SMARTPHONE WHATSAPP APPLICATION RELIABILITY AS A TELERADIOLOGY FOR EVALUATION OF HEAD CT IN TRAUMATIC BRAIN INJURY

DR MOHAMAD NAZRI BIN MUNAWAR KHAN

UNIVERSITI SAINS MALAYSIA

2022

BY

DR MOHAMAD NAZRI BIN MUNAWAR KHAN

DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF MEDICINE (RADIOLOGY)

UNIVERSITI SAINS MALAYSIA

2022

ACKNOWLEDGEMENT

I would like to express my gratitude to Allah SWT for giving me the opportunity and endlessly guiding me throughout the completion of this thesis. My appreciation to those who have contributed to the success of this study and helped me from the beginning until the completion of my dissertation.

My deepest gratitude to my supervisor, Dr Muhamad Zabidi Ahmad from the Department of Radiology, Institut Perubatan & Pergigian Termaju, my co-supervisor, Dr Mahedzan bin Mat Rabi from Department of Radiology, Hospital Seberang Jaya, and Professor Dr Ibrahim Lutfi bin Shuaib from Department of Radiology, Institut Perubatan & Pergigian Termaju, my ex-supervisor for their priceless scientific guidance and advice for my research.

I sincerely appreciate the invaluable help from the Hospital Universiti Sains Malaysia (HUSM) radiology department radiographers and doctors for supporting and assisting in this study.

Special thanks to the Hospital Director, Professor Dr Ahmad Sukari Halim, and Head of the Department of Radiology, Associate Prof Dr Mohd Shafie Abdullah for the approval and support for conducting the study.

Most importantly, I also would like to thank my mother, Kamariah bt Mohd Nordin, and my dearest wife, Norarbaeyati bt Robert, my family, and friends, for their endless support, understanding, and sacrifice throughout the study.

TABLE OF CONTENT

LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

3G	Third generation cellular network
ACR	American College of Radiology
AO	Arbeitsgemeinschaft für Osteosynthesefragen
App	Application
CD	Compact disc
CT	Computed Tomography
CXR	Chest X-Ray
DICOM	Digital Imaging and Communications in Medicine
ED	Emergency Department
FPS	Frame per Second
GCS	Glasgow Coma Scale
HD	High-definition
HUSM	Hospital Universiti Sains Malaysia
ICP	Intracranial pressure
ICU	Intensive Care Unit
IMS	Instant Messaging Service
MB	Megabyte
MMS	Multimedia Messaging Service

NCCT	Non contrasted CT
NPV	Negative predictive value
PACS	Picture Archiving and Communication System
PDA	Personal Digital Assistant
PPV	Positive predictive value
RIS	Radiology Information System
SD	Standard Deviation
SPSS	Statistical Product and Service Solutions
TBI	Traumatic Brain Injury
MOH	Ministry of Health
κ	Kappa

ABSTRAK

Latar belakang: Teleradiologi telah digunakan sebagai kaedah perundingan dalam Kecederaan Otak Traumatik (KOT) di hospital yang tidak mempunyai kepakaran Neurosurgeri. Mengambil gambar dan video imbasan tomografi berkomputer serta menghantarnya melalui aplikasi WhatsApp telah menjadi kaedah yang biasa digunakan untuk proses komunikasi di antara pegawai perubatan. Kaedah tersebut juga telah digunakan untuk membantu membuat keputusan bagi pengkelasan dan pemindahan pesakit KOT yang memerlukan pembedahan. Seperti yang kita ketahui, pemampatan video WhatsApp untuk proses penghantaran digabungkan dengan saiz, resolusi dan fungsi video yang terbatas jika dibandingkan dengan stesen kerja radiologi mungkin meningkatkan kadar salah tafsir. Tujuan kajian ini ialah untuk menilai kebolehpercayaan video WhatsApp sebagai kaedah Teleradiologi bagi KOT.

Metod: Kajian prospektif kebolehpercayaan dan persetujuan telah dijalankan di HUSM melibatkan 85 orang pesakit. Pesakit-pesakit ini telah menjalani pemeriksaan imbasan tomografi berkomputer kepala apabila dimasukkan ke Unit Kecemasan setelah terlibat dengan trauma. Rakaman video imbasan tomografi berkomputer telah dihantar melalui WhatsApp dan telah dinilai oleh dua orang penilai yang berpengalaman menggunakan iPhone 7 plus bagi mengesan pendarahan otak, peralihan garis tengah, kepatahan tulang serta pneumokranium. Analisis imbasan tomografi berkomputer pesakit yang sama telah dijalankan sekali lagi selepas 4 minggu menggunakan stesen kerja radiologi. Analisis Kappa telah digunakan untuk perbandingan persetujuan diantara penilai yang berbeza dan penilai yang sama bagi penemuan dari imbasan tomografi berkomputer.

Keputusan: Untuk taksiran di antara penilai yang sama dan penilai yang berbeza, nilai κ adalah 0.68-0.70 untuk pendarahan otak, 0.16-0.96 untuk jenis pendarahan, 1.0 untuk peralihan garis tengah, 0.59-0.73 untuk patah tulang dan 0.55-0.57 untuk pneumocranium.

Kesimpulan: Terdapat persetujuan hampir sempurna bagi pendarahan subaraknoid dan peralihan garis tengah walaubagaimanapun penemuan yang lain menunjukkan nilai κ dibawah 0.90. Ini menunjukkan bahawa pengunaan WhatsApp untuk teleradiology mempunyai nilai yang terbatas dalam mendiagnosis KOT.

Kata kunci: Kecederaan Otak Traumatik, Teleradiologi, Telefon pintar, WhatsApp, Imbasan tomografi berkomputer, Pendarahan otak, Kebolehpercayaan.

ABSTRACT

Background: Teleradiology has been used as a method of consultation in Traumatic Brain Injury (TBI) for hospitals without neurosurgical expertise. Capturing images and recording videos of CT scans and sending via WhatsApp has become a common means of communication between physicians. It has been used as an aid for decision-making in triaging and transfer of TBI cases that need surgical intervention. It is known that WhatsApp uses video file compression for transmitting video, and combined with the limited size, resolution, and functionality of video compared to radiology workstation may increase the rate of misinterpretation. The purpose of this study is to evaluate the reliability of WhatsApp video as a method of teleradiology in TBI.

Methods: A prospective reliability and agreement study was conducted in HUSM on 85 patients. These patients are subjected to emergency head CT after being admitted to the emergency department for prior history of trauma. Video recording of CT scan was transmitted via WhatsApp and evaluated for intracranial haemorrhage, midline shift, fracture, and pneumocranium by two experienced raters from iPhone 7 plus. Reading of the CT scan of the same patients was repeated from a radiology workstation after 4 weeks interval. Kappa analysis was used to compare the interrater and intrarater agreement regarding the CT scan findings.

Results: For the assessment of both the intra and interrater agreement, the κ values were found to be 0.68-0.70 for the presence of intracranial haemorrhage, 0.16-0.96 for types of intracranial haemorrhage, 1.0 for midline shift, 0.59-0.73 for fracture, and 0.55-0.57 for pneumocranium.

Conclusion: There was an almost perfect agreement for subarachnoid haemorrhage and midline shift with most of the other findings showing less than 0.90 κ score. This signifies that using WhatsApp for teleradiology could be of limited value in the diagnosis of TBI-related injury.

Keywords: Traumatic Brain injury, Teleradiology, Smartphone, WhatsApp, Ct scan, Intracranial haemorrhage, Reliability

CHAPTER 1: BACKGROUND

1.1 Introduction

Traumatic brain injury is one of the commonest contributors to death and disability. The worldwide burden of TBI has been estimated at 69 million cases per year (Dewan et al., 2019). In Malaysia, roads traffic accidents are the sixth (7.2%) leading cause of public hospital admissions in 2017 (Zainal et al., 2020) and the third leading cause of Intensive Care Unit admissions (7.7%) (Li et al., 2016). Even though the main bulk of these patients will fall into the mild category of TBI, 0.00073 % of the population is estimated to suffer severe TBI each year (Dewan et al., 2019) and a larger proportion will be needing consultation from neurosurgery.

Given the limited availability of hospitals with neurosurgical expertise, the majority of TBI patients will be managed in the district hospitals. (Klauber et al., 1989) have shown that the majority of the mortality involving head-injured patients is from the low-risk group. Multiple authors (Hailey et al., 2002; Hazebroucq and Fery-Lemonnier, 2004; Holguin et al., 2011; Iaccarino et al., 2008; Kreutzer et al., 2008; Migliaretti et al., 2013; Oguchi et al., 2001; Reponen et al., 2005; Servadei et al., 2002) have demonstrated the clinical and cost-effectiveness of transferring the CT image as a part of the treatment guideline with the patients being managed in non-referral centres. It causes a significant change in the management of the patients (81%) and a reduction in the unnecessary transfer (Hailey et al., 2002).

Teleradiology is a branch of medicine that involves the usage of computers and telecommunication networks in the transmission of the diagnostic image that is acquired in one location, to be reviewed and interpreted in a different location. It is a branch of telemedicine that first started in the year 1930 where the Queen Mary Oceanliner used the ship's radiotelephone for a medical consult. In the '60s and '70s, extensive research has been conducted for medical image transmission using closed circuits and broadcast television. However, it was deemed not practical considering the tedious process of transmission, high cost, and low image quality produced.

The first standard for digital storage of medical images was introduced in 1983 by the American College of Radiology (ACR) and the National Electrical Manufacturers Association (NEMA). It has subsequently revised in 1988 and 1993 to a more widely accepted standard Digital Imaging and Communications in Medicine (DICOM) as we know it today (Horii and Bidgood, 1992). The first standard for teleradiology was produced by ACR in 1994 where requirements for image acquisition and display, teleradiologist, work environment, and a few other recommendations were outlined. Teleradiology usage since then has gained worldwide acceptance not only in a hospital setting but also in the military.

Multiple methods have then been evaluated for communicating radiological images such as using an ambulance, computerized image transfer system, email, mobile phone, video consultation with the most recent using iPad and smartphones (Filip et al., 2012; Mitchell et al., 2011). (Demaerschalk et al., 2012) have successfully incorporated a smartphone application (app) for teleradiology using cloud base ResolutionMD into a telestroke system. (Handelman et al., 2018) have produced good inter-observer reliability in interpreting images of chest x-ray (CXR) being transferred using WhatsApp and (Stahl et al., 2017) had a similar finding when sending a video of thoracolumbar fractures using WhatsApp.

Effective specialized app has been developed for remote and rapid visualization of radiological images (Zennaro F et al., 2012) which are also secure. However, these are costly and burdensome due to the need of visualization server, cloud computing and installation of application to the source and receiving smartphone. Remote consultation from rural hospital will require the radiologic images to be exported to the tertiary hospital before consultation can begin which increase the intricacy and duration of the whole process.

1.2 Problem statement

Usage of instant messaging app to interpret CT scan of the brain from smartphones carries a risk for medical malpractice as this method of image transfer are subject to degradation of image quality from compression of the video by the app. WhatsApp uses lossy compression to reduce the size of the video file to save internet bandwidth while uploading the file to its server. Hence the recipient will get a low-resolution version of the original file. The maximum video file size for WhatsApp is 16 Megabyte (MB) and the footage length of a video size ranges from 90 seconds to 3 minutes.

Furthermore, the resolution and size of the smartphone screen and camera quality will limit its ability to demonstrate pathology. This study will test the reliability of this image communication system in the setting of TBI which is the main bulk of indication for head CT and poses a significant risk to the patient and practitioner if intracranial haemorrhages and its complications are misinterpreted.

1.3 Objectives

1.3.1 General Objective

To determine the reliability of the WhatsApp app as teleradiology in the interpretation of the CT for TBI.

1.3.2 Specific Objectives

1. To identify the compression effect on the video sent using the WhatsApp app.
2. To determine the intrarater and interrater agreement of the findings from smartphone and Picture Archiving and Communication System (PACS) workstation.
3. To determine the intrarater and interrater reliability of the findings from smartphone and PACS workstations

1.4 Null Hypothesis

WhatsApp video of CT brain images cannot be reliably used for the evaluation of head injury.

1.5 Research Question

1. Does the WhatsApp app video of CT brain done in TBI patient seen from smartphone be reliably used for teleradiology?

CHAPTER 2: LITERATURE REVIEW

2.1 Traumatic Brain Injury

2.1.1 Overview

Traumatic Brain Injury, a disorder that is frequently referred to as a silent epidemic (Dewan et al., 2019) is a major cause of worldwide death and disability. The estimated incidence of TBI worldwide is 64 to 74 million cases per year. In Malaysia, TBI is reported as the top three common admissions to ICU (Li Ling, 2018) with limited research and reporting system available on this topic (Arulsamy and Shaikh, 2020).

The severity of TBI is graded clinically using the Glasgow Coma Scale (GCS) into mild (GCS of 13-15), moderate (GCS of 9-13), and severe (score of 3-8). The mortality rate with moderate and severe TBI is 21% and 46% respectively (Clement, 2019). The role of imaging in the management of TBI includes immediate triaging, serial imaging for neurologic deterioration, and prognostication. Noncontrast CT is the recommended modality for initial imaging as well as subsequent follow-up for clinical deterioration.

Imaging findings can be classified into primary injury, i.e., direct manifestation of the trauma (intra-axial or extra-axial haemorrhages, skull fracture, and vascular injuries) or secondary injury which are complications developing within 24 hours of trauma (ischemic injury, herniation, and oedema). Mechanism of injury will largely influence the imaging findings which includes blunt trauma, penetrating trauma, acceleration/deceleration or blast injury.

2.1.2 Primary injury in TBI

Epidural hematoma is a haemorrhage collection within the dura and inner table of the skull. It can originate from arterial or venous injury and typically results from injury to branches of the middle meningeal artery. On CT, it will appear as a hyperdense lenticular extra-axial collection with an associated skull fracture. The presence of the Swirl sign indicates active bleeding and is independently associated with a high mortality rate. The rapid expansion of the hematoma can lead to cerebral herniation and ischemia.

Subdural hematoma is a result of injury to the bridging cortical veins and manifests as the accumulation of blood between the dura and arachnoid membrane forming a crescentic shape that does not cross the midline. The elderly population is more susceptible to this type of haemorrhage due to brain volume loss and vessel fragility. In the pediatric population, rapid acceleration/deceleration which occurs in Shaken Baby Syndrome is a responsible mechanism for its high incidence. The associated vasogenic oedema can cause a midline shift which together with the maximum thickness of haemorrhages will determine the need for surgical management.

Subarachnoid haemorrhage can either be caused by injury of the vein within the subarachnoid space, redistribution of intraventricular haemorrhage, or perforation of subarachnoid space by an adjacent intraparenchymal haemorrhage. On CT, it will appear as hyperdensities along the sulci, fissure, and cisterns. Further evaluation of this haemorrhage with CT Angiography is advised in cases of central subarachnoid haemorrhage within the cisterns and Sylvian fissure to exclude the underlying aneurysm. Isolated subarachnoid haemorrhage in the setting of mild TBI has a low level of clinical deterioration and surgical intervention.

Intraventricular haemorrhage is rare in the setting of TBI but has a high mortality rate (Clement, 2019). This is a result of injury to the corpus callosal/subependymal vessels, injury to paraventricular structures, direct penetration of intraparenchymal haemorrhage, or redistribution of subarachnoid haemorrhage. It can be complicated by acute obstructive hydrocephalus and increased ICP.

Cortical contusions are small haemorrhages that frequently occur at the site of injury and the opposite side (counter-coup) due to head motion against the inner surface of the skull. It usually originates from the highly vascular grey matter and can extend into the white matter. On CT it usually appears as a wedge shape haemorrhage within the gyrus.

2.2 Smartphone

2.2.1 Usage in the medical field

The first telephone was debuted by Alexander Graham Bell in the year of 1876 at the Centennial Exhibition Philadelphia. Since then, its technology has evolved from the landline-based phone, mobile phone, cellular phone, internet-enabled phones, personal digital assistants (PDA) with the second most important event is Apple's first-generation iPhone launched in 2007 by Steve Job which considered by many, the first modern smartphone (Reid, 2018).

The usage of smartphones has become more frequent and widespread with hundreds of new applications produced every day which can be used in almost every aspect of our daily activity including medical-related applications. Instant messaging services (IMS) such as WhatsApp and iMessage have also gained popularity and changed the way people communicate. Its usage in the field of medicine has gained popularity particularly in the field of telemedicine. A Brazilian study has shown that medical officers and students used IMS as a tool for clinical case discussion, the interaction between the healthcare provider and patient as well as dissemination of information and knowledge (Borges Do Nascimento et al., 2020).

2.2.2 WhatsApp Messenger

WhatsApp is a free messaging app that supports multiple platforms. It is first launched in 2009. It allows users to make video and voice calls, send text messages, share their status, and many more using an internet connection. It has advanced security features such as end-to-end encryption, no personal information stored by the app, two-factor authentication, and messages that can only be sent by people who are approved by the user.

There are over 2 billion registered users from 180 countries with 1 billion active daily users. It is the leading messaging app in 169 countries and has been selected as the most popular globally in 2021. However, there are a few disadvantages of using this app. WhatsApp only allows the user to communicate with people within its platform. It does not have any virtual assistant and there is a restriction to the maximum size of file, photo, or video sent using this application.

2.3 Reliability and agreement

Reliability is defined as the ability of a measurement to differentiate among subjects or objects whereas agreement is the degree to which scores or ratings are identical (Kottner et al., 2011). Collectively, these parameters will give information about the degree of measurement error in the result and not the validity of the results. The level of reliability and agreement of different users in smartphone-based teleradiology is largely unknown.

The scope of this review is limited to published works, works in English, regarding reliability for the usage of smartphones as a method of image transmission in diagnostic imaging. Most of the study reviewed has shown a high level of agreement between rater when evaluating CT scan or CXR in the form of image or video which was read from a smartphone.

2.4 Smartphone-based teleradiology

(Waran et al., 2012) haves shown sufficient quality of the image to a base emergency decision for a patient with neurosurgical problems using mobile telephones with Multimedia Messaging Service (MMS) and video recording capabilities taken directly from the CT console. They tested 56 consecutive neurosurgical consultations within 1 year period including 27 head trauma, 16 spontaneous intracerebral haemorrhage, 8 postoperative complications, 3 hydrocephalus, and one ischemic stroke and intracerebral infection.

The MPEG video was then transmitted via MMS message over the 3G network, subsequently viewed by 2 neurosurgeons from a Nokia N95 phone, and was compared to a radiologist review of the original images from PACS. The agreement between the two neurosurgeons was perfect (100%) for the diagnosis and almost perfect with the radiologist (98%, kappa 0.88). The agreement of management decision based on the diagnosis was significant between the two surgeons (89%, kappa 0.77) despite similar diagnosis was made which the author conclude due to professional difference in opinion.

However, this method has the drawback of being unable to adjust the contrast of the video, indefinite delay in transmission of the image during peak MMS service usage, and no securities for the image being transmitted. With the advancement of technology, smartphone and 4G network with much more speed and capabilities has become widely available. WhatsApp which is an instant messaging app offers the ability to share images and videos at higher speed and end-to-end user encryption which is available across multiple platforms.

Unwell patients having imaging out of normal working hours will benefit from quick second opinions and advice from senior medical staff. After previous unsatisfactory image quality was found when the assessment was done with CXR sent via MMS, the quality of the camera and screen of the smartphone has dramatically increased. (Handelman et al., 2018) have conducted a study to determine the inter and intraobserver reliability of interpreting CXR communicated via WhatsApp instant messaging. A set of 100 CXR images was reviewed by two radiologists and their consensus was used as the gold standard and was categorized into "urgent" (where they had findings that required clinician input within 24 hours), "clinically significant" (where they required non-urgent clinician input & could wait beyond 24 hours) or "incidental" (where there were isolated asymptomatic findings not requiring inpatient clinical or radiological follow up). Image of the CXR was taken using Samsung Galaxy S6 (16 megapixel camera, android 6.0.1, resolution 5312 x 2988 pixels).

Images were sent via WhatsApp to six research participants in 3 different hospitals and the original DICOM files images were uploaded to an online DICOM viewer with standard image manipulation for viewing by the participants. The results were viewing CXRs on a workstation versus on WhatsApp demonstrated no intraobserver differences in their ability to identify or rule out acute pathology - there were no statistically significant differences in sensitivity, specificity, positive predictive value (PPV), or negative predictive value (NPV) between the two modalities.

Another good example is a controlled environment reliability study using ResolutionMD (a mobile application that runs on a Smartphone) technology that has been conducted within a controlled environment in 2012 (Demaerschalk et al., 2012). The study objective was to assess the level of agreement of brain CT scan interpretation in a telestroke network between hub vascular neurologists using ResolutionMD in iPhone 4, spoke radiologists using a PACS, and independent adjudicator. Fifty-three patients with CT were evaluated by a hub vascular neurologist, a spoke radiologist, and by blinded telestroke adjudicators, and agreement over clinically important radiological features was calculated. Agreement (κ and 95% CI) between hub vascular neurologists using ResolutionMD and the spoke radiologist; and independent adjudicators, respectively, were made on identification of intracranial haemorrhage, neoplasm, any radiological contraindication to thrombolysis, early ischemic changes, and hyperdense artery sign.

They have found that CT head interpretations of telestroke network patients by vascular neurologists using ResolutionMD on Smartphones were in excellent agreement with interpretations by spoke radiologists using a PACS and those of independent telestroke adjudicators using a desktop viewer. The agreement between vascular neurologists using ResMD and radiologists and independent telestroke adjudicators using standard PACS and desktop viewers over-identification of the most critical radiological features on non-contrast CT brain scans such as intracranial haemorrhage, neoplasm, and any contraindications to thrombolysis was excellent. The agreement over the identification of more subtle radiological features such as early ischemic changes and hyperdense artery signs was moderate and fair, respectively. This study limitation was the small sample size as 12 of the consented patients were not enrolled, retrospective design, and time constraint of real-world stroke emergency. ResolutionMD is now one of the FDA-approved mobile applications to be used in radiology.

(Sharma et al., 2022) has conducted a reliability study in the field of urology for evaluation of CT scan images of the abdomen. This prospective study involving 30 patients presenting acutely to the emergency department whereby the clinical data and CT scan images of the abdomen was transmitted via Whatsapp and was rated for image quality, provisional diagnosis and initial management strategy by one senior resident and three consultant urologist using iPhone 11, One plus 5T, iPhone 8 and iPhone 6S. The result showed wide inter-rater variability for image quality with good interobserver agreement for diagnosis and management strategy.

Smartphone-based teleradiology has also been for the evaluation of spinal fracture. (Stahl et al., 2017) has conducted a study on the reliability of using video clips of radiographic scans taken from PACS workstations and sent via WhatsApp for viewing. CT scan of 30 adults with thoracolumbar fracture has been captured using iPhone 6 and was then sent to the personal smartphone of 5 spine surgeons. Images were evaluated for diagnosis, classify and determine the course of treatment.

The evaluation was then repeated after 4 weeks using the same case viewed from a workstation-based PACS. The result showed that interobserver agreement for determining fracture level was near a perfect, substantial agreement for AO and the Denis classifications, neural canal penetration, and treatment recommendation, and moderate agreement for loss of vertebral height and kyphosis. However, the study was conducted in a controlled setting with only CT images used to arrive at the diagnosis.

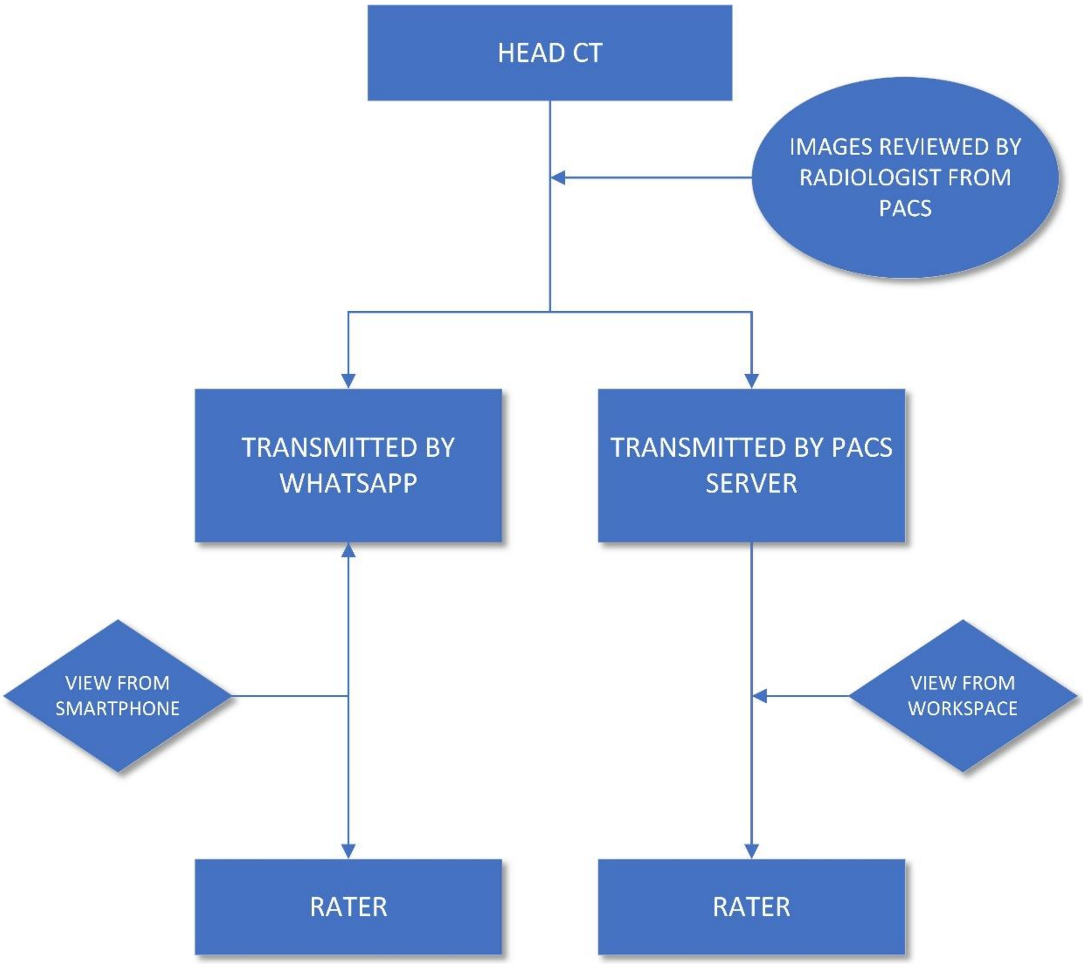
As for TBI cases, a fairly recent study by (Inan et al., 2020) has concluded that Whatsapp app can be use to evaluate emergency head CT. A total of 94 patient who underwent CT with provisional diagnosis of intracranial haemorrhage was retrospectively recorded and evaluated by two radiologist from Whatsapp using Samsung Note 8 and Samsung Galaxy Edge 7. This was then compared with finding from two other radiologist which reviewed done using PACS workstation. Interobserver agreement was near perfect for detection of intraparenchymal hematoma and substantial for identification of subdural hematoma, epidural hematoma, fractures and normal findings. Moderate agreement seen for parenchymal contusion and subarachnoid haemorrhage.

Another controlled setting agreement study by (Aldinc and Gun, 2021) has also demonstrated satisfactory accuracy of CT scan reading which was done from smartphone and compared to a LED display. A set of 50 preselected captured CT scan images which included intracranial heamorrhage and skull fracture was evaluated by 12 neurosurgeon from a smartphone and subsequently from a LED display. Calculated

Kappa score ranges from 0.725 – 1.0 with 80 – 100 % agreement for subarachnoid haemorrhage, epidural haemorrhage and bone fracture. This study however did not specify what type of smartphone used and the monitoring of the same CT image right after the first evaluation may have introduce bias.

Most of the critical radiological features in each imaging modality have shown high agreement between the rater when comparing WhatsApp against the PACS workstation with moderate agreement shown in the less critical or subtle findings. However, most of the studies are done in a controlled environment and the sample size are relatively small. There is also a trend to categorize multiple findings into small groups which does not reflect the daily clinical practice.

2.5 Conceptual framework



2.6 Rationale of the study

Given the effectiveness of teleradiology in the management of TBI, there will be a constant need for this type of consultation in the future. The instant messaging app which are already deeply integrated into our lifestyle and easily accessible will be used for this purpose despite some countries already putting on legal restrictions on its usage.

This study has tried to simulate the real working environment by selecting a patient who is acutely treated in the emergency department and has undergone a CT scan of the head. This was done to assess for small but significant finding which will likely be not included if only referred cases was selected. iPhone 7 plus was selected for video acquisition and image viewing (Deviceatlas Limited 2022, 2019).

This study has tested the reliability of this image communication system in the setting of TBI between two experienced raters to reduce the cognitive error which can contribute to missed findings. We can also identify which primary injury that can be missed from the CT brain since this is the likely initial finding that will need to be picked up during after working hours usage.

CHAPTER 3: METHODOLOGY

3.1 Study Design

This is a prospective reliability and agreement study using WhatsApp video from iPhone 7 plus among patients who underwent emergency head CT for TBI in HUSM from the period of 1st December 2020 until 31st May 2021.

3.2 Sample Population

i. Reference population: Head injury patients in Kelantan.
ii. Source population: TBI patient who undergone CT scans of the brain in HUSM.
iii. Target population: TBI patients who attended the emergency department in HUSM.
iv. Sampling frame: Patient registration list for CT scan.

3.3 Sample Size Calculation

1. The sample size for the second and third objectives was calculated based on the recent study done by (Stahl et al., 2017) with an agreement of 95 percent for fracture level and 90 percent for AO classification using sample size calculator version 2.0.

E1	Kappa (2 raters)	
	Minimum acceptable kappa (k0)	0.60
	Expected kappa (k1)	0.88
	Proportion of outcome (p)	0.30
	Significance level (α)	0.050 Two-tailed
	Power (1-β)	0.800
	Non-centrality parameter	7.849
	Drop-out	10%
	Sample size	76
	Sample size (with drop-out)	85

Reference: Donner, A., Eliasziw, M. (1992). A goodness-of-fit approach to inference procedures for the kappa statistic: Confidence interval construction, significance-testing and sample size estimation.Statistics in medicine, **11**, 1511-1519. E1

Excel file prepared by Dr. Wan Nor Arifin, Unit of Biostatistics and Research Methodology, School of Medical Sciences, Health Campus, Universiti Sains Malaysia. This file can be downloaded from http://wnarifin.github.io

Suggested reference:
APA: Arifin, W. N. (2017). Sample size calculator (Version 2.0) [Spreadsheet file]. Available from http://wnarifin.github.io
Vancouver: Arifin WN. Sample size calculator (Version 2.0) [Spreadsheet file]. Author: 2017. Available from http://wnarifin.github.io

With an additional 10% dropout rate, the sample size is 85.

3.4 Sampling Method

All consecutive patients who underwent emergency head CT scan, who fulfil the inclusion and exclusion criteria from 1st December 2020 till 31 May 2021 were recruited for the study and was assigned with numbers. From a total of 387 eligible patients, 85 patients were randomly selected using SPSS version 26 and enrolled in this study.

3.5 Subject Criteria

The subject selection was done at the radiology department if inclusion and exclusion criteria were fulfilled. The patient who was admitted to the emergency department HUSM with a history of trauma irrespective of age were included.

3.5.1 Inclusion Criteria

1. Image of patients irrespective of age who underwent a head CT scan for suspected brain injury.

2. Definitive history of trauma.

3. Admitted to the emergency department

3.5.2 Exclusion Criteria

1. Nondiagnostic image of the CT scan.
2. Repeated study for a reassessment of intracranial haemorrhage.
3. Concomitant other space-occupying lesions on CT scan

3.6 Research tools

i. Radiology Information System (RIS) – PACS version 6.0 for image acquisition and demographic/clinical data information.

ii. Pre-selected CT brain images acquisition obtained from 160 slices CT Toshiba Aquilion Prime in HUSM.

iii. Diagnostic workstation with 3 MegaPixel monitor- (Barco E-3620 MA monitor– resolution 2048 x 1536) for image viewing and analysis.

iv. SPSS version 26 was used for data analysis.

v. CT brain imaging answer sheets - reporting form for NCCT brain report modified from (Stahl et al., 2017) after discussion with the supervisor.

vi. iPhone 7 plus using native/preinstalled IOS 10 camera app were used to record video with WhatsApp app used for transmitting and viewing video of CT images because it is the most commonly used smartphone in Malaysia by the time the proposal was prepared (Deviceatlas Limited 2022, 2019).

3.7 Operational Definition

Rater: Two radiology registrar in HUSM who has at least 3 years of experience in interpreting CT scan of the brain.

TBI: disruption in the normal function of the brain that results from a bump, blow or jolt to the head or a penetrating head injury

Brain window: W80 L40.

Bone window: W3000 L500

Blood (Subdural)window: W:130-300 L:50-100

3.8 Data Collection

3.8.1 Image acquisition

Non-contrasted CT of the brain performed using 160 multislice Toshiba CT model Aquillion Prime. The image have been obtained from just below the foramen magnum through vertex at 120 kV and 200-400 mA. Images was then reconstructed at 1 mm and 5 mm thickness into soft tissue and bone algorithm which can be used to create multiplanar images.

3.8.2 Data collection method

Images of the CT scan from a database who had undergone a head CT for suspected TBI in emergency department HUSM were collected for 6 months duration. Selected CT scan images were recorded from a PACS workstation (Barco E-3620 MA, 20.8-inch 3 Megapixel display with a screen resolution of 2048 x 1536) into video clips using the iPhone 7 plus (Apple Inc., Cupertino, California, USA) video camera app (2160p HD video recording, 30 fps) while manually scrolling down through the CT scan and stored as a MOV file. iPhone 7 plus was selected because this is the most commonly used smartphone according to an online data tracking website in 2019 (Deviceatlas Limited 2022, 2019) . The anonymized image of CT which is stretched to fullscreen mode is taken in portrait orientation since the target viewing device is a smartphone. A tripod stand was used to hold the phone at a fixed distance of 30 cm from the workstation monitor (Aldinc et al., 2021) at a flat angle with the aid of a grid to standardize video acquisition.

Room illumination was adjusted to meet the standard reporting room illumination with the usage of inset ceiling lighting. Entire CT images of the brain from vertex to base of skull were recorded in the axial plane in brain, subdural, and bone window with 5 mm slice thickness using smartphone video camera while manually scrolling down through the CT scan.

Then, using the WhatsApp Messenger instant messaging application (version 2.19.244) which includes video file compression as an integral function, the video clips of each case are transmitted to the smartphone involved. The videos were interpreted without clinical information separately on a designated smartphone (iPhone 7 plus, 5.5-inch retinal display, 1920 x 1080 screen resolution). Then questionnaire of predefined categories was completed by the participants.

Recall bias was reduced by randomizing case numbers and participants have evaluated the same set of images from a standard PACS computer screen (Barco E-3620 MA, 20.8-inch 3 Megapixel display with a screen resolution of 2048 x 1536) and complete the same questionnaires after 4 weeks interval (Stahl et al., 2017).

3.9 Statistical analysis

All data were collected, tabulated, and statistically analyzed using Statistical Product and Service Solutions (SPSS) for Windows, SPSS Inc.© (Version 26, SPSS Inc., Chicago, IL, USA).

The descriptive statistics for discrete variables were presented as n=frequency (%). Most data were expressed as mean ± standard deviation (SD). Statistical analyses were presented in tables. A diagnostic test was used to determine reliability whereby the extent of intra-rater and interrater agreement assessed using Kappa analysis.

A p-value of < 0.05 was considered statistically significant. The study has been reported according to the Guidelines for Reporting Reliability and Agreement Studies (GRRAS) (Kottner et al., 2011).

3.10 Confidentiality and Privacy

Unique serial research numbers identified the subjects. No individual patient identifiable data were shared publicly. Upon completion of the study, all data were stored in a password-protected computer. This computer was only able to be accessed