ORIGINAL ARTICLE

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Neuroradiology Using Secure Mobile Device Review

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ABSTRACT: ***Background:*** Image review on computer-based workstations has made film-based review outdated. Despite advances in technology, the lack of portability of digital workstations creates an inherent disadvantage. As such, we sought to determine if the quality of image review on a handheld device is adequate for routine clinical use. ***Methods:*** Six CT/CTA cases and six MR/MRA cases were independently reviewed by three neuroradiologists in varying environments: high and low ambient light using a handheld device and on a traditional imaging workstation in ideal conditions. On first review (using a handheld device in high ambient light), a preliminary diagnosis for each case was made. Upon changes in review conditions, neuroradiologists were asked if any additional features were seen that changed their initial diagnoses. Reviewers were also asked to comment on overall clinical quality and if the handheld display was of acceptable quality for image review. ***Results:*** After the initial CT review in high ambient light, additional findings were reported in 2 of 18 instances on subsequent reviews. Similarly, additional findings were identified in 4 of 18 instances after the initial MR review in high ambient lighting. Only one of these six additional findings contributed to the diagnosis made on the initial preliminary review. ***Conclusions:*** Use of a handheld device for image review is of adequate diagnostic quality based on image contrast, sharpness of structures, visible artefacts and overall display quality. Although reviewers were comfortable with using this technology, a handheld device with a larger screen may be diagnostically superior.

RÉSUMÉ: Utilisation d'appareils mobiles sécurisés dans le cadre d'analyses neuroradiologiques. ***Contexte***: L'analyse d'images à des postes de travail informatisés a rendu obsolète l'impression de ces images. En dépit des progrès de la technologie, la pénurie de tels postes de travail représente assurément un inconvénient. À cet égard, nous avons tenté de déterminer dans quelle mesure la qualité des images analysées au moyen d'appareils mobiles pouvait convenir à une utilisation clinique de routine. ***Méthodes***: De manière indépendante, trois neuroradiologistes ont examiné six cas de patients soumis à la tomodensitométrie (TDM) et à l'angiographie par tomodensitométrie ainsi que six autres cas soumis à des examens de résonnance magnétique et d'angiographie par résonance magnétique. Pour ce faire, ils ont utilisé des appareils mobiles alors que la luminosité ambiante était élevée ou faible mais aussi, dans des conditions idéales, des postes de travail pour imagerie tout à fait courants. Dans un premier temps, à l'aide d'une luminosité ambiante élevée, ils ont établi pour chacun des douze cas un diagnostic préliminaire en utilisant un appareil mobile. Après avoir modifié les conditions d'analyse, on a demandé aux neuroradiologistes si quelque autre aspect observé pouvait modifier leur diagnostic préliminaire. On leur a également demandé de se prononcer sur la qualité clinique générale de l'analyse menée et sur la qualité d'imagerie fournie par les appareils mobiles. ***Résultats***: Après avoir analysé les cas de TDM à l'aide d'une luminosité ambiante élevée, des analyses ultérieures ont signalé d'autres observations dans 2 cas sur 18. À la suite de l'analyse initiale d'angiographie par tomodensitométrie à l'aide d'une luminosité ambiante élevée, on a pu noter, dans la même veine, des observations additionnelles dans 4 cas sur 18. De ces 6 observations, seulement une a permis d'affiner le diagnostic établi lors de l'analyse initiale. ***Conclusions***: L'utilisation d'appareils mobiles pour analyser des images permet de poser de bons diagnostics. Ces derniers reposent sur une bonne qualité d'affichage ainsi que sur des images bien contrastées, des structures nettes et d'éventuels artefacts bien visibles. Bien que les radioneurologistes évaluateurs aient utilisé avec facilité ces appareils, des écrans plus larges pourraient s'avérer plus efficaces sur le plan diagnostique.

Keywords: DICOM, handheld, iPad, iPhone, mobile phone, PACS, PDA radiology

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Introduction

The gold standard in diagnostic imaging has advanced from reviewing images on film to computer-based display workstations.[1] Images are available immediately, they can be reviewed from different workstations, and a computer's functionality provides reviewers with the tools to magnify, rotate and calculate measurements on images.[2] Guidelines have been created for digital workstations, with respect to such

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things as screen resolution, pixel counts, luminance ratings and ambient light.[3]

A key disadvantage of digital workstations, commonly situated in rooms with low ambient lighting, thus creating ideal conditions to interpret images,[4] is lack of portability. Accessibility is limited, obtaining a second opinion becomes time-consuming, and teaching of clinical trainees and even patients and families is less available in real time. A solution to this problem is to use a handheld device.[5-7] We sought to determine if the quality of image review on a handheld device, such as an iPhone or iPod touch, is sufficient to make a clinical diagnosis by comparing it to image review on a conventional picture archiving and communication systems (PACS) digital workstation.

Table 1: Case List

CT/CTA	MR/MRA
Small intracranial aneurysm—circle of Willis	MS lesions—moderate disease—intracranial
Early ischemic stroke	MS lesions/demyelination—spinal cord
CTA ischemic stroke with distal M1 or M2—occlusion	Small intracranial aneurysm—circle of Willis
CT scan—SAH—Fisher grade 1	Glioma
CT scan—glioma	Meningioma
CT scan—subdural haemorrhage	Acute stroke—small size or lacunar

Methods

Three neuroradiologists rated images on the following criteria: image contrast resolution, sharpness of the display, display of artefacts and whether the image is of acceptable quality for clinical use. CT and MR studies were reviewed on a handheld device running ResolutionMD Mobile in both high and low ambient light. The same images were then reviewed in typical clinical review conditions on a digital workstation in low ambient light.

Images were selected to represent common neurological conditions that would be encountered in a tertiary care setting. Selection of cases was made by an independent neuroradiologist (MG). Six CT or CT angiography studies and six MR or MR angiography studies were chosen; CT/CTA studies were assessed as a group followed by the six MR/MRA scans.

Three neuroradiologists (all U.S. board certified and Fellows of the Royal College of Physicians and Surgeons of Canada) independently reviewed and dictated a report on each study. Each was provided with a standard handheld device. They each sequentially and independently reviewed all scans on the handheld device, first in a high ambient light environment (usual hospital hallway conditions), then in an idealized low ambient light environment, and finally on a standard diagnostic imaging workstation in a low ambient light environment (ideal reading conditions). Cases were reviewed during one three-hour period, in random order and under each lighting condition.

Each neuroradiologist dictated a report for each case. They were asked to comment on the imaging diagnosis and particular features of the case, as they would have done normally. On the second and third reviews of each case, they were additionally asked if the change in reviewing conditions allowed them to observe any additional diagnostic features. Finally, they were asked to comment qualitatively on: (a) image contrast for differentiation of subtle tissue density; (b) sharpness of edges and tissue borders; (c) artefacts due to image display; (d) overall clinical image display quality; and (e) whether they considered the image display to be of sufficiently acceptable quality for routine use and decision-making.

The portable handheld system consisted of an iPod touch (Apple Inc., Cupertino, CA), client image viewing software (ResolutionMD Mobile, Calgary Scientific Inc., Calgary, Canada) and a visualization server. The iPod touch had 8 GB of flash memory and a 3.5-inch diagonal screen with 320×480 pixels (pixel pitch = 0.15 mm, luminance = 500 cd/m^2). It ran the ResolutionMD Mobile client program, which handled user input, communication with the visualization server and display of transmitted images. The client software allows for 2D and 3D visualization with interactive window/level, translation, rotation and zoom functions. In 3D mode, the user can also select from a range of tissue-rendering modes. The visualization server had a 2.4-GHz Intel Core 2 Quad central processing unit, 8GB RAM and 2 NVidia GeForce 8800 (512MB) graphics cards. It ran the application ResolutionMD Enterprise (Calgary Scientific Inc., Calgary, Canada), which allows remote 2D/3D visualization of digital imaging and communications in medicine (DICOM) images through a web browser or a mobile device (iOS and Android platforms). The visualization server first reformats a series of 2D DICOM images into a 3D volume. It then performs a rendering operation on the 3D volume to produce a 2D image for interpretation. This 2D image is converted into streaming joint photographic experts group (JPEG) format and then transmitted to the client program running on the mobile handheld device. User interaction on the device, such as a touch or drag event, causes a new rendering operation on the server and transmission of a new image. Communication between the visualization server and the handheld device occurs over a secure wireless network (Wi-Fi 802.11g). This system is capable of delivering and displaying up to 14 images per second on a mobile handheld device. In our experience, a single visualization server can accommodate 10 or more simultaneous handheld device users. Importantly, all patient data remain on the visualization server with this system. The stream of rendered images is not saved on the device, ensuring data security in compliance with health data privacy legislation.

Gold-standard diagnosis occurred on a radiology workstation (IMPAX 6.3.1.3815, Agfa Healthcare, Belgium) connected to a medical-grade 21-inch liquid crystal display (MD21GS-3MP, NEC). This display has a resolution of 2048×1536 pixels (pixel pitch = 0.21 mm) and a luminance of 400 cd/m^2.

Data are reported using standard descriptive statistics. Qualitative reporting is provided descriptively.

Results

The 12 cases were reviewed in two groups, separated based on their modality (Table 1) and in various lighting conditions

Table 2: Ambient Light Intensity

Place	Lumens (mean, *SD*)
iPhone Hallway	157.8 (33.1)*
iPhone dark	6.2 (3.3)*
PACS dark	4.6 (2.7)*

*$p < 0.001$ (ANOVA) for all comparisons to iPhone Hallway adjusted for multiplicity (Scheffé test). Light intensity was not different between iPhone dark and PACS dark ($p = 0.982$).

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Table 3: CT Case Review

Reviewer		iPhone hallway	iPhone dark	PACS
Case 1	WM	Initial diagnosis	A	A
	WH	Initial diagnosis	A	B
	JL	Initial diagnosis	B	A
Case 2	WM	Initial diagnosis	A	A
	WH	Initial diagnosis	A	A
	JL	Initial diagnosis	A	A
Case 3	WM	Initial diagnosis	A	B
	WH	Initial diagnosis	A	A
	JL	Initial diagnosis	A	A
Case 4	WM	Initial diagnosis	A	B
	WH	Initial diagnosis	C	B
	JL	Initial diagnosis	A	B
Case 5	WM	Initial diagnosis	A	A
	WH	Initial diagnosis	A	B
	JL	Initial diagnosis	B	B
Case 6	WM	Initial diagnosis	A	C
	WH	Initial diagnosis	A	B
	JL	Initial diagnosis	B	B

A = no changes/additional findings; B = seeing findings clearer/more confidently; C = an additional finding.

(Table 2), resulting in 108 distinct interpretations. Additional findings were identified in low ambient light handheld review in 1 instance (5.6%) for the CT/CTA case group and in 1 instance (5.6%) for the MR/MRA case group. Similarly, additional findings were identified in a low ambient light PACS workstation review in 1 instance (5.6%) for the CT/CTA case group and in 3 instances (16.7%) for the MR/MRA case group. Confidence in the findings was reported more often in the low ambient light conditions, both for the handheld and the PACS workstation review (Tables 3 and 4).

Combining all cases where an additional finding was seen on second or third review, only one out of six contributed to the initial diagnosis, but none were diagnostically relevant. The increased clarity and confidence of findings was judged to be helpful but clinically insignificant. Qualitatively, all reviewers felt comfortable making a preliminary diagnosis for CT/CTA and MR/MRA studies on a handheld device, and all initial diagnoses made on the handheld device in high ambient light were clinically correct (Table 5).

Conclusions

We found that interpretation of neuroimaging studies using a portable handheld system is reliable and accurate for principal imaging diagnosis. We have also shown that low ambient lighting is qualitatively relevant for the completeness of and confidence in imaging interpretation. Although some findings were seen with more confidence in low ambient light conditions, they did not contribute further to the clinical diagnoses made in high ambient lighting. Each neuroradiologist felt comfortable using a handheld device to make preliminary principal diagnoses in lighting conditions typical of a hospital hallway. However, detailed review on a gold-standard workstation should be completed to ensure that ancillary imaging findings may be identified. This information expands on previous studies of imaging interpretation using

Table 4: MR Case Review

Reviewer		iPhone hallway	iPhone dark	PACS
Case 1	WM	Initial diagnosis	A	C
	WH	Initial diagnosis	B	A
	JL	Initial diagnosis	B	A
Case 2	WM	Initial diagnosis	A	B
	WH	Initial diagnosis	A	A
	JL	Initial diagnosis	A	C
Case 3	WM	Initial diagnosis	A	B
	WH	Initial diagnosis	B	B
	JL	Initial diagnosis	B	A
Case 4	WM	Initial diagnosis	A	No data collected
	WH	Initial diagnosis	A	C
	JL	Initial diagnosis	C	B
Case 5	WM	Initial diagnosis	A	A
	WH	Initial diagnosis	A	A
	JL	Initial diagnosis	A	A
Case 6	WM	Initial diagnosis	A	A
	WH	Initial diagnosis	A	A
	JL	Initial diagnosis	A	A

A = no changes/additional findings; B = seeing findings clearer/more confidently; C = an additional finding.

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Table 5: Qualitative Assessment

	Reviewer WM	Reviewer WH	Reviewer JL
Image contrast for subtle tissue density	Very good	Excellent	Good
Sharpness and border definition	Very good	Excellent	Good
Display artefacts	Minimal	None	Minimal
Overall image quality	Very good	Excellent	Good enough to make the diagnosis
Acceptable for routine use	Yes. "I would be comfortable enough with the image quality to use this to give an immediate preliminary opinion."	Yes. "I feel that the overall performance could be further enhanced with the use of a larger display portable device."	Yes. "ResolutionMD Mobile is of sufficiently acceptable quality for use. I am comfortable with my decision."

mobile devices, which placed an emphasis on user experience with a mobile device rather than on diagnostic capabilities.[8,9]

Compared to a conventional workstation, the mobility of a handheld device poses a potential security risk related to sensitive patient data. To address this, the ResolutionMD Mobile system has been designed with important data security features.[7] First, confidential patient information is not stored on the device, where it could potentially be carried outside the hospital network firewall—a feature that is not integrated into all mobile DICOM viewers.[10,11] Instead, this information resides remotely on a secure visualization server. An added benefit of this design is that the remote visualization server can rapidly load, and render, large medical image datasets containing several hundred DICOM images. This allows diagnostic interpretation to begin almost immediately, even from remote locations. Second, when the ResolutionMD Mobile software is closed, the network connection to the server is automatically terminated.[12]

Although reviewers felt comfortable assessing CT/CTA and MR/MRA studies on the handheld iPod touch, there are advantages of using a larger screen: studies can be viewed side by side; the user can link various views and scroll through image series simultaneously; important patient demographic information is available to aid in accurate diagnoses; and the larger screen has a greater conspicuity compared to a smaller one. Use of tablet or web platform versions of viewing software or newer-generation handheld devices with larger screens might resolve these limitations.[12]

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Disclosures

This was an unfunded study. MH, MG and WH own stock in Calgary Scientific Inc., the company that markets the software used for image display.

Statement of Authorship

PR wrote the first draft of the manuscript. MG chose cases for review. WM, JL and WH reviewed cases. MH designed the study. All authors participated in data analysis and critical review of the manuscript.

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