Emerg Radiol (2012) 19:127–133
DOI 10.1007/s10140-011-1011-2

ORIGINAL ARTICLE

Emergency CT brain: preliminary interpretation with a tablet device: image quality and diagnostic performance of the Apple iPad

Patrick Mc Laughlin · Siobhan O. Neill · Noel Fanning · Anne Marie Mc Garrigle · Owen J. O. Connor · Gerry Wyse · Michael M. Maher

Received: 27 September 2011 / Accepted: 1 December 2011 / Published online: 16 December 2011

Abstract Tablet devices have recently been used in radiological image interpretation because they have a display resolution comparable to desktop LCD monitors. We identified a need to examine tablet display performance prior to their use in preliminary interpretation of radiological images. We compared the spatial and contrast resolution of a commercially available tablet display with a diagnostic grade 2 megapixel monochrome LCD using a contrast detail phantom. We also recorded reporting discrepancies, using the ACR RADPEER system, between preliminary interpretation of 100 emergency CT brain examinations on the tablet display and formal review on a diagnostic LCD. The iPad display performed inferiorly to the diagnostic monochrome display without the ability to zoom. When the software zoom function was enabled on the tablet device, comparable contrast detail phantom scores of 163 vs 165 points were achieved. No reporting discrepancies were encountered during the interpretation of 43 normal examinations and five cases of acute intracranial hemorrhage. There were seven RADPEER2 (understandable) misses when using the iPad display and 12 with the diagnostic LCD. Use of software zoom in the tablet device improved its contrast detail phantom score. The tablet allowed satisfactory identification of acute CT brain findings, but additional research will be required to examine the cause of "understandable" reporting discrepancies that occur when using tablet devices.

Keywords Teleradiology · CT · Handheld · Display

P. Mc Laughlin · S. O. Neill · N. Fanning · G. Wyse · M. M. Maher (✉)
Department of Radiology, Cork University Hospital, Wilton, Cork, Ireland
e-mail: m.maher@ucc.ie

P. Mc Laughlin · S. O. Neill · O. J. O. Connor · M. M. Maher
Department of Radiology, University College Cork, Cork, Ireland

A. M. Mc Garrigle
Department of Physics, Cork University Hospital, Wilton, Cork, Ireland

Introduction

The smartphone, which became commercially available in recent years, has become an invaluable asset to many radiologists. Smartphones when compared with conventional cellphones offer a number of advantages to the radiologist including a larger display with better image quality as well as improved access to the internet and a multitude of educational resources including educational cases, reference applications, online textbooks, and journals.

Initial trials suggested that commercially available smartphones could potentially be used for the review and preliminary interpretation of images by radiologists, when remote from the acute hospital campus [1, 2]. At our institution, we were initially excited by the potential use of the Apple iPhone (Apple, Cupertino, CA, USA) for preliminary image interpretation and completed a study of the value of this smartphone in this setting. Once our initial enthusiasm abated, our institution abandoned the idea of using commercially available smartphones for preliminary image interpretation, because of their small physical display size and their limited display resolution (Table 1). Another major factor in our decision to abandon consideration of the use of the smartphone for clinical image interpretation was the American College of Radiology's recomendation (published in their technical standard for electronic practice of medical imaging) that a device's display resolution should ideally be at least as large as that of the acquisition matrix [3]; the display resolution of the previously tested device, a first to third generation iPhone was 420×380 pixels, which represents 40% less pixels than recommended to display CT images at their native resolution of 512×512 pixels [4].

The recent development of tablet devices has again generated enormous interest in the healthcare industry regarding possible applications to clinical practice both within hospitals and at sites remote from tertiary referral centers. The recently released Apple iPad (Apple, Cupertino, CA, USA) has a screen resolution of 1,024×768 pixels; this represents approximately five times greater number of pixels than the first to third generation iPhone. In addition, the iPad's display size is almost three times larger, measuring 25 cm diagonally compared with 9 cm for the Apple iPhone [5]. Numerous applications for the iPad already allow radiologists to display DICOM format images. These applications allow window width and level adjustments, as well as imaging measurements such as distance, hounsfield unit density, and signal intensity to be performed. Applications have also been developed to facilitate transfer of images from PACS systems to tablet devices.

The authors considered that tablet devices would potentially be of much greater value than the smartphone for preliminary image interpretation because of their larger screen size and display matrix. We identified a requirement to formally examine the performance of tablet devices prior to their routine use and conducted a study with two aims:

1. To objectively compare the spatial and contrast resolution of a commercially available tablet device with a diagnostic grade 2 megapixel monochrome liquid crystal display (LCD) using a contrast detail phantom and
2. To investigate the reporting discrepancies encountered between preliminary interpretation of emergency CT brain examinations on a tablet computer and formal review on a diagnostic grade 2 megapixel monochrome liquid crystal display.

Materials and methods

This study was approved by our institutional research ethics committee. Tablet devices are defined as complete personal mobile computers typically larger than a mobile phone or personal digital assistant. For the purpose of this study, we chose to evaluate the Apple iPad, a tablet computer which became commercially available in April 2010. The dimensions of the display of this device are 24×19 cm, and it weighs 680 g; the dimensions and weight fall between those of contemporary smart phones and a typical laptop computer. The specifications of the tested tablet device are detailed in Table 1 where they are compared with those of three other commercially available smartphones.

For review of the clinical images, we utilized the Osirix Mobile application (Osirix Foundation, Geneva, Switzerland) which was downloaded from the Osirix website (http://www.osirix-viewer.com) onto the tablet computer. Time taken for transmission of each CT brain examination (n=100) to the tablet computer over an 802.11 n wireless network was recorded. In addition, as part of the review, any technical issues experienced with the tablet computer during the image interpretation were recorded.

Contrast detail analysis

The CDRAD 2.0 phantom (Artinis Medical Systems B.V., Zetten, Netherlands) was used to objectively quantify the low-contrast detectability and detail resolution of both the

Table 1 Display and physical specifications of the iPad and HP Touchpad (commercial release Jun 2011) tablet devices and for comparison the iPhone 4G and HTC Thunderbolt smartphones

Model	iPad	HP touchpad	iPhone 4G	HTC thunderbolt
Release date	April 3, 2010	June, 2011	June 24, 2010	March 17, 2011
Operating system	iOS (Apple)	WebOS (Hewlett Packard)	iOS (Apple)	Android 2.2
Display				
Size (cm)	25	25	9	11
Matrix size (pixels)	1,024×768	1024×768	960×640	400×800
Pixel density (pixels per in.)	132	132	326	217
Processor	1 GHz Apple A4	1.2 GHz Qualcomm	Apple A4	1 GHz Qualcomm
Storage	Up to 64 Gb	Up to 32 Gb	Up to 32 Gb	Up to 40 Gb
Weight (g)	680	740	137	177
Dimensions (mm)	243×190×13	240×190×14	115×59×9	121×62×14

tablet computer display and a 2-megapixel diagnostic grade monochrome PACS monitor (Barco Coronis 2MP—MFGD 2621; Barco NV, Kortrijk, Belgium). CDRAD 2.0 phantom is a polymethylmethacrylate phantom consisting of a 26× 26-cm polymethylmethacrylate panel with a 15×15 array of precision milled cylindrical holes of exact diameter and depth. Both diameter and depth are changed logarithmically from 0.3 to 8.0 mm which when exposed provides an image pattern of defined circular lucencies of decreasing contrast detail and size (Fig. 1).

The CDRAD 2.0 phantom was exposed at 90 kVp using a digital radiography system (Philips Digital Diagnost; Philips, Hamburg, Germany). A radiographic image of the phantom showed 225 boxes. Apart from the first three rows, each test square had two lucent dots; the first dot was in the center of the box and the second was in a randomly chosen corner. The milled holes exponentially decreased in depth horizontally across the phantom creating a pattern of dots with decreasing radiographic contrast across the exposed image. Similarly in the vertical direction, the diameter of the holes decreases exponentially from 0.3 to 8.0 mm, which creates a pattern of dots with decreasing size on the exposed image. Correct identification of the dot location along a column of boxes allows one to determine the spatial threshold of the test display (Fig. 2).

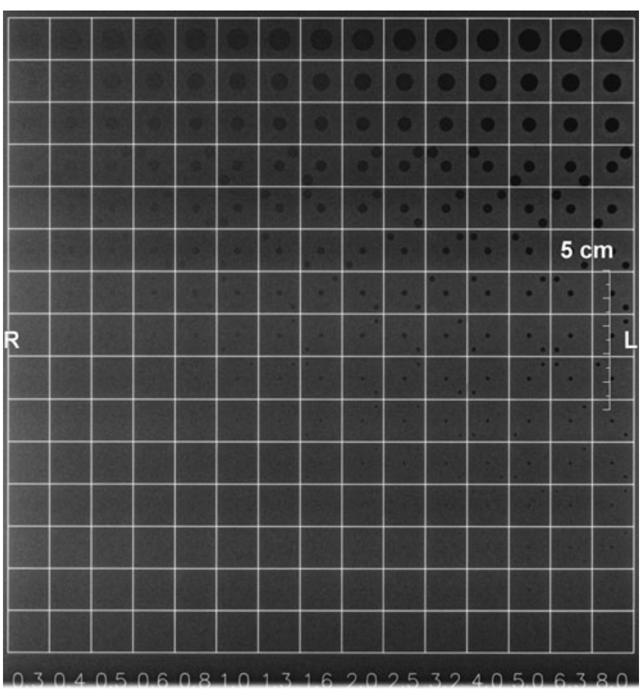

Fig. 1 Radiographic image of Artinis CDRAD 2.0 Polymethylmethacrylate phantom—a 26×26-cm polymethylmethacrylate panel with a 15×15 array of precision milled cylindrical holes of exact diameter and depth exposed at 90 kVp using a digital bucky system (Philips Digital Diagnost, Philips, Hamburg, Germany)

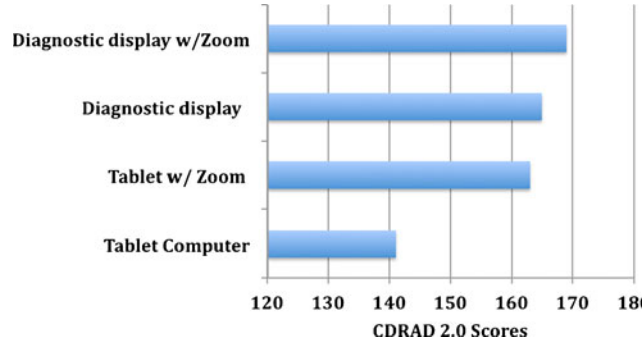

Fig. 2 This figure compares the CDRAD 2.0 test scores between the iPad and Barco 2MP [MFGD 2621] monochrome display with and without software zoom

Image analysis

The phantom images were uploaded onto the tablet computer and a PACS system (Agfa IMPAX 6, Mortsel, Belgium), respectively. Accurate identification of the varying positions of each dot within the boxes across the phantom image formed the basis of the CDRAD 2.0 scoring system. When the user correctly determined the position of the dots within an individual box, a score of one point was awarded. The scores for each individual box were added resulting in a total score for each display.

The review of the CDRAD 2.0 phantom image for each display was completed in consensus by a medical physicist experienced in contrast detail analysis and by a radiologist with 5 years clinical experience. Viewing conditions while interpreting the phantom image on both the tablet computer and the diagnostic monochrome PACS display were controlled with an ambient light intensity of 8 lx and viewing angle of 90°. Two sets of CDRAD scores were recorded for both displays: the first score was recorded without the benefit of software zoom function, and a second score was recorded with software zoom function available.

Performance of tablet computer in emergency CT brain interpretation

One hundred consecutive CT brain examinations acquired on patients, referred from the emergency department (ED) at a single institution, were uploaded onto the iPad. All CT studies were performed on a General Electric Lightspeed VCT 64 slice CT system (General Electric Company, Milwaukee, WI, USA) with a collimation of 2.5 mm at the base and 4 mm through the cerebrum without intravenous contrast. These CT studies had been previously interpreted, in a clinical setting, by staff radiologists on a 2-megapixel diagnostic monochrome PACS display (Barco Coronis 2MP—MFGD 2621; Barco NV, Kortrijk, Belgium).

All CT images were interpreted on the iPad using the Osirix Mobile application in consensus by two radiologists (PMcL and MM) with 5 and 16 years experience, respectively. Neither radiologist had previously reviewed the CT studies or their reports. Imaging findings were recorded, and reports were generated following this review. These reports were compared with the reports from the initial review performed on the PACS display in the clinical setting, at the time of attendance at the emergency room. The radiologists (MM and PMcL) when reading the CT studies on the tablet computer did not have access either to clinical findings on requisition forms or any previous imaging studies and were therefore disadvantaged when compared to the radiologists, who initially interpreted the CT studies on the PACS display, in the clinical setting. These two interpretations were then compared, and discrepancies were recorded and were scored under peer review according to the American College of Radiology's RADPEER scoring system (Fig. 3) [6].

Results

Contrast detail analysis

CDRAD 2.0 test pattern scores were lowest when using the tablet computer without image zoom, a score of 62% (141 correct boxes out of a total of 225) was achieved. Employing the software zoom function improved the tablet computer's CDRAD score to 72% (163 correct boxes out of a total of 225) which was comparable with a score of 73% (165 correct boxes out of a total of 225) achieved by the diagnostic 2-megapixel monochrome display without zoom. Employing the zoom function with the diagnostic 2-megapixel monitor resulted in a minimal increase in CDRAD score to 75% (169 correct boxes out of a total of 225).

Efficacy of tablet device in CT brain interpretation

Transmission of each CT brain examination (n=100) to the tablet computer over an 802.11 n wireless network took less than 10 s per CT scan. No technical issues were experienced with the tablet computer during the interpretation of the 100 datasets.

A total of 100 CT scans in 99 patients were included, 44 female and 55 male with a mean age of 48.9 years. No pathological imaging findings were identified in 43 studies, and complete diagnostic agreement between the interpretation on the tablet computer and on the diagnostic 2-megapixel monitor was achieved in all normal cases.

Of the clinically significant acute findings, there was complete agreement in the detection and characterization of all five acute intracerebral hemorrhages and five of six cerebral infarcts. A subtle lentiform nucleus infarct in a single patient, which was identified on initial interpretation of two consecutive CT scans on a 2-megapixel diagnostic monochrome PACS display, was not identified when both CT scans were examined on the tablet computer (see Fig. 4a). In addition, one case of craniocervical fusion (RADPEER 2b) and three subcutaneous hematomas (RADPEER 2a), seen on the 2 megapixel diagnostic monochrome PACS display, were also missed on the tablet computer.

There were 12 additional imaging findings identified during interpretation with the iPad display which were not identified during formal interpretation using the diagnostic

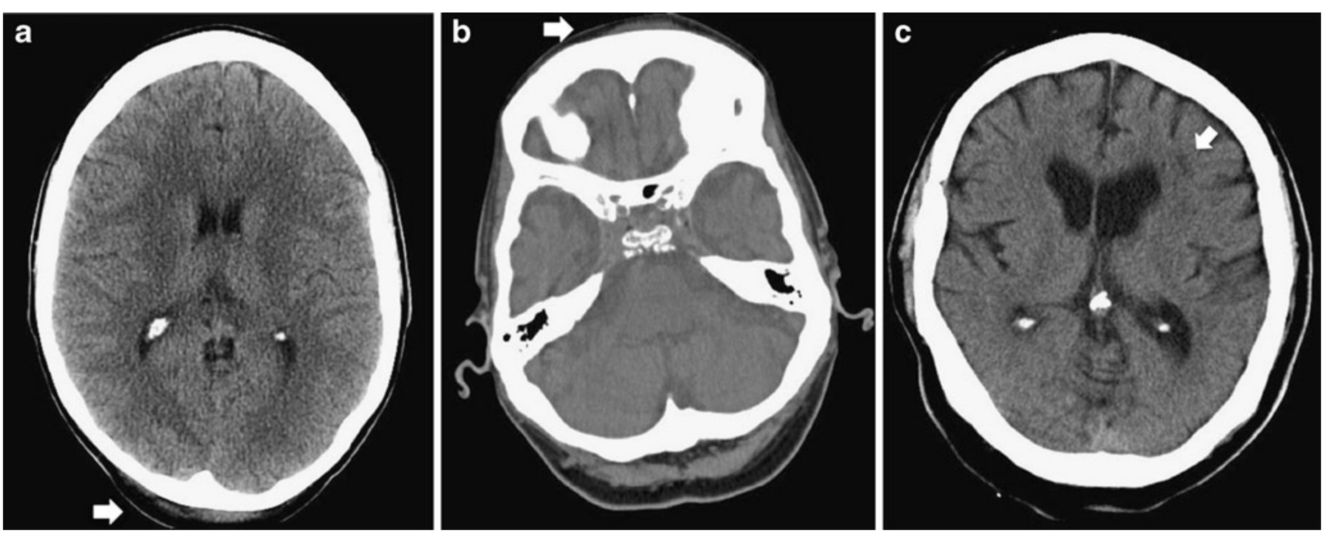

Fig. 3 **a** RADPEER 2a discrepancies—subcutaneous hematoma over the occiput missed when using the tablet computer display. **b** RADPEER 2a discrepancies—forehead laceration missed when using the tablet computer display. **c** RADPEER 2a discrepancies—white matter hypodensity in the left frontal lobe missed when using the tablet computer display

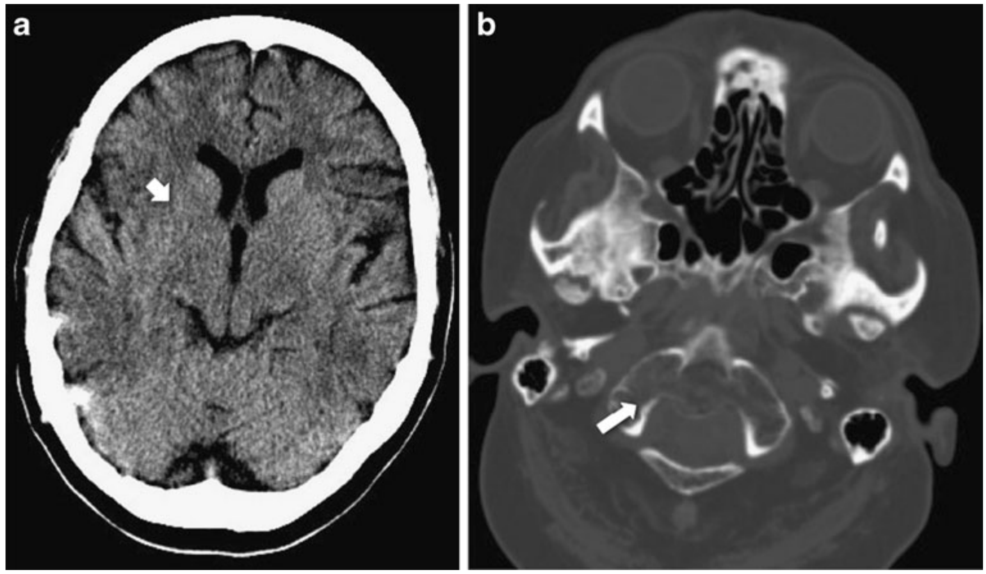

Fig. 4 **a** RADPEER 2b discrepancies—acute right lentiform nucleus ischaemia missed when using the tablet computer display. **b** RADPEER 2b discrepancies—congenital craniocervical fusion when using the tablet computer display

monochrome display. These included three RADPEER 2b clinically significant additional pickups (two calvarial fractures and one case of tonsilar ectopia, see Table 2). Further comparison of the interpretations of the CT studies on the iPad display to the diagnostic 2-megapixel monitor suggested that there was discrepant reporting of white matter hypodensities and paranasal sinus disease between the two interpretations (Table 3).

Discussion

When compared with handheld devices previously trialed in the radiology literature, the larger display resolution and screen size of recently introduced tablet computers suggest they may potentially be more favorable for preliminary image review [1]. Other potential uses include expert subspecialist consultation when the radiologist is remote from hospital campus or for disseminating key images to requesting physicians. Simply accepting that a tablet computer will facilitate interpretation in a remote setting on the basis of its technical specifications alone without robust clinical assessment could result in unsafe practice. A display must provide not only sufficient detail resolution but must also provide adequate low-contrast detectability, thereby allowing the interpreting radiologist to distinguish subtle differences in tissue density or tissue signal, which is fundamental to the everyday practice of radiology.

We therefore performed a contrast detail analysis with the CDRAD 2.0 phantom that has previously been used to determine a display's threshold for low-contrast detectability and detail resolution [7]. CDRAD 2.0 has been used to assess the perceptive contrast and detail characteristics of radiographic systems during the transition from CRT monitors to LCD monitors and also during the transition from computed radiography to digital radiography [8–10]. The score, which a display obtains from CDRAD phantom analysis, reflects one of the most important outcomes in imaging namely the detection of small low-contrast objects, which is

Table 2 Summary of the RADPEER 2a and 2b imaging misses and additional findings encountered when using the iPad display

RADPEER 2a	Number of cases
Additional findings when using tablet	
Mucosal thickening of sinuses	8
Arachnoid cyst	1
Misses when using tablet	
Subcutaneous hematoma	3
White matter hypodensities	1
RADPEER 2b	Number of cases
Additional findings when using tablet	
Calvarial fracture	2
Tonsilar ectopia	1
Misses when using tablet	
Acute lentiform nucleus ischaemia	2 (same patient)
Congenital craniocervical fusion	1

Table 3 Imaging findings identified on the iPad and diagnostic monochrome displays

Display	iPad	Diagnostic monochrome	Both
Normal examination	43	43	43
Intracranial hemorrhage	5	5	5
Cerebral infarct	5	7	5
White matter hypodensities	19	19	18
Sinus disease	23	15	15

potentially the greatest challenge for any radiological display [11, 12].

In our study, a medical physicist and radiologist, both experienced in contrast detail phantom interpretation, performed all analyses. A completely systematic approach was employed forcing the observer to interpret all 225 boxes of the test pattern. This evaluation protocol takes the observer to their absolute limits, forcing them to read very subtle and physically small (0.3 mm) lucent details which may not even be interpretable on radiographic examinations [7].

It is important to emphasize that viewing conditions during the phantom study were controlled with an ambient light intensity of 8 lx and viewing angle of 90°. Ambient light intensities would be significantly increased if image review on the tablet computer was performed in standard office lighting (320–500 lx) or in full daylight (10,000–25,000 lx) which could undoubtedly impact the diagnostic performance of any display. Therefore, further detailed assessment will need to be performed in a variety of settings (i.e. standard office, daylight, etc.) before robust recommendations can be issued regarding the use of the tablet device for clinical image interpretation especially in locations remote from the hospital campus.

Similar CDRAD scores of 163 vs 165 points were achieved between the tablet computer and the 2-megapixel diagnostic monochrome display, respectively, when the iPad's software zoom function was employed. Subjectively we found the tablet computer's touch screen zoom function allowed user-friendly, quick, and reliable navigation through the phantom and CT images.

Comparison of diagnostic interpretations performed on the iPad and the 2-megapixel diagnostic monochrome display revealed that total diagnostic agreement was achieved in 93 of the 100 ED CT brain examinations. Agreement was seen across all of the clinically significant acute imaging findings that would be classed as RADPEER 3 (not understandable to miss) including five cases of intracranial hemorrhage and five acute cerebral infarcts. A single subtle lentiform nucleus infarct on two consecutive CT scans in a single patient was not identified on the iPad display, this was classed as a RADPEER 2b understandable miss. There were a number of additional discrepancies when interpretations on the two devices were compared; four additional "understandable" RADPEER 2a misses were encountered when initial interpretation was performed on the iPad display alone, three subcutaneous hematomas and a "white matter hypodensity" in one case. However, iPad interpretation identified 12 findings not appreciated on initial interpretation on the 2-megapixel diagnostic monochrome PACS display including eight cases of mucosal thickening of the paranasal sinuses, one arachnoid cyst, two calvarial fractures, and one case of tonsilar ectopia. Overall, comparison of interpretations of CT studies on both the iPad and the diagnostic 2-megapixel monitor suggested that there was discrepant reporting of white matter hypodensities and paranasal sinus disease. However, these differences are likely explained by the subjective nature of these findings, and different perspectives among radiologists regarding the appropriateness of reporting these findings,

The primary limitation of our study design was that we were unable to objectively determine if important imaging findings were truly obscured by the iPad display or if discrepancies arose mainly from differences in radiologist's interpretation alone. Other limitations of our study include the testing of only a single DICOM viewer software application (Osirix Mobile) on a single tablet computer (iPad). Essentially an efficacy study of the tablet device was performed under ideal viewing conditions. This adds limitations to applicability of our results, and ultimately, an efficiency study of the iPad in real-world conditions would be required prior to adoption. Many other tablet computers with a range of operating systems and DICOM viewers are now becoming available or are in development, and an application developed for DICOM image transfer to the iPad (Mobile Mim; MIM Software Inc., Cleveland, OH USA) recently gained FDA 510(k) clearance in February 2011 [13].

Undoubtedly, rapid advances will occur in the coming months and years in tablet computer technology and this may improve their potential for the preliminary review of diagnostic images. The issue of secure DICOM image transfer from PACS servers to tablet computers should also be addressed so that this process can satisfy healthcare industry regulation and protect patient identity and confidentiality.

Conclusion

We found that the iPad display performed inferiorly to the diagnostic monochrome display when using the CDRAD 2.0 contrast detail phantom without the ability to zoom. When the software zoom function was enabled on the tablet device, comparable contrast detail phantom scores were achieved. Interpretation of the CT images was performed with ease on the tested tablet computer, and no technical difficulties were experienced during the interpretation of 100 datasets.

There was satisfactory identification of acute findings on emergency CT brain examinations, and overall, the tablet display potentially represents a device which may make remote interpretation of imaging studies more feasible. More focused research will need to be performed to better differentiate between the potential sources of diagnostic error when using tablet devices. We believe that further software development allowing improved access to clinical request information and previous imaging examinations could potentially increase the diagnostic performance of these devices and anticipate that with further development, tablet technology will assume a major role in provision of expert radiological opinion to remote sites, in the acute setting.

References

1. Toomey RJ, Ryan JT, McEntee MF et al (2010) Diagnostic efficacy of handheld devices for emergency radiologic consultation. AJR 194:469–474
2. Choudhri AF, Radvany MG (2011) Initial experience with a handheld device digital imaging and communications in medicine viewer: OsiriX mobile on the iPhone. J Digit Imaging 24:184–189
3. ACR Technical Standard for Electronic Practice of Medical Imaging (2007) http://www.acr.org/SecondaryMainMenuCategories/quality_safety/guidelines/med_phys/Electronic_Practice.pdf. Accessed 30 May 2011
4. Apple iPhone 3GS—size, weight, battery life and other specs (2011) http://www.apple.com/iphone/iphone-3gs/specs.html. Accessed 30 May 2011
5. Apple—iPad—view the technical specifications for iPad (2011) http://www.apple.com/ipad/specs/. Accessed 30 May 2011
6. Jackson VP, Cushing T, Abujudeh HH et al (2009) RADPEER scoring white paper. J Am Coll Radiol 6:21–25
7. Peer S, Giacomuzzi SM, Peer R, Gassner E, Steingruber I, Jaschke W (2003) Resolution requirements for monitor viewing of digital flat-panel detector radiographs: a contrast detail analysis. Eur Radiol 13:413–417
8. Fischbach F, Ricke J, Freund T et al (2002) Flat panel digital radiography compared with storage phosphor computed radiography: assessment of dose versus image quality in phantom studies. Invest Radiol 37:609–614
9. Samei E, Ranger NT, Delong DM (2008) A comparative contrast-detail study of five medical displays. Med Phys 35:1358–1364
10. Geijer H, Geijer M, Forsberg L, Kheddache S, Sund P (2007) Comparison of color LCD and medical-grade monochrome LCD displays in diagnostic radiology. J Digit Imaging 20:114–121
11. Dobbins JT, Rice JJ, Beam CA, Ravin CE (1993) Threshold perception performance with computed and screen film radiography: implications for chest radiography. Radiology 183:179–187
12. Funama Y, Awai K, Nakayama Y et al (2005) Radiation dose reduction without degradation of low-contrast detectability at abdominal multisection CT with a low-tube voltage technique: phantom study. Radiology 237:905–910
13. Press announcements > FDA clears first diagnostic radiology application for mobile devices (2011) http://www.fda.gov/NewsEvents/Newsroom/PressAnnouncements/ucm242295.htm. Accessed 30 May 2011