Handheld Device Review of Abdominal CT for the Evaluation of Acute Appendicitis

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Abstract Advances in handheld computing now allow review of DICOM datasets from remote locations. As the diagnostic ability of this tool is unproven, we evaluated the ability to diagnose acute appendicitis on abdominal CT using a mobile DICOM viewer. This HIPAA compliant study was IRB-approved. Twenty-five abdominal CT studies from patients with RLQ pain were interpreted on a handheld device (iPhone) using a DICOM viewer (OsiriX mobile) by five radiologists. All patients had surgical confirmation of acute appendicitis or follow-up confirming

no acute appendicitis. Studies were evaluated for the ability to find the appendix, maximum appendiceal diameter, presence of an appendicolith, periappendiceal stranding and fluid, abscess, and an assessment of the diagnosis of acute appendicitis. Results were compared to PACS workstation. Fifteen cases of acute appendicitis were correctly identified on 98% of interpretations, with no false-positives. Eight appendicoliths were correctly identified on 88% of interpretations. Three abscesses were correctly identified by all readers. Handheld device measurement of appendiceal diameter had a mean 8.6% larger than PACS measurements ($p=0.035$). Evaluation for acute appendicitis on abdominal CT studies using a portable device DICOM viewer can be performed with good concordance to reads performed on PACS workstations.

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Introduction

Acute appendicitis is the most common surgical emergency in the USA, with an incidence of 1.1 cases per 1,000 people per year and a lifetime incidence of 7%. Computed tomography of the abdomen and pelvis (CT-A/P) has become the diagnostic modality of choice for evaluation of acute right lower quadrant abdominal pain [1–3]. CT-A/P has become an important diagnostic tool to diagnose or exclude acute appendicitis, with a sensitivity and negative predictive value that surpasses compression sonography and clinical exam [4–7]. The rates of negative appendectomies have decreased from up to 20% to as low as 1.7% when using preoperative CT scans [8, 9]. Evaluation of equivocal CT-A/P studies in patients with right lower

quadrant pain and suspected appendicitis may benefit from subspecialist consultation, particularly in the academic setting where preliminary interpretations are carried out by resident physicians [6, 10, 11].

While there have been previous investigations on the use of portable devices for selective review of medical images [12–14], advances in handheld computing have made viewing full DICOM datasets from a remote location possible. Remote access to CT-A/P studies by radiologists may facilitate subspecialist evaluation of difficult cases where the on-call radiologist requires consultation with a faculty member or colleague who may not have ready access to a dedicated PACS workstation. Additionally, the availability of CT-A/P studies for review on handheld devices could allow consultant surgeons to evaluate cases for triage in which bowel perforation and/or abscess formation are suspected. However, the diagnostic ability of handheld device review of CT-A/P to evaluate for acute appendicitis is unproven. To this end, we sought to evaluate the ability to identify signs of acute appendicitis on CT-A/P examinations using a mobile DICOM viewer.

Methods

This study was conducted after protocol approval from our Institutional Review Board and was HIPAA compliant. We identified 25 CT examinations of the abdomen and pelvis in patients with right lower quadrant pain. The studies were identified through a RIS search of cases ordered from the emergency department with a clinical indication of right lower quadrant pain as a part of creation of a digital

teaching file for residents documenting a spectrum of severity of pathology. The studies were selected and reviewed by two radiologists who did not serve as readers for the study. There were 13 males and 12 females. The mean age of the patients was 38.4 ± 14.3 years (range 18–75). All patients had either surgical confirmation of the diagnosis of acute appendicitis or follow-up clinical evaluation confirming no acute appendicitis. Exclusion criterion included absence of appropriate follow-up to confirm the presence or absence of acute appendicitis and age <18 years.

Full DICOM datasets were transferred to a personal computer (MacBook Pro, Apple Inc, Cupertino, CA, USA) and loaded into an open source DICOM viewer (OsiriX, OsiriX foundation, Geneva, Ch) [15]. Datasets were DICOM anonymized, including removal of patient name, all patient demographic data, and the date and time of the original study. After full DICOM anonymization, studies were securely transferred to a handheld device (iPhone 3 G, Apple Inc, Cupertino, CA, USA) over a 128-bit encrypted wireless network. The iPhone display is 420×380 pixels at 163 ppi (3.5 in. diagonal viewing area). The device had the OsiriX Mobile (OsiriX, OsiriX Foundation, Geneva, Ch) DICOM viewing software installed (Fig. 1) [16]. This software is not limited to a specific PACS vendor, allows communication with any DICOM protocol system, and permits scrolling through DICOM images, review of different imaging series, window-level adjustments, measurement tools, zooming, and image rotation.

The handheld/iPhone device used for this study had telephone access disabled through SIM card removal and wireless internet access disabled once studies had been loaded onto the device. The device was protected with a

Fig. 1 Screen captures from the OsiriX mobile application demonstrating a view of the right lower quadrant in a patient with surgically confirmed perforated acute appendicitis (a) at 1:1 pixel resolution, and a 300% zoom of the appendix in the same case showing the measurement tool (b)

passcode and when not being used for the purposes of this study was kept locked in a secure location to which only one author (AFC) had access. After completion of the study, a low-level system reformat was performed erasing all data from the handheld device.

Each study was evaluated for the following parameters: the ability to identify the appendix, determination of the maximum appendiceal diameter, the presence or absence of an appendicolith, evidence of periappendiceal stranding and fluid, signs of abscess formation, and a binary assessment of the diagnosis of acute appendicitis. Interpretations were recorded on data entry forms which were kept in a secure location until data analysis.

Studies were evaluated by five radiologists blinded to the patient diagnosis and outcomes. As 25 studies were evaluated by each of the five radiologists, there were 125 total interpretations on a mobile device. All participating radiologists received training on the use of the OsiriX–iPhone viewer, including how to scroll, magnify, rotate, measure, and adjust window levels. The five radiologists reviewing the study were in their final year of radiology training (PGY-5 level) and had passed the American Board of Radiology (ABR) written examination for physics, as well as the ABR written clinical examination. Assessments made on the handheld devices were compared to interpretations performed on a dedicated PACS workstation by two board certified radiologists with a subspecialty of gastrointestinal radiology who had four (DLL) and 22 years (SBG) of clinical experience at an academic institution.

Scan Parameters

CT examinations of the abdomen and pelvis were performed on 16 or 64 slice helical scanners (GE Lightspeed 16e or GE Lightspeed VCT 64) during the portal venous phase of intravenous contrast after administration of 100 cc Omnipaque 350 or 100 cc Visipaque 320 intravenous contrast. Patients drank water-soluble contrast material for 1–3 h prior to the study. No rectal contrast material was administered. Scans were performed from the diaphragms to the ischial tuberosities. Images were reconstructed at 5.0 mm thickness at 5.0 mm intervals (no slice overlap and no inter-slice gap) using a soft tissue algorithm. No sagittal or coronal reconstructions were used in this study. Axial images were obtained at 512×512 pixels.

Statistics

Continuous variables (age, appendiceal diameter) were compared with the Kruskal–Wallis test (non-parametric ANOVA) with a non-parametric post-test (Mann–Whitney *U* test).

Paired results were evaluated with the paired *t* test. Discrete variables were compared using Fisher's exact test. A *p* value of less than 0.05 was considered statistically significant. After determination of true-positive, true-negative, false-positive, and false-negative results, standard equations were used to determine specificity, sensitivity, positive predictive value, and negative predictive value. Statistics were performed using Microsoft Excel 2008 (Microsoft, Redmond, WA, USA) and SPSS v16.0 (SPSS Inc, Chicago, IL, USA).

Results

Fifteen of 25 patients (60%) had acute appendicitis, based upon the PACS interpretation of CT-A/P scans with surgical confirmation. On handheld device review, there were 74 true-positive interpretations and 1 false-negative. In the ten patients without the imaging or clinical diagnosis of acute appendicitis, there were no false-positive interpretations. This corresponds to a sensitivity of 98.6%, specificity of 100%, positive predictive value of 100%, and a negative predictive value of 98.0%.

No statistically significant difference in age or gender was noted between those with and without acute appendicitis. Eight of 15 patients with acute appendicitis had appendicoliths, which were correctly identified in 35 of 40 (88%) handheld device interpretations. Abdominal abscesses were identified in 3 of the 15 patients with acute appendicitis and were identified correctly by all five handheld device readers.

All 15 patients with acute appendicitis had periappendiceal stranding, which was identified in 72 of 75 (96%) of handheld device interpretations. Ten of the 15 patients with acute appendicitis (67%) had periappendiceal fluid, which was identified on 47 of 50 (94%) of handheld device interpretations.

The appendiceal diameter for all cases was 9.3 ± 3.8 mm (range 3–17 mm) as measured on a dedicated PACS workstation and measured 10.1 ± 3.7 mm (range 4–17 mm) on the handheld device ($p=0.035$). None of the ten patients without acute appendicitis was identified to have periappendiceal stranding, periappendiceal fluid, an appendicolith, or an abscess on a PACS workstation or on handheld device review. One patient with a retrocecal appendix and one patient with a partial bowel malrotation with the appendix located in the mid-abdomen were both correctly identified by all readers.

The appendiceal diameter of the normal appendices was 5.6 ± 1.2 mm (range 3–8 mm), as compared to 11.8 ± 2.7 mm (range 7–17 mm) for the abnormal appendices based upon PACS measurement ($p<0.0001$).

Discussion

Diagnosing acute appendicitis on CT scans of the abdomen and pelvis using a portable device DICOM viewer can be

performed with good concordance to interpretations performed on PACS workstations in this preliminary investigation. This technology may be particularly useful in an academic setting where on-call faculty physicians may not have immediate access to a computer. Additionally, remote viewing of images may also allow consultant physicians to make decisions on treatment, including open versus laparoscopic appendectomy.

The 15 cases of acute appendicitis in this series were each viewed by five radiologists, comprising 75 total reviews of cases with acute appendicitis. There was one false-negative in this series, which occurred on the first study reviewed by this particular radiologist and as such may be related to inexperience with handheld device viewing of studies. Additionally, this degree of variation may also be expected on multi-reader viewing of studies on a dedicated PACS workstation. Further investigations into the accuracy of handheld viewing of DICOM images will be required for this and other emergent diagnoses. Regardless, review of clinical studies interpreted preliminarily on a handheld device should be performed as soon as feasible to confirm the findings.

Handheld device measurements of the appendix on the OsiriX viewer had a mean almost 1 mm larger than measurements on a PACS workstation, suggesting that appendiceal diameter should not be used as the sole basis the diagnosis or exclusion of acute appendicitis. This is of particular importance in the setting of a dilated appendix without other features suggestive of acute appendicitis. Previous studies have documented the limitations of using appendiceal diameter as the sole diagnostic criteria for acute appendicitis, given the overlap in the size range of the normal and inflamed appendix [7]. Accuracy of size measurements on handheld devices such as the iPhone may improve as radiologists gain more experience and with refinements in the software. Larger studies can evaluate the inter- and intra-rater reliability of measurements on both handheld devices and PACS workstations.

Acute appendicitis has a varied appearance, and evaluation of a larger variety of cases will be important in future studies, with particular focus on more subtle presentations. We attempted to include a range of disease severity with some subtle or borderline cases, including five cases of acute appendicitis with an appendiceal diameter less than 1 cm, as well as three normal studies with an appendiceal diameter of 7 or 8 mm. In clinical practice, identification of alternative etiologies of abdominal pain including obstructive uropathy, Crohn disease, and gynecologic pathology is critical in the absence of acute appendicitis; however, this was not evaluated in the current study. Experience with larger patient series will allow assessment of the accuracy in diagnosing varying degrees of subtlety of

disease presentation. Investigations into the impact of ambient light on mobile device image review are also warranted.

Previous studies have discussed the role of mobile review of imaging studies [12–14], but these investigations have looked only at software that reviews compressed images or is proprietary to a specific PACS vendor. The OsiriX mobile software used in this study can communicate with any DICOM compliant server; however, at present, it is only available on devices using the Apple iPhone operating system. As OsiriX mobile uses DICOM data, as opposed to compressed data such as .jpg files or proprietary data formats, calibrated measurements of distance, area, and regions of interest can be performed. Since the performance of this study, a newer version of the mobile device has been released (iPhone 4, Apple Inc., Cupertino, CA, USA) with a higher pixel count and smaller pixel size (960×640 pixel display with 326 pixels per inch for the iPhone 4 versus 480×320 pixel display at 163 pixels-per-inch for previous models such as the one used in this study) [17]. Increased display resolution may impact the diagnostic accuracy of mobile devices.

The software and device combination used within this study is not currently approved by the US Food and Drug Administration for clinical interpretations. Prior to clinical use, several barriers to handheld device use for viewing of DICOM imaging studies must be overcome. The first and foremost concern is patient privacy. Handheld devices used for this purpose must have a passcode lock enabled. Additionally, it may be beneficial for the DICOM viewing software to have its own password to access locally stored studies. At present, locally stored studies are not encrypted. The iPhone system used in this study allows for virtual private network (VPN) connections either through the cellular network or through wireless networks; any patient data transfer over an unsecured network must utilize VPN security. However, even with these precautions, care must be taken to prevent non-medical personnel from seeing the patient information. Thus, discretion is important when viewing studies even if appropriate digital security measures are in place. Additionally, while secure transfer of DICOM data to handheld devices is possible, data transfer may be slow on some networks.

The handheld device–software combination used does not allow creation of multiplanar reformats, and only axial images were made available for review in this study. In clinical use, sagittal, coronal, or thin-slice axial images could be processed on a workstation prior to being sent to the handheld device; however, this would increase size of the dataset and thus increase the transfer time.

The time required for mobile review of imaging studies needs to be compared to the time required on a dedicated PACS workstation. This was not directly studied in this

investigation. Additionally, the time required for data transfer needs to be included in this comparison, as transfer over wireless networks is typically slower than LAN connections. Transfer of a CT-A/P had a mean time of approximately 3 min per study over a wireless LAN. Larger studies or the inclusion of thin-section data and multiplanar reformats would increase transfer time. For remote consultation when a wireless LAN is not available, transfer over a cellular network could take up to ten times longer with currently implemented technology [16].

If these issues are overcome, liability issues related to mobile device interpretations are unclear and will likely remain so until legal challenge. If this technology proves to be useful in a clinical setting, significant delays in reviewing a study for on-call physicians who do not have handheld device access to imaging could perhaps even be considered a deviation from standard of care. While this may not be the case at first, the tethering of the on-call physician will likely only increase as technology is further intertwined into medical practice.

Advances in device and network technology will improve the speed and ease at which studies can be remotely accessed, and, with more experience, physicians will be able to access these studies in a secure manner which protects patient privacy while maximizing clinical benefits. Differing viewing conditions could impair optimal image interpretation, and contrast sensitivity will be decreased with bright lighting conditions.

Handheld device review of CT examinations of the abdomen and pelvis using the OsiriX viewer in patients with right lower quadrant abdominal pain provides a reliable means of diagnosing acute appendicitis and associated complications. Handheld technology is rapidly advancing, and newer tablet devices with larger screens with higher resolution and faster processors [17–19] could allow better visualization and manipulation of DICOM images as well as capabilities to have multiple image series displayed simultaneously. This technology may obviate any delays associated with the need to find a workstation with internet or PACS access or the need to come to the hospital to review imaging studies. Handheld device review of CT scans has the potential to aid in appropriate and expeditious triage of patients with acute appendicitis, ultimately improving patient outcomes.

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