 11/Oct/19

Head : Health
PO Box 227, Bloemfontein 9300
4th Floor, Executive Suite, Bophelo House, cnr Maitland and, Harvey Road, Bloemfontein
Tel: (051) 408 1646 Fax: (051) 408 1556 e-mail: [illegible]@fshealth.gov.za/[illegible]@fshealth.gov.za/[illegible]@fshealth.gov.za

www.fs.gov.za

Appendix D

DATA SHEET

XRAY NUMBER :
REGISTRAR NUMBER :

	Present	Absent	Unsure
Mediastinal abnormality			
Lung abnormality			
Pleural abnormality			
Bone abnormality			
Soft tissue abnormality			
Abdominal abnormality			

BODY PART IMAGED :

DIAGNOSIS:

Appendix E

Diagnostic accuracy of smartphone captured radiologic images communicated via whatsApp

ORIGINALITY REPORT

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PRIMARY SOURCES

www.cureus.com

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STUDENT PAPERS

1

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3

Mindy Y. Licurse, Sung H. Kim, Woojin Kim, Alexander T. Ruutiainen, Tessa S. Cook. "Comparison of diagnostic accuracy of plain film radiographs between original film and smartphone

capture: a pilot study", Journal of Digital Imaging, 2015

Digital Receipt

This receipt acknowledges that Turnitin received your paper. Below you will find the receipt information regarding your submission.

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Submission author:	Unathi Ntja
Assignment title:	Publishable Manuscript
Submission title:	Diagnostic accuracy of smartphone …
File name:	For_TurnitIn.docx
File size:	92.84K
Page count:	23
Word count:	7,300
Character count:	42,200
Submission date:	10-Feb-2021 08:31PM (UTC+0200)
Submission ID:	1490709704

Abstract

Background: Sending radiographic images as instant messages have become a common means of communication between physicians, aiding in triaging and transfer decision-making in emergencies. While the use of technology is increasing, this is not the case for the underserved or rural areas of South Africa with no picture archiving and communications system (PACS) or advanced hardware in place. In these areas, however, the medical population tends to have nearly universal access to smartphones and would benefit from the ability to share images quickly and easily with trained radiologists. South African data on diagnostic reliability of smartphone radiology images is lacking.

Objectives: The objective of the study was to determine the accuracy and reliability of diagnoses made on radiologic images with a smartphone compared to radiologic images on PACS.

Method: This was a cross-sectional study. Radiographs from 1 June 2018 to 1 July 2019 were selected from the PACS system at a tertiary hospital in the east-central South Africa. The images were displayed on a PACS computer screen and captured by the researcher using a smartphone. Five radiology registrars received the images via WhatsApp® and reviewed them on their phones. After three weeks, the registrars viewed the images in random order on a PACS station. McNemar's test was used to compare the diagnostic accuracy of smartphone and PACS. Kappa values were calculated for agreement. Reliability was assessed by analyzing the results of different registrars and diagnoses separately.

Results: One hundred and thirty-five X-rays, representative of common emergency conditions, were selected. For all registrars, the PACS accuracy was generally higher than the smartphone accuracy. The Kappa values all indicated fair to moderate agreement between smartphone and PACS diagnosis.

Conclusion: Capturing radiographic images using at least a 12-megapixel smartphone and sharing them via WhatsApp® is a reliable method that can be used with a high degree of confidence in emergencies to aid clinical decision making. This method of viewing medical imaging is however not a substitution for images viewed on PACS.