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FULL PAPER

iPad-based primary 2D reading of CT angiography examinations of patients with suspected acute gastrointestinal bleeding: preliminary experience

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Objective: To evaluate the effectiveness of the iPad (Apple Inc., Cupertino, CA) for two-dimensional (2D) reading of CT angiography (CTA) studies performed for suspected acute non-variceal gastrointestinal bleeding.

Methods: 24 CTA examinations of patients with suspected acute gastrointestinal bleeding confirmed (19/24, 79.2%) or ruled out (5/24, 20.8%) by digital subtraction angiography (DSA) were retrospectively reviewed by three independent readers on a commercial picture archiving communication system (PACS) workstation and on an iPad with Retina Display® 64 GB (Apple Inc.). The time needed to complete reading of every CTA examination was recorded, as well as the rate of detection of arterial bleeding and identification of suspected bleeding arteries on both devices.

Results: Overall, the area under the receiver operating characteristic curve, sensitivity, specificity, positive- and negative-predictive values for bleeding detection were

not significantly different while using the iPad and workstation (0.774 vs 0.847, 0.947 vs 0.895, 0.6 vs 0.8, 0.9 vs 0.944 and 0.750 vs 0.667, respectively; $p > 0.05$). In DSA-positive cases, the iPad and workstation allowed correct identification of the bleeding source in 17/19 cases (89.5%) and 15/19 cases (78.9%), respectively ($p > 0.05$). Finally, the time needed to complete reading of every CTA study was significantly shorter using the iPad (169 ± 74 vs 222 ± 70 s, respectively; $p < 0.01$).

Conclusion: Compared with a conventional PACS workstation, iPad-based preliminary 2D reading of CTA studies has comparable diagnostic accuracy for detection of acute gastrointestinal bleeding and can be significantly faster.

Advances in knowledge: The iPad could be used by on-call interventional radiologists for immediate decision on percutaneous embolization in patients with suspected acute gastrointestinal bleeding.

Tablet computers are emerging as promising devices for mobile visualization of medical images from cross-sectional modalities (such as CT and MRI), owing to their good screen resolution, larger display size than that of conventional smartphones and excellent power-to-weight ratio.¹ Among them, the iPad (Apple Inc., Cupertino, CA) has gained wide popularity in the medical community owing to its high screen resolution (>3 MP, *i.e.* comparable to regular radiological workstations), its reasonably fast processor and large storage capacity (allowing browsing smoothly through large image data sets) and the availability of digital imaging and communications in medicine (DICOM)-compliant apps for image viewing and sharing that can retrieve DICOM images via wireless networks or cloud services connected to a picture archiving communication system (PACS) infrastructure. A potential perspective of this technological evolution is the usage of

tablets in a teleconsultation setting for remote two-dimensional (2D) reading of emergency CT examinations, requiring fast, on-the-fly reviewing of images in the absence of a dedicated workstation.^{2,3} In this respect, evidence exists in the literature that the iPad can successfully be used for 2D reading of emergency pulmonary CT angiography (CTA), head CT and spinal MRI studies, with a diagnostic accuracy comparable to regular PACS workstations.⁴⁻⁷

Acute non-variceal gastrointestinal bleeding (ANVGIB) is a life-threatening condition associated with elevated morbidity and mortality rates, requiring immediate diagnosis and treatment. CTA is now considered the mainstay for ANVGIB diagnosis owing to its high diagnostic accuracy in detection of acute arterial bleeding, thus helping to optimize treatment planning.⁸⁻¹⁰ Digital subtraction angiography (DSA) followed by transcatheter embolization of the bleeding source is

increasingly recommended as the most appropriate treatment of ANVGIB and should be carried out as soon as possible to stop the bleeding, minimize the chance of bleeding recurrence and possibly improve the patient's outcome. The feasibility of the endovascular treatment is established based on the patient's clinical parameters and vascular anatomy and should be assessed by dedicated vascular interventional radiologists owing to its invasiveness and its potential complications.^{8–14} However, such specialists are not always physically available in every hospital unit on a 24/7 basis, making prompt remote consultation of CTA examinations by a vascular interventional radiologist a vital issue. In this scenario, remote tablet-based preliminary 2D reading of CTA studies of patients with suspected ANVGIB by on-call interventional radiologists could be a time-saving and cost-effective solution for the management of such patients.

Our aim was to assess the performance of the iPad for preliminary 2D reading of emergency CTA studies of patients with suspected ANVGIB in terms of diagnostic accuracy and image reading time compared with a conventional PACS workstation.

METHODS AND MATERIALS

Patient selection and CT angiography protocol

24 CTA examinations of patients (17 males and 7 females aged between 50 and 84 years; mean age, 64 years) with suspected ANVGIB performed at the Department of Diagnostic and Interventional Radiology of the University of Pisa, Pisa, Italy, were retrospectively retrieved from the PACS (Synapse; Fujifilm, MI, Italy). All CTA studies had been carried out in an emergency setting on a 64-row CT scanner (LightSpeed VCT®; GE Healthcare, Milwaukee, WI) consecutively from March 2009 to February 2013 and had been followed in all cases by DSA to confirm diagnosis and perform transcatheter embolization of the bleeding site, where present. Out of them, active arterial bleeding was confirmed by DSA in 19/24 cases (79.2%) and ruled out in the remaining 5/24 cases (20.8%).

Every CTA examination consisted of a pre-contrast scan of the entire abdomen followed by a triple-phase post-contrast acquisition (consisting of an arterial, a venous and a late phase) over the same imaging volume for bleeding detection and characterization. The same scanning parameters (tube voltage, 100–120 kV depending on the patient's weight; tube current, 100–600 mA with angular and z-axis modulation; detector configuration, 64 × 0.625 mm; detector collimation, 1.25 mm; reconstruction interval, 0.625 mm; beam pitch, 0.984:1) and contrast medium injection protocol {100–120 ml of iodixanol 320 mg of iodine per millilitre [VISIPAQUE™ (iodixanol) injection 320; GE Healthcare, Oslo, Norway] administered at 4–5 ml s⁻¹ flow rate via an 18-gauge needle in the antecubital vein, followed by 40 ml of saline flush injected at the same flow rate using a power injector} were used in all cases. Accurate timing of contrast medium injection with the beginning of every CTA scan was ensured by bolus tracking in the upper abdominal aorta with a density threshold of 150 HU and a scan delay of 10 s.

Digital subtraction angiography

DSA was performed in all patients within 1 h after CTA using a 5-French femoral approach on Advantx LC Vascular (GE

Healthcare) and Innova (GE Healthcare) units. Diagnostic angiograms of the coeliac trunk and the superior and inferior mesenteric arteries were obtained using a 5-French catheter in order to locate the bleeding source as detected at CTA, followed by superselective catheterization of the culprit vessel(s) with a 3-French microcatheter in all cases.

Image reading

All CTA data sets (including source axial images and multiplanar reformatted series where available, but maximum intensity projection and volume rendering reconstructions were excluded to avoid any potential facilitation in diagnosis) were anonymized and exported in DICOM format on a dedicated commercial workstation (Advantage Windows® 4.6; GE Healthcare, Fairfield, CT) for retrospective image analysis. The same anonymized data sets were also transferred to a PACS server (iMac® 27-inch; Apple Inc.) connected to our hospital PACS running OsiriX 64-bit v. 5.8 (www.osirix-viewer.com) and then exported wirelessly in DICOM format with JPEG 2000 lossless compression to an iPad with Retina Display® 64 GB (Apple Inc.) running OsiriX HD® v. 4.0.2 (www.osirix-viewer.com) using the Bonjour® protocol (Apple Inc.).

Three radiologists with experience of more than 5 years in vascular and gastrointestinal radiology independently reviewed all CTA data sets on the workstation. None of the readers had previously read any of the CTA examinations or performed DSA on any of the patients involved in the study, and all of them were blinded to DSA findings or any other information related to the patients' clinical condition (including parameters such as haemoglobin levels and blood pressure) or previous imaging findings.

In order to reasonably prevent any memory effect by the readers, each of them reviewed the same data sets independently in a random order on the iPad under the same lighting conditions 4 weeks after the end of the first round of CTA image readings. Prior to the beginning of the image reading session on the iPad, the iPad screen had been calibrated using a dedicated application (MediCal QAWeb Mobile®; Barco Srl, Milan, Italy). Moreover, all readers had previously undergone a 1-month period of training on CT image reading on the iPad, as empirically deemed sufficient so as to gain adequate self-confidence and speed in CT image reading on the iPad.

In both image reading sessions, all readers had been instructed to mark all cases as positive or negative related to the CTA finding of active arterial bleeding (defined as contrast medium blush in the arterial phase growing in the subsequent post-contrast acquisitions), as well as to indicate the most likely source of bleeding in terms of the major artery likely feeding the suspected "culprit" vessel (classified as coeliac trunk, left/right gastric artery, gastroduodenal artery, pancreatoduodenal arteries, superior mesenteric artery and inferior mesenteric artery) (Figures 1–3). Any additional finding other than the suspected active arterial bleeding was ignored. In case of disagreement among readers with either device, agreement was reached through consensus reading.

Figure 1. Axial CT image showing tiny contrast medium blush in the arterial phase in the pancreatoduodenal groove (arrows) as seen on the iPad (Apple Inc., Cupertino, CA) (a) and on the workstation (b), respectively. This finding was consistent with active arterial bleeding fed by pancreatoduodenal arteries, as subsequently confirmed by digital subtraction angiography.

(a)

(b)

DSA was considered as the diagnostic gold standard for diagnosis and localization of arterial bleeding and had been performed by a pool of vascular interventional radiologists with a subspecialty experience of at least 5 years.

Statistical analysis

Receiver operating characteristic (ROC) curve analysis was performed to calculate the overall area under the ROC curve (AUROC), sensitivity, specificity, positive-predictive value (PPV) and negative-predictive value (NPV) in CTA-based arterial bleeding detection using the iPad and workstation with DSA considered as the gold standard. Such figures were obtained by combining the responses of the three readers in concordant cases and consensus readings in cases of disagreement (as specified above), and compared by means of χ^2 statistics.

In addition, the agreement of workstation and iPad in correctly locating the bleeding source with respect to DSA in positive cases was assessed and compared using Fisher's exact test.

Moreover, the mean time needed to complete reading of every CTA data set on each device was measured by each reader using a digital timer and compared with the two-tailed Mann–Whitney test. Inter-reader agreement in locating the culprit vessel (or in ruling out active arterial bleeding in DSA-negative cases) was calculated using the Cohen k coefficient.

Overall AUROC, sensitivity, specificity, PPV and NPV were expressed as mean and 95% confidence interval (CI_{95%}), while image reading time was expressed as mean $\pm$ standard deviation.

Statistical analysis was carried out using the software STATA® v. 13 (www.stata.com). A p -value <0.05 was considered as statistically significant.

RESULTS

Overall AUROC, sensitivity, specificity, PPV and NPV of the iPad and the workstation in CTA-based detection of arterial bleeding are reported in Table 1. To this purpose, compared with the workstation, the iPad had comparable AUROC (0.774, CI_{95%}: 0.528–1.000 vs 0.847, CI_{95%}: 0.639–1.000; $p = 0.48$), sensitivity (0.947, CI_{95%}: 0.719–0.997 vs 0.895, CI_{95%}: 0.655–0.981; $p = 0.36$) and specificity (0.6, CI_{95%}: 0.170–0.927 vs 0.8, CI_{95%}: 0.299–0.989; $p = 0.47$). The PPV of the iPad and workstation was 0.9 (CI_{95%}: 0.669–0.982) and 0.944 (CI_{95%}: 0.706–0.997) ($p = 0.26$), while the NPV was 0.75 (CI_{95%}: 0.219–0.987) and 0.667 (CI_{95%}: 0.241–0.940) ($p = 0.08$), respectively.

Out of DSA-confirmed bleeding cases, the iPad and workstation allowed correct identification of the bleeding source in 17/19 cases (89.5%) and 15/19 cases (78.9%), respectively ($p = 0.18$). Overall, agreement with DSA, including DSA-positive and DSA-negative

Figure 2. Axial CT image as displayed on the iPad (Apple Inc., Cupertino, CA) showing a small contrast medium blush (arrow) in the arterial phase inside the duodenal lumen. This finding was consistent with active arterial bleeding fed by pancreatoduodenal arteries and was not detected on the workstation.

Figure 3. Axial CT image as displayed on the iPad (Apple Inc., Cupertino, CA) showing tiny blush-like hyperdense spots (arrows) in the arterial phase inside the horizontal part of the duodenum. This finding was interpreted as active arterial bleeding only on the iPad but was not confirmed by digital subtraction angiography.

cases, was reached in 20/24 cases using the iPad (83.3%) and in 19/24 cases using the workstation (79.2%). Consensus reading was required in 2/24 of iPad readings (8.3%) and 3/24 of workstation readings (12.5%), respectively.

The time needed to complete reading of every CTA study was significantly shorter using the iPad than using the workstation (169 ± 84 vs 222 ± 70 s, respectively; $p < 0.01$). Inter-reader agreement in CTA readings with the iPad and workstation was substantial (0.78 and 0.75, respectively) (Table 2).¹⁵

DISCUSSION

Our results show that the diagnostic accuracy of a tablet computer such as the iPad in detecting active arterial bleeding on CTA images was comparable to that of a commercial workstation connected to the hospital PACS, yielding a very high PPV and a good NPV (0.900 vs 0.944 and 0.750 vs 0.667, respectively), as well as a substantial agreement in localization of the bleeding site compared with DSA as the diagnostic gold standard. Such findings are in line with those provided by several

authors with other applications of emergency CT and MRI, such as pulmonary CTA for suspected pulmonary embolism, head CT for detection of intracranial haemorrhage and spinal MRI for review of spinal MRI examinations.^{4–7} In particular, Johnson *et al*⁴ found that compared with a conventional PACS workstation, the iPad showed no significant differences in sensitivity (98% vs 100%), specificity (98% vs 96%) and overall diagnostic accuracy (98% vs 98%, respectively) in detection of arterial pulmonary emboli down to the subsegmental level. Moreover, Park *et al*⁶ compared the diagnostic performance of an iPad 2 with that of a workstation with a clinical liquid-crystal display monitor for assessment of subtle intracranial haemorrhage under conventional lighting conditions and found that both devices had high sensitivity and specificity, along with an AUROC value as high as 0.935 for the iPad vs 0.900 for the workstation.

Such a successful performance of the iPad is likely owing to several technical factors, including an acceptable screen size (9.7-inch diagonal) and a high screen resolution currently exceeding three million pixels (*i.e.* 2048×1536 pixels or 264 p.p.i.), which is adequate for proper visualization of medical images with relatively low matrices, such as CT (512×512 pixels) or MRI images (usually lower).^{2,3,16–18} Besides, this may explain the substantial inter-reader agreement obtained in our study with the iPad and workstation, which is in line with the literature.¹⁸

Moreover, current models of the iPad and other state-of-the-art tablets are equipped with increasingly fast wireless connections, large amounts of in-built storage capacity (up to 128 GB) and powerful processors (*e.g.* A6X and A7 chips), enabling reasonably fast transfer of larger sets of medical images through WiFi networks and smooth image browsing even with very large data sets, such as those from multidetector CT examinations. Such an increase in hardware resources has been paralleled by the development of dedicated image viewing apps that support image sharing with remote DICOM nodes and allow full integration with their desktop versions or other DICOM-compliant viewers. A popular example is OsiriX HD, which can be downloaded from the Apple Store (<http://store.apple.com>) and provides the main tools for basic image reviewing (such as panning, zooming, scrolling, changing window and level settings and, more recently, multiplanar

Table 1. Overall area under the receiver operating characteristic curve (AUROC), sensitivity, specificity, positive-predictive value (PPV) and negative-predictive value (NPV) of the workstation and the iPad for CT angiography-based acute non-variceal gastrointestinal bleeding detection

Parameters	Workstation	iPad	<i>p</i> -value ^a
AUROC	0.847 (0.639–1.000)	0.774 (0.528–1.000)	0.48
Sensitivity	0.895 (0.655–0.981)	0.947 (0.719–0.997)	0.36
Specificity	0.8 (0.299–0.989)	0.6 (0.170–0.927)	0.48
PPV	0.944 (0.706–0.997)	0.900 (0.669–0.982)	0.26
NPV	0.667 (0.241–0.940)	0.750 (0.219–0.987)	0.08

^a $p < 0.05$ indicates statistical significance.

iPad manufactured by Apple Inc. (Cupertino, CA).

Table 2. Time needed for completing review of CT angiography data sets and inter-reader agreement with the workstation and the iPad

Parameters	Workstation	iPad	<i>p</i> -value ^a
Time (s) ^b	222 ± 70	169 ± 84	<0.01 ^b
Inter-reader agreement ^c	0.75	0.78	

^a*p* < 0.05 indicates statistical significance.

^bValues are expressed as mean ± standard deviation.

^cInter-reader agreement was expressed using the Cohen *k* coefficient.

iPad manufactured by Apple Inc. (Cupertino, CA).

reformatting), comparable to the same tools available on conventional workstations.^{16,17}

This latter circumstance may partly explain the shorter time needed for readers to complete reviewing of CTA studies on the iPad than on the workstation. Indeed, tablets and smartphones are gaining more and more popularity among radiologists and other physicians both inside and outside hospitals, and in our study, the readers had preliminarily undergone intensive training on visualization of CT images on the iPad in order to become fully familiar with the device.^{2,3,16–18} Moreover, iPad gestures for browsing through cross-sectional images are quite easy to learn and can be performed instantly with a single hand on the display without the need for additional peripherals (such as a keyboard or mouse), which are instead unavoidable with conventional workstations.

Another potential explanation for the faster diagnostic performance of the iPad than that of the workstation may be the fact that, on the relatively small iPad screen and with the basic image viewing tools available on the iPad, the readers' attention was more focused to the task of looking for CT signs of active arterial bleeding, with less distraction owing to a more panoramic view that may be favoured by the larger workstation display. This latter circumstance may also partly explain the slightly higher (albeit not significantly different) sensitivity of the iPad than that of the PACS workstation (0.947, CI_{95%}: 0.719–0.997 *vs* 0.895, CI_{95%}: 0.655–0.981; *p* = 0.36). In fact, a reader might feel more concerned in avoiding missing even subtle CT signs of active arterial bleeding on the smaller iPad display using basic touchscreen gestures as the only way of image browsing (which actually reduces the perceived distance between the reader and the device, in opposition to the more indirect mouse- and keyboard-based interaction with the workstation), thus being willing to accept more positive findings than to discard potential false-negative ones.

Our study has several limitations. The first limitation may be our choice of restricting image analysis to CT signs of arterial bleeding only, as one might expect a radiologist to be able to reliably assess all the information provided by an emergency CTA study, including potential incidental findings, which may theoretically have their own impact on patient management. However, looking for findings other than CT signs of arterial bleeding was outside the scope of our study and would likely have required additional time for readers, thus leading of a bias in assessing the performance of the workstation and iPad related to that specific task.

A second limitation may be the fact that we did not evaluate the time needed to transfer CT images on the iPad over consumer internet connections [such as commercial asymmetric digital subscriber line (ADSL) connected to a WiFi router] outside the hospital environment, as would happen in a real-life scenario to an on-call vascular interventional radiologist asked for consultation on an emergency case. In fact, effective network speed depends on several factors, especially in the case of mobile connections (*e.g.* network coverage and saturation, server saturation in case of multiuser platforms, concurrent processing using network resources on the client side), and is actually not accurately predictable in different real-life situations, although the increasing availability of faster ADSL and mobile networks (*e.g.* 4G/long-term evolution) at lower prices is expected to be advantageous to boost and possibly harmonize wireless network performance. To put things into perspective, in our study, the time needed to download CT images in DICOM format with JPEG 2000 lossless compression on the iPad using the Bonjour protocol was always less than 5 min. Moreover, tests with a subset of CTA studies downloaded via cloud on the iPad in the same format using a 4G connection revealed that less than 12 min were needed to complete image transfer (*i.e.* generally much less than needed for an on-call radiologist to come to hospital and see images on a PACS workstation) (Faggioni *et al*, personal communication).

A third limitation may be the relatively small number of DSA-negative cases (5/24, 20.8%) that has apparently magnified a difference in specificity between the iPad (3 negative responses out of 5 DSA-negative cases, 60%) and the workstation (4 negative responses out of 5 DSA-negative cases, 80%). However, we elected to restrict our analysis to a subset of 24 consecutive CTA studies to avoid any potential bias related to the use of different CT scanners and image acquisition protocols at different diagnostic centres of our institution. Moreover, patients with suspected ANVGIB had undergone accurate clinical selection prior to CTA (which may explain the low rate of DSA-negative cases), and sensitivity and NPV were high with both devices and even slightly better with the iPad than with the workstation (*i.e.* 0.947 and 0.750 *vs* 0.895 and 0.667, respectively), suggesting that preliminary CTA image reading on the iPad can safely avoid missed performance of DSA in an actively bleeding patient.

Finally, a fourth limitation may be the fact that CTA image readings were performed sequentially rather than in a randomized manner, as this may have introduced a recall bias with a potential impact on image interpretation. However, we believe

that a time distance of 4 weeks between the two rounds of readings is long enough to prevent any reasonable recall bias and was actually longer than the minimum time interval of 2 weeks between readings as reported by Johnson et al.⁴

In conclusion, our preliminary findings show that iPad-based 2D readings of CTA studies for detection of ANVGIB had comparable diagnostic performance and were significantly faster than those

based on a conventional workstation connected with the hospital PACS. Such results might lead to a significant improvement in the diagnostic and therapeutic management of these patients and should be corroborated on a larger patient sample.

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