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An Assessment of the iPad 2 as a CT Teleradiology Tool Using Brain CT with Subtle Intracranial Hemorrhage Under Conventional Illumination

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Abstract We examined the potential of the iPad 2 as a teleradiologic tool for evaluating brain computed tomography (CT) with subtle hemorrhage in the conventional lighting conditions which are common situations in the remote CT reading. The comparison of the clinician's performance was undertaken through detecting hemorrhage by the iPad 2 and the clinical liquid crystal display (LCD) monitor. We selected 100 brain CT exams performed for head trauma or headache. Fifty had subtle radiological signs of intracranial hemorrhage (ICH), while the other 50 showed no significant abnormality. Five emergency medicine physicians reviewed these brain CT scans using the iPad 2 and the LCD monitor, scoring the probability of ICH on each exam on a five-point scale. Result showed high sensitivities and specificities in both devices. We generated receiver operating characteristic curves and calculated the average area under the curve of the iPad 2 and the LCD (0.935 and 0.900). Using the iPad 2 and reliable internet connectivity, clinicians can provide remote evaluation of brain CT with subtle hemorrhage under suboptimal viewing condition. Considering the distinct advantages of the iPad 2, the popular out-of-hospital use of mobile CT teleradiology would be anticipated soon.

Keywords Brain CT · Clinical image viewing · iPad · Teleradiology

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Introduction

Tablet PCs are frequently used in hospitals where they have a variety of applications including medical education, journal searching, and the viewing of medical images [1]. More recently, they have been examined for mobile teleradiology via wireless networks [2]. It is thought that this technology will prove extremely useful in emergency departments (EDs) where the real-time radiologic image review by a radiologist or senior physician is not available 24 h a day like many EDs in South Korea [3]. Among the available tablets, Apple's iPad 2 has the highest worldwide market share and several distinct features, including its slim profile, light weight (less than 601 g), internet connectivity, relatively large display, and numerous applications for viewing and transferring radiological images [4, 5]. Consequently, the iPad 2 is arguably one of the most updated hand-held teleradiology devices. However, just a few feasibility studies have been undertaken using it, focusing on the contrast detail and diagnostic agreement mainly under the typical illumination, 15–60 lux for computed tomography (CT), or MR reading [6–9]. But there was not any study assessing the potential of the teleradiologic displaying device under the realistic situation like suboptimal lighting, real-time network utilization, and subtle abnormal images.

In this study, we examined the potential of the iPad 2 as a CT teleradiology tool, for which we chose the brain CT with subtle intracranial hemorrhage (ICH) of a Korean emergency department as an example. This was chosen due to the following reasons. First, brain CT exam is frequently performed in the EDs. Second, the evaluation of brain CTs with obvious lesions is thought to be less dependent on the quality and type of display and so probably does not vary between devices, which requires less remote consultation in actual practice [3, 10]. Third, emergency brain CT is thought a typical study for intensively evaluating the mobile CT teleradiology because clinicians usually apply delicate adjustment of window level and width to every single brain scan throughout the whole exam, not to miss subtle hemorrhage [11, 12]. We assessed the iPad 2's performance when viewing CT brain images in the suboptimal lighting conditions of an ED, comparing the ability of clinicians to detect subtle hemorrhage using the iPad 2 and the clinical liquid crystal display (LCD) monitor.

Method

Overview

We selected 100 non-contrast-enhanced brain CT examinations performed for head trauma or headache. Fifty had subtle radiological signs of intracranial hemorrhage, while the other 50 showed no significant abnormalities, as confirmed by the neuroradiologist. Five observers (emergency medicine attending physicians or residents) reviewed these brain CT scans using an iPad 2 and also an LCD monitor of the ED desktop PC, scoring the probability of ICH on each exam on a five-point scale. The study was approved by the in-hospital ethics committee.

Selection of Images

The brain CT images were acquired using a 16-channel multidetector row CT scanner (Somatom Sensation 16, Siemens, Germany) with the following specifications: 0.75×12 mm^2 of collimation, 12 kVp, 300 effective mAs with automatic exposure control, 24 mm of rotation table feed, and 0.55 pitch. The detector array was positioned parallel with the skull base line in the lateral aspect. Images were acquired from the vertex to the lower margin of the body of the second cervical vertebra. None of the images was contrast-enhanced.

The study used a total of 100 brain CT exams performed for head trauma or headache presenting to the emergency department from 2010 to 2011. The age of the patients ranged from 1 to 96 years, and 66 were male. Fifty exams of these showed signs of intracranial hemorrhage. These signs were subtle, as indicated by the fact that first- or second-year emergency medicine residents had initially missed them, which a neuroradiologist and emergency attending physicians detected on the next day review. Another 50 examinations without remarkable abnormalities were selected and matched for age and sex. All reports were verified by the neuroradiologist.

The iPad 2 Teleradiology System

The iPad 2 and the Clinical LCD Monitor with ED Desktop PC

The iPad 2 (Apple, Cupertino, CA, USA) was used as the remote visualization device, connected to the Internet via a wireless network. Its size was $241.2 \times 185.7 \times 8.8$ mm, with a 246-mm screen (diagonal dimension) (see Fig. 1) [13]. The specifications of the display are shown in Table 1 [6]. The iPad 2 uses a LED backlight screen with a resolution of $1{,}024 \times 768$ pixels. The operating system used was iOS5 with a remote viewing application. The device supported coded network communication, thus protecting the integrity of the data. Since current 300–400-cd/m^2 radiological monitors mostly provide comfortable luminance, we set the brightness to 400 cd/m^2, along with true color depth [14]. The display was not calibrated by standard grayscale.

The desktop computer used for comparison was a PC operating Windows XP used for viewing radiologic images

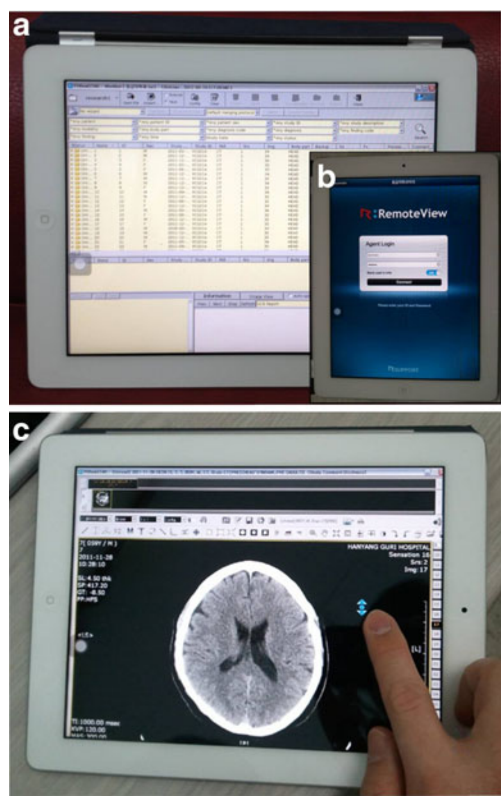

Fig. 1 *A* The remote-controlled PACS worklist on the iPad; *B* the login screen of the RemoteView application on the iPad; *C* observers viewed the remote-controlled PACS CT images on the iPad by touching and scrolling the screen

Table 1 Characteristics of the two displays used in the study

	iPad 2	Clinical LCD monitor
Display type	Color LED	Color LCD
Number of pixels	1,024×768	1,600×1,200
Maximum luminance (cd/m^2)	410	300
Minimum luminance (cd/m^2)	0.43	0.30
Used luminance (cd/m^2)	400	170[a]
Viewable image size, diagonal (cm)	24.64	54
Contrast ratio	962:1	1,000:1
DICOM calibration	None	Calibrated

[a]The manufacturer's default calibration software supported only 170 cd/m^2 which the American College of Radiology recommends as the minimum level for clinical monitors' maximum luminance [16]

in the emergency department on a daily basis. This machine also functioned as the ED image server and allowed the iPad 2 to wirelessly access the image data held there. Officially, our hospital still does not support Windows 7, so we used Window XP, current operating system for our hospital PCs, which did not have any problem to operate our iPad teleradiologic system. The monitor used was a 1,600×1,200-pixel LCD (MX210, EIZO, Japan), and viewing software was a DICOM viewer (PiViewSTAR, Infinitt, Seoul, South Korea) (see Fig. 2). The detailed specifications of the clinical LCD are shown in Table 1. The LCD monitor was calibrated using DICOM Grayscale Standard Display Function with quality control software (RadiCS, EIZO) and External Sensor (UX1 Sensor, EIZO) [15]. Manufacturer's default calibration software supported only 170 cd/m^2 for our ED clinical monitor's maximum luminance, which American College of Radiology (ACR) guidelines recommended as the minimum level for clinical monitor reading [16].

Wireless Remote Viewing

RemoteView Agent 5.0 (Rsupport Co, Seoul, South Korea) and RemoteView for the iPad 2 were installed on the ED

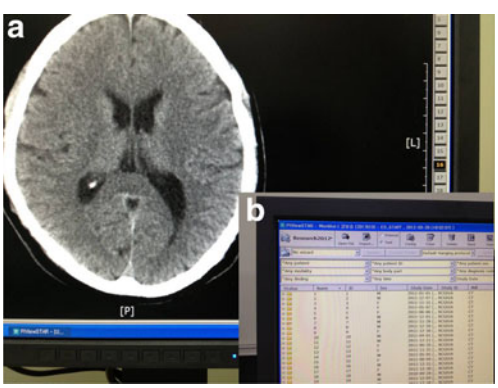

Fig. 2 *A* The clinical LCD monitor of the ED desktop PC, which enabled the clinician to view ED radiological images using a DICOM viewer; *B* the brain CT images were randomly assigned the numbers between 1 and 100

image server and the iPad 2, respectively, from the remote viewing service provider's website (https://www.rview.com) and iTunes (https://www.apple.com/itunes) [17, 18]. These applications establish a secure wireless link (802.11 g) via Rsupport's relay server, allowing the ED image server's screen to be visualized on the iPad 2 [19]. The radiological images were transferred from the ED image server using lossless compression, true color depth, and end-to-end encryption [19]. The wireless network used had a maximum data transfer rate of 6.91 Mbps for download and 9.29 Mbps for uplink. All functions of the DICOM viewer were supported by the remote viewing application on the iPad 2.

Review of Brain CT

Five emergency medicine physicians (two attending physicians, three senior residents) reviewed the 100 selected examinations without any clinical information except the age and history of headache or head trauma. The reviewers were instructed to grade the likelihood of ICH in each case using a five-point scale (1 = no ICH, 2 = unlikely ICH, 3 = inconclusive, 4 = likely ICH, 5 = clear ICH). All reviews were attempted within the operating ranges of the viewing angles, less than 30° from the perpendicular viewing axis, using a 1,024×1,024-pixel display in the ED where Wi-Fi was available. The ambient lighting level was 200 lux, measured directly anterior from the display switched off, with the photometer perpendicular to the center of monitor [16]. Both screens were set up not to be reflected to the ambient lighting, in accordance with ACR guideline [16].

Before the start of the study, all observers familiarized themselves with the iPad 2 and the DICOM viewer. We randomly assigned each case a number from 1 to 100. Three observers, randomly selected, first evaluated cases numbered from 1 to 50 with the iPad 2 and 51 to 100 with the LCD monitor, and then 4 weeks later, they reversed cases on the two different devices. The other two observers had their first reviewing session with the LCD monitor for one to 50 cases and the iPad 2 for 51 to 100 cases, and then 4 weeks later, they also reversed them on the two different devices. No time limit was set, but mandatory rests of 10 min were imposed after reviewing 25 cases and of 30 min after 50 cases.

Observers were allowed to use all functions of the DICOM viewer on both systems, including zooming, panning, and control of width and level in the window. Technical assistance was available for any urgent technical or operating problems with the iPad 2.

Data Analysis

The reviewers were judged as not observing any significant abnormality, negative intracranial hemorrhagic finding, when they graded an examination as 1 or 2. And they were considered to have observed significant abnormality, positive intracranial hemorrhagic finding with grades of 3 or more. The neuroradiologist's interpretation was set as the gold standard for ICH detection. We used McNemar's test to compare the sensitivity and specificity of the iPad 2 and the LCD monitor [20]. The areas under the receiver operating characteristic (ROC) curves for the displaying devices were compared by the Dorfman–Berbaum–Metz method, using RSCORE and semi-parametric estimation of ROC indices with DBM-MRMC software (version 2.3, available from http://perception.radiology.uiowa.edu) [21]. In assessing the differences between overall reviewer's performances, the areas under the ROC curves were calculated by the above same method. Ninety-five percent confidence intervals were obtained, and reviewers and cases were taken as random factors. The level of intra-observer agreement between the iPad 2 and the LCD monitor was quantified using the kappa coefficient.

Result

The mean age of the patients was 45.2 years old, and the standard deviation was 22.8. The mean time of reviewing 100 cases with the clinical LCD monitor was 110.5 min, and with the iPad 2 was 108.3 min. Sensitivity (SE) and specificity (SP) values for the diagnosis of subtle ICH were high for all reviewers without any significant difference (p_{SE}= 1.000, p_{SP}=0.885; Tables 2 and 3). In calculating the areas under the ROC curves (AUC), four observers obtained better scores with the iPad 2 and one with the clinical LCD monitor. But the average AUC for reading with the iPad 2 and the clinical LCD monitor were 0.935 and 0.900, respectively (P=0.183; Table 4), demonstrating no statistical significant difference. The weighted kappa values showed moderate-to-very good intra-observer agreement between the iPad 2 and the LCD monitor (Table 5) [22].

Table 2 Sensitivity and specificity for the diagnosis of subtle intracranial hemorrhage using the remote-controlled PACS CT images on the iPad 2 and the original CT images on the clinical LCD monitor

Observer	Measure	iPad 2	Clinical LCD monitor	*P* value[b]
Attending physician 1[a]	Sensitivity	0.86	0.78	0.344
	Specificity	0.80	0.80	1.000
Attending physician 2[a]	Sensitivity	0.84	0.82	1.000
	Specificity	0.88	0.82	0.453
4th-year resident	Sensitivity	0.90	0.88	1.000
	Specificity	0.80	0.88	0.344
3rd-year resident 1	Sensitivity	0.94	0.92	1.000
	Specificity	0.86	0.82	0.500
3rd-year resident 2	Sensitivity	0.98	0.94	0.500
	Specificity	0.80	0.84	0.625
Overall	Sensitivity	0.85	0.85	1.000
	Specificity	0.79	0.80	0.885

[a] Korean Board of Emergency Medicine

[b] McNemar's test

Discussion

This study has several different points in the methods compared with the previous studies (Table 6) [3, 6–8]. First, we tested our teleradiologic system in the realistic ED situation considering ambient lighting, subtle radiologic lesions, and currently available network. Moreover, our remote viewing software was almost newly applied to the teleradiologic field. In the prior studies, many of researchers used OsiriX for DICOM-viewing software. But OsiriX had network security problem to access the DICOM files in the database of the hospital. Therefore, most studies downloaded DICOM image files on the teleradiologic devices via other storage, like a portable hard disk, which is time-consuming job in the real ED situation.

The areas under the ROC curves for the observers were overall high with both the iPad 2 and the 2-megapixel

Table 3 The matched sample table for ICH and unremarkable groups

		LCD		*P* value[a]
5 reviewer's overall sensitivity for 50 ICH cases				
		TP	FN	
iPad 2	TP	187	26	1.000
	FN	26	11	
5 reviewer's overall specificity for 50 unremarkable cases				
		FP	TN	
iPad 2	FP	27	25	0.885
	TN	23	175	

TP true positive, *FN* false negative, *FP* false positive, *TN* true negative

[a] McNemar's test

Table 4 Diagnostic performance (area under the ROC curve) of the five observers for the diagnosis of subtle intracranial hemorrhage using the remote-controlled PACS CT images on the iPad 2 and the original CT images on the clinical LCD monitor

Observer	Area under the ROC curve		Difference between areas	*P* value	95 % CI
	iPad 2	LCD			
Attending physician 1	0.896	0.843	0.053	0.325	−0.053, 0.159
Attending physician 2	0.910	0.882	0.028	0.503	−0.055, 0.111
4th-year resident	0.920	0.935	−0.016	0.722	−0.103, 0.071
3rd-year resident 1	0.980	0.907	0.072	0.338	−0.077, 0.222
3rd-year resident 2	0.971	0.932	0.039	0.187	−0.019, 0.097
Overall	0.935 (0.907 to 0.963)	0.900 (0.842 to 0.957)	0.035	0.183	−0.017, 0.088

Data in parentheses are 95 % confidence intervals of the area under the ROC curve value

CI confidence interval

clinical LCD monitor. The comparison of the ROC results revealed that the diagnostic performance of the iPad 2 was similar to that of the clinical LCD monitor for evaluating subtle ICH (Table 4). We could not totally reject that there is no difference between the iPad 2 and the LCD monitor in detecting subtle ICH under the real ED situation. However, it is thought that the key results of this work suggest the following practical conclusions: First, emergency physicians with substantial experience and training could show similar diagnostic performance of detecting subtle ICH or similar lesions on brain CT scans using the iPad 2 with high diagnostic accuracy under Wi-Fi network and conventional ambient lighting as do with the clinical LCD monitor under the same conditions. Second, some variations of the intra-observer agreements, moderate-to-very good degree, could be caused by unknown individual factors, however, which involved only five observers, hardly suggesting any definite conclusion. Thus, further study would be required. Nonetheless, because kappa value of more than 0.4 has clinical acceptance, our intra-observer agreements between the iPad 2 and LCD monitor (kappa value 0.504–0.872) could be clinically acceptable (Table 5) [22].

We chose clinicians, especially emergency physicians, as reviewers, because they are actual strong candidates for remote radiologic consultation. Surely, in the future, we think that radiologists would join this kind mobile teleradiologic system; however, under the current complicated environment in South Korea (including manpower shortage, over time pay issue, and low level of collaboration), it would be hard to expect their active participation, soon. Thus, emergency physicians with substantial experience, strong possible users of iPad 2 for "remote viewing" consult, were chosen. We included ten pediatric cases because our study attempted to reflect real practice of emergency department. Small volume of pediatric images might have influenced the accuracy itself, but were not thought to affect the comparison of accuracy between the two displays.

Even though the iPad 2 showed similar performance to the clinical LCD monitor, reviewers suggested somewhat difficulties with its specific operations. Screen touch, replacing desktop PC's mouse function, wheeling, and click dragging, allows reviewers to navigate through the whole CT scans and delicately control window width and level, achieved by the iPad 2 application (RemoteView®). However, continuous touch for 20−30 min created some frictional resistance due to sweat on fingertips, along with relatively difficult touch or scroll movement, requiring more concentration to observers.

It is obviously impossible to perform our study in a blinded way to prevent that the user knows if he uses the tablet or the conventional PC, which might influence the results. One positive potential is that using the iPad might increase overall attention due to the fact that is providing a new user interface and that its use might be simply exciting.

Table 5 Intra-observer agreement for the diagnosis of subtle intracranial hemorrhage using the remote-controlled PACS CT images on the iPad and the original CT images on the clinical LCD monitor

Observer	Weighted kappa iPad with LCD	*P* value	Standard error
Attending physician 1	0.504	<0.001	0.078
Attending physician 2	0.546	<0.001	0.072
4th-year resident	0.521	<0.001	0.078
3rd-year resident 1	0.857	<0.001	0.090
3rd-year resident 2	0.872	<0.001	0.097
Overall	0.597	<0.001	0.029

Table 6 Key features of recent teleradiologic studies using tablet devices

	Device	DICOM viewer	Network	Teleradiologic method	Ambient illumination	Subjectives
Kang BS et al. (this study)	iPad 2	RemoteView®	IEEE 802.11g	Real time	Moderate indoor lighting (250–300 lux)	Brain CT (50 with subtle ICH/50 normal)
McLaughlin et al. [6]	iPad	OsiriX®	Not used	Pre-download	Not described	Consecutive brain CT (57 various pathologies/43 normal)
Kim DK et al. [3]	UMPC	Emergency DICOM viewer	CDMA 1x EV-DO WIBRO HSDPA	Real time	Not described	Brain CT (5 various pathologies/7 normal)
Johnson PT et al. [7]	iPad	Syngo Web Viewer®	Not described	Real time	Not described	Chest CT (25 PE/25 normal)
McNulty JP et al. [8]	iPad	Ziltron iPad®	Not described	Real time	Dim indoor lighting (30 lux)	Spine MR (13 various pathologies/18 normal)

IEEE Institute of Electrical and Electronics Engineers, *UMPC* ultra-mobile personal computer (1,024×600 pixels, 4.5 in., LCD panel), *CDMA* code division multiple access, *EV-DO* evolution-data optimized, *WIBRO* wireless broadband Internet, *HSDPA* high-speed downlink packet access, *PE* pulmonary embolism

Meanwhile, in spite of the suboptimal viewing condition of the emergency department lighting and the unavailability of the DICOM calibration with the iPad 2, the study outcome was not affected significantly. Actually, the screen reflectance in high ambient lighting, the most important parameter for a mobile display, can significantly reduce the visibility and readability of screen content through reducing the contrast of the displayed visual information by adding reflected luminance to the emitted luminance [23]. With most of up-to-date mobile devices, including smart phone and tablet PC, frequently used in bright ambient lighting, effective contrast rating is particularly critical, currently being achieved by lowering screen reflectance and glossy display. The iPad 2 is known to deliver the best screen visibility and picture quality in bright environments with the low end of the range of reflectance values. Additionally, Yoshimura et al. suggested that the grayscale calibration, grayscale standard display function (GSDF) or gamma 2.2, was more critical than the display grade, medical or general, and that gamma 2.2 would be superior to GSDF in interpreting brain CT images [24]. With iPad 2, though somewhat steeper than standard 2.2, gamma 2.6 was utilized for gray calibration, which was thought to be another possible reason of our result. Though current 300–400-cd/m^2 radiological monitors mostly provide comfortable luminance, we set the brightness of LCD to 170 cd/m^2 because manufacturer's default calibration software supported only 170 cd/m^2 for ER clinical LCD monitor, which ACR guideline recommends as the minimum luminance (Max) for clinical monitor reading [16]. Basically, the calibration software is available for greater than 170 cd/m^2. However, this application requires an additional cost, then gaining just a slight extra white range of luminance, approximately just-noticeable difference of greater than 550 [14].

More recently, tablet devices have been introduced for mobile teleradiology via wireless networks [2, 10, 12]. In comparison with those devices in the medical literature, the iPad 2 has several distinct advantages, including the relatively large display, its slim profile, light weight (less than 601 g), zero booting time, and internet connectivity, all these producing greatly enhanced portability. In addition, numerous iPad 2 applications have been developed to view and transfer radiological images, including OsiriX®, developed for DICOM format image files, and RemoteView, a typical web-based remote viewing solution [17, 25, 26]. Consequently, the iPad 2 is arguably one of the best handheld teleradiology device for remote CT reading. However, the current up-to-date android-based tablet devices, including Motorola Xoom, Asus Transformer, Acer Iconia A500, Samsung Galaxy Tab, had similar display characteristics with the iPad 2. Display resolutions were commonly 1,280×800 pixels, and this was a little higher than that of the iPad 2. And they had similar value with the iPad 2 in maximum and minimum brightness. If any DICOM viewer and wireless communication software is available with these tablet devices, we presume the similar outcomes through the same study design.

Some teleradiologic researchers with hand-held device have used OsiriX® to operate DICOM image data [3, 26], but we did not choose it from the following reasons: First, hospital network system should add the iPad to the DICOM network, which is associated with security issue, requiring the permission of network manager. Second, hardware capacity of handheld device, especially memory and storage, is known to be limited while receiving the data, possibly affecting OsiriX®'s operation [26, 27]. But Remote View® is not restricted by the device memory capacity [19, 27]. Third, the slower transfer of DICOM image files over a wireless LAN, from the in-hospital DICOM network to the mobile OsiriX®-operating iPad 2, demands the whole 100 exams downloaded on the iPad 2 in advance before review, which is thought to be time-consuming and partially free from the network status as is not the case in the real situation.

In general, the outcomes of the present study showed that the iPad 2 is an effective teleradiologic tool for remote evaluation of brain CT in the conventional viewing condition. Our non-enhanced brain CTs had small disparity between brightness levels of tissues like white and gray matter. Because CT scans of other organs like abdomen or chest have same or greater range of brightness, the glossy display and artificial contrast of the iPad 2 will show better capacity to find abnormal findings than that of matte display or relatively low contrast devices. A recent study also suggested the potential of the first generation iPad as an excellent teleradiologic device for CT and MR which used a mobile OsiriX® for DICOM image displaying software; however, the iPad were not connected to the PACS network due to security issues. Instead, they transferred the DICOM images of the studies from the PACS server to a portable hard disk and subsequently wirelessly transmitted to the iPads via a Macbook laptop (Apple Inc., Cupertino, CA, USA), not having investigated full teleradiology [28].

Lastly, several limitations need to be considered on the network issue. First, we used free Wi-Fi network in hospital; however, most of the area in South Korea requires some reasonable cost to use it. Second, although wireless network (802.11 g) covers most of the metropolitan area in South Korea, there are locations where Wi-Fi is unavailable. In this area, 3G network should be utilized, which is currently slower than Wi-Fi and more costly, thus requiring further feasibility test. Third, the Wi-Fi network condition in the hospital has the good quality; however, in the remote locations, away from the hospital, the network reliability could be challenged by the network traffics.

Conclusion

Using the iPad 2 and reliable internet connectivity, clinicians can provide remote evaluation of brain CT with subtle intracranial hemorrhage under suboptimal viewing condition. Considering the distinct advantages of the iPad 2, the popular out-of-hospital use of mobile CT teleradiology would be anticipated soon.

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