Clinical application of real-time tele-ultrasonography in diagnosing pediatric acute appendicitis in the ED

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Abstract
Purpose: We investigated the effectiveness of tele-mentored ultrasonography between emergency medicine (EM) residents and remote experts in diagnosing acute appendicitis.

Methods: This prospective observational study was performed in an academic emergency department. Beginning in June 2014, the EM residents performed the initial ultrasonography for suspected pediatric acute appendicitis; then, the remote experts observed/mentored the residents’ practice using the tele-ultrasonography system; and finally, an onsite expert verified the diagnosis. The diagnostic confidence of each examiner (resident, remote expert, and onsite expert) was rated on a 5-point Likert scale. The appendicitis identification rate and the diagnostic values: sensitivity, specificity, positive predictive value (PPV) and negative predictive value (NPV) for each type of examination were calculated.

Results: A total of 115 pediatric cases with suspected acute appendicitis, including 36 with pathology-confirmed acute appendicitis, between June 2014 and February 2015 were enrolled in this study. In 9 of the 115 (7.8%) cases, a non-appendicitis diagnosis was determined in the absence of the successful identification of an appendicitis. On these, seven appendices were identified upon expert tele-ultrasonography. The diagnostic values for expert tele-ultrasonography were higher (sensitivity: 1.000, specificity: 0.975, PPV: 0.947, NPV: 1.000) than those for resident-performed ultrasonography (sensitivity: 0.917, specificity: 0.899, PPV: 0.895, NPV: 0.959) and similar to those for onsite expert-performed ultrasonography (sensitivity: 1.000, specificity: 0.987, PPV: 0.973, NPV: 1.000).

Conclusion: Tele-ultrasonography with tele-mentoring between EM residents and experienced mentors was effectively applied in diagnosing pediatric acute appendicitis in an emergency clinical setting.

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1. Introduction

Ultrasonography is a useful noninvasive means of determining a diagnosis of acute appendicitis at the bedside in the emergency department (ED). As concerns about exposure to radiation have increased, the accuracy of ultrasonography has improved substantially with no harmful radiation, which is especially important in pediatric patients and reproductive women [1]. However, the efficacy of ultrasound examination is highly user-dependent, and thus, access to a trained practitioner is an essential requirement for applying it. Because there are insufficient numbers of trained experts available in emergency departments (EDs), computed tomographic (CT) scans are still widely used for diagnosing acute appendicitis in radiation-sensitive patients because ultrasonography is not always readily available within 24 hours [2–5].

Tele-ultrasonography is a technology that is expected to compensate for this limitation. Informatics technology facilitates the real-time interpretation by remote experts of transferred ultrasound videos acquired by a less-experienced onsite ultrasound user [6–9]. Several studies have demonstrated the possibilities of real-time tele-mentored ultrasonography in various emergency clinical settings, such as for pneumothorax or fluid collection in trauma patients [7–9]. However, these have mostly been limited to simple ultrasound examinations, such as the extended Focused Assessment with Sonography for Trauma (e-FAST), which do not require high-resolution images or detailed mentor guidance. By contrast, the mentoring and tele-interpretation that are necessary for evaluating acute appendicitis are quite complex. Furthermore, there have been few previous studies in which a smart phone with a small screen has been used as a remote viewing display.
We developed a tele-ultrasonography system (E-Cube 15, Alpinion Medical Systems, Korea) that can transfer ultrasound video sequences to be viewed in real time on a remote smart phone. In this study, we investigated the effectiveness of applying tele-ultrasonography between emergency medicine residents with ultrasound experience of less than two years and remote mentors for the diagnosis of acute appendicitis.

2. Methods and materials

2.1. Study design and setting

This prospective observational study was conducted at an academic ED between June 2014 and February 2015. The ED was running a four-year emergency medicine (EM) residency training program, including emergency ultrasound training. There were three attending physicians present with advanced ultrasonography skills who were certified by the Korean Society of Ultrasound Medicine. They were charged with the ultrasound education of the EM residents and with examining emergency ultrasonography results in the ED. However, they could not always be available 24 hours a day because of their insufficient number. They were typically available during the daytime (8 a.m. to 7 p.m., 7 days a week, including Saturday and Sunday). During this time, the emergency residents performed initial ultrasonography for suspected pediatric appendicitis. In each case, an ultrasound-skilled attending emergency physician was located in another room, 20 m away from the patient, and observed the ultrasound video sequences and the resident’s practice (background videos) in real time using a smart phone. The expert merely observed, without mentoring (verbal assistance with image acquisition and/or interpretation), until the resident determined a diagnosis. After completing the examination without mentoring, the resident graded the probability of acute appendicitis using a five-point Likert scale and then performed ultrasonography again with the guidance (mentoring) of the remote expert physician. If the remote expert had already determined the diagnosis by merely observing the resident’s practice without guidance, the second process (mentoring) was omitted. The remote expert was also requested to grade the probability of acute appendicitis using a 5-point Likert scale. Finally, the ultrasound expert left the remote viewing room and verified the diagnosis by performing onsite ultrasonography in person on the actual ED patient; these results were also graded on a 5-point Likert scale. The ultrasound criteria that were used for the determination of acute appendicitis (periappendiceal fat infiltration and obstructing appendicolith) were selected based on our previous study [5]. The practitioners made their determinations regarding the likelihood of appendicitis in accordance with the above criteria even in cases with a non-visualized appendix [10]. Beginning in June 2014, the results of the use of tele-ultrasonography were recorded in a predesigned registry.

These procedures were conducted under slightly dim ambient light (75-150 lux), in accordance with the recommendations of the American Association of Physicists in Medicine [11,12], and performed with the informed consent of the patients’ guardians. The study was approved by our institutional review board.

2.2. Tele-ultrasonography system

The tele-ultrasonography system, which can simultaneously transmit ultrasound video sequences and background videos (a simultaneous video of the resident applying the ultrasound probe on the patient as shown in Fig. 1) to a remote display in real time, was developed by Alpinion Medical Systems in collaboration with us (CubeView, Alpinion Medical Systems, Korea). They provided us with this system for this study. This system generated the transmitted ultrasound video sequences by continuously capturing the ultrasound images displayed on the monitor of the ultrasound machine at a rate of more than 25 frames per second (FPS) and then transmitted each image to the server computer over the 100-megabit-per-second (Mbps) broadband fixed-line Internet network. The background videos showing the sonographers’ practice were captured by an Internet protocol camera and were simultaneously transmitted to the server computer. The combined videos (ultrasound video sequences with background videos) were transmitted to the remote smart phone display over the mobile Internet network (Fig. 1). The remote mentor could communicate with the onsite practitioner via voice calls while watching the transmitted videos in real time.

The transmitted data were secured by encryption and password protection.

2.3. Remote viewer

A smart phone (iPhone 5S; Apple, Inc, Cupertino, CA) was used as the remote display in this study. The detailed specifications of the device are shown in Table 1. The luminance was fixed to its maximum during the examination. The CubeView application was downloaded to the smart phone from iTunes [13]. A long-term evolution (LTE) network (SK telecom, Korea) was used as the mobile Internet network in this study.
Table 1
The specifications of the smart phone display used in this study

<table>
<thead>
<tr>
<th>Type of display</th>
<th>LED-backlit IPS LCD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Screen shape</td>
<td>16:9</td>
</tr>
<tr>
<td>Number of pixels</td>
<td>1,136 × 640 (326 PPI)</td>
</tr>
<tr>
<td>Luminance (max), cd/m²</td>
<td>556</td>
</tr>
<tr>
<td>Display size, diagonal (cm)</td>
<td>10.2</td>
</tr>
<tr>
<td>Contrast ratio</td>
<td>800:1</td>
</tr>
</tbody>
</table>

LCD, Liquid crystal display; LED, light-emitting diode.

2.4. Study populations

All pediatric cases (aged under 19) that were recorded in the registry between June 2014 and February 2015 were included in this study. The inclusion criteria were as follows.

1. Pediatric patients younger than 19 years
2. Cases with suspected acute appendicitis
3. Cases in which emergency physician-performed ultrasonography was performed first during the period of availability of an attending physician with ultrasound expertise
4. Cases with the informed consent of the patients' guardians

The exclusion criteria were as follows.

1. Cases in which a CT scan was performed first
2. Cases lost to follow-up

A total of 12 EM residents and three attending EM physicians certified by Korean Society of Ultrasound Medicine participated in this study. The EM residents had 1 to 2 years of experience with ultrasonography, and the attending EM physicians had more than 6 years of clinical experience with abdominal ultrasonography. All participants had participated in a training course to improve the experts' guidance of the onsite residents' hand coordination abilities. In this course, lectures were presented that included the names of landmark structures adjacent to the appendix and terminology for probe manipulation (eg, rotation, tilt and alignment). The program also included 20-minute simulation training sessions.

2.5. Data collection

The data collection registry was designed via discussion and consensus with all investigators participating in this study. All participants were provided with instructions regarding the study variables and recording methods before collecting data. They recorded the variables on the registry form after performing each examination. The information was reviewed by author HJC and was then recorded in the Internet database. Only authors THL and JHO could access the original data, and these authors monitored the data collection during the study period. Finally, author CK reviewed the original data forms after the completion of data collection.

The pathology reports for patients treated with surgery were reviewed. The outcomes for patients treated without surgery were determined either by reviewing the follow-up records from the outpatient clinic or via a telephone survey of patients without a follow-up visit in May 2015.

2.6. Variables

The collected data included the patient information (ID, sex, and age), the onsite practitioners' training (residency level and years of experience with ultrasonography), and the remote mentors' training (years of experience with ultrasonography, specialty and position).

The diagnostic confidences of the residents for suspected acute appendicitis before mentoring, those of the attending physicians using tele-mentored ultrasonography, and those of the attending physicians using onsite ultrasonography were recorded. All were instructed to grade the likelihood of appendicitis using a 5-point Likert scale (1 = definite absence of appendicitis, 2 = probable absence of appendicitis, 3 = uncertain but possible absence of appendicitis, 4 = probable presence of appendicitis, and 5 = definite presence of appendicitis). The graders were blinded to each other's scores. They also recorded whether the appendix was successfully identified.

The remote mentors recorded several additional variables, included the following: the mobile network connection speed that was measured using the smart phone application BENCHBEE 2.2.9 (BENCHBEE, Seoul, Korea) at the end of each examination [13], any difficulties encountered during the procedures and subjective quality assessment scores for the transmitted videos displayed on the smart phone on a 5-point Likert scale (single-stimulus method: 1 = bad, 2 = poor, 3 = fair, 4 = good, 5 = excellent).

2.7. Main outcomes and data analysis

The appendix identification rate as well as the sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) of the diagnosis of acute appendicitis were calculated for each of the three types of examination. A score of 3 or lower was deemed negative for appendicitis, and the gold standards for diagnosis in each case were the pathology reports or the results of clinical follow-up or the telephone survey, as applicable.

The diagnostic performances achieved via resident-performed, remote expert tele-mentored and onsite expert-performed ultrasonography for the diagnosis of acute appendicitis were evaluated. The areas under the curves (AUCs) of the receiver operating characteristics (ROC) for each examination were calculated.

The mean subjective image quality assessment scores were calculated, and a score greater than four was regarded as indicative of high quality [14,15].

The descriptive data were expressed as means with standard deviations. Statistical analysis was conducted using the MedCalc 15.4 software package (MedCalc, Mariakerke, Belgium) [16]. Graphs of the ROC curves were plotted using this software.

3. Results

3.1. Participants

A total of 8125 pediatric patients (age < 19 years) were presented to the ED during the study period (between June 2014 and February 2015), and 3386 patients visited during times of expert availability (weekdays). Of these, 124 patients had suspected appendicitis, and all except 6 patients, who had an initial CT scan, underwent emergency physician-performed ultrasonography first. Three further patients were excluded because they were lost to follow-up. Thus, 115 cases, including 65 (56.5%) male patients, were enrolled in the study population. The diagnosis of appendicitis was confirmed by histopathology in 36 patients (31.3%) and the remaining 79 (68.7%) were verified as not exhibiting appendicitis. The mean age was 10.6 years (SD 3.3).

3.2. Main results

The grading scores for each examination are shown in Table 2. The percentage of findings classified as uncertain (score of three) for tele-mentored ultrasonography (9.6%) was quite low in comparison with that for resident-performed ultrasonography (22.6%), indicating that the diagnostic confidence was increased with the use of tele-ultrasoundography.

The appendix detection rates for each examination are also shown in Table 2. The residents were unable to find the appendix in the initial ultrasonographic examination in nine of the 115 (7.8%) cases: 9 (11.4%) of the 79 cases of normal appendices and none (0%) of the cases of appendicitis. Of these, 7 appendices were detected upon tele-mentored ultrasonography.
Sensitivity, specificity, PPV, and NPV for resident, tele-mentored, and onsite ultrasound readings are summarized in Table 3. Two of 79 cases of normal appendices were falsely diagnosed as positive for appendicitis via tele-mentored ultrasonography. The ultrasonographic findings in these cases were ambiguous; the appendiceal diameters were both greater than 6 mm, and the slightly increased echogenicity in the fat adjacent to the appendix was suspicious, but there was no obstructing appendicolith. The remote experts suspected acute appendicitis. However, the pathology reports revealed no inflammation. Of these, one case was also falsely diagnosed as acute appendicitis even by onsite expert-performed ultrasonography.

The AUC values of the ROC curves (Fig. 2) are summarized in Table 4 which are statistically similar, but the graph (Fig. 2) and Tables 2 and 3 demonstrate the clinical importance of the additional diagnostic accuracy of the tele-mentored ultrasonography.

3.3. Subjective image quality assessment scores

The mean of the subjective quality assessment scores provided by all physicians was 4.18 (SD: 0.70), and the mean of each physician’s scores was also greater than four (Table 5). These findings of the single-stimulus method for the subjective quality assessment of the images transmitted from the ultrasound machine indicate that the videos displayed on the smart phone maintained a high level of image quality and that the small display of the smart phone did not significantly detract from image usefulness. The mean mobile Internet speed was 59.1 Mbps (SD 13.8) during tele-mentored ultrasonography (Table 5).

4. Discussion

To our knowledge, this was the first study of the clinical application of tele-ultrasonography in the diagnosis of acute appendicitis performed in a real clinical emergency setting. Remote mentor-guided tele-ultrasonography was found to be effective in diagnosing pediatric acute appendicitis. The diagnostic performance of tele-mentored ultrasonography was as high as that of onsite expert ultrasonography and was higher than that of solo resident ultrasonography. The mentoring provided additional diagnostic accuracy in identifying three cases of appendicitis that would have been missed, and greater diagnostic certainty in some of the negative cases. Diagnostic confidence was also increased in the case of tele-ultrasonography in comparison with...
resident-performed ultrasonography. Twenty-six cases (22.6%) were classified as grade three (uncertain diagnosis but possible absence of appendicitis) following resident-performed ultrasonography, meaning that they were determined to be normal appendices but with a lack of confidence. All of these cases were later confirmed to be non-appendicitis cases; thus, these diagnoses were correct, but their diagnostic confidence was quite low. Given that the proportion of these low-confidence cases decreased to 9.6% upon tele-mentored ultrasonography, it can be concluded that tele-mentored ultrasonography can increase diagnostic confidence as well as diagnostic performance in the diagnosis of pediatric acute appendicitis. Moreover, mentoring can assist inexperienced physicians in identifying the appendix. In this study, the residents were always able to find the appendix in cases of acute appendicitis; however, they could not identify the appendix in study, the residents were always able to

Table 4
Receiver operating characteristic (ROC) curve analysis for each type of examination

<table>
<thead>
<tr>
<th>Variable</th>
<th>AUC</th>
<th>SE</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resident-performed US</td>
<td>0.943</td>
<td>0.018</td>
<td>0.883 - 0.978</td>
</tr>
<tr>
<td>Tele-mentored US</td>
<td>0.995</td>
<td>0.004</td>
<td>0.959 - 1.000</td>
</tr>
<tr>
<td>Onsite expert-performed US</td>
<td>0.999</td>
<td>0.0008</td>
<td>0.967 - 1.000</td>
</tr>
</tbody>
</table>

AUC: area under the curve; SE: standard error; CI: confidence interval; US: ultrasonography.

by an attending emergency physician based on these criteria was very high (sensitivity of 1.00 and specificity of 0.987), consistent with the findings of our previous study [5]. High-resolution images are critically required to assess these detailed findings, unlike simple criteria such as an appendiceal diameter of > 6 mm.

The telesonography system used in this study can transmit videos without loss. The image size of a single frame losslessly captured by CubeView is typically 880 × 660 pixels, which can be compressed to between 100 and 150 kilobytes (kb) in PNG format. Such images can be theoretically transmitted at more than 20 FPS if the mobile connection speed is greater than 24 Mbps. Given that the average connection speed of the LTE network was 59.1 Mbps during this study, high-quality videos without loss could be continuously transmitted without any interruption in motion.

In fact, the human perception of the image quality of the videos transmitted to the smart device was found to be excellent in this study, as indicated by the mean subjective image-quality assessment score of more than four. The subjective assessment of image quality is known to be the most accurate method of capturing the characteristics of the human perception of image quality [18,19]. There was no case in which interpretation was not possible due to a low level of transmitted video quality in this study.

This tele-system could be more effectively utilized if a workstation were to be used as the remote display instead of a smart phone. Indeed, this system may be more frequently used at home at a workstation rather than over a smart phone. However, smart phones are advantageous over workstations with regard to device access. Remote experts are almost always able to access their handheld devices immediately. There are some expert physicians who do not have workstations at home and cannot access a workstation outside of the hospital. This is the reason that we used an iPhone rather than a workstation as the remote display in this study. We believe that if such smart phone-based telesonography is feasible, then workstation-based telesonography, with a larger screen and a faster, wired network connection, will certainly be possible.

4.1. Limitations

Experts who are skilled in using smart devices and in interpreting transmitted images on a small display are necessary for the effective application of tele-ultrasonography. The experts who participated in this study have been actively investigating the possibilities of tele-interpreting using hand-held smart devices for the past three years [20–24] and thus were familiar with the use of smart phones and with ultrasonographic interpretation using such small displays. However, not all experts may be proficient at remotely mentoring inexperienced physicians or interpreting transmitted images using a small screen. Nevertheless, we believe that this procedure is not exceedingly difficult, and thus, most can become accustomed to this procedure with relatively little practice prior to use. Based on our experience, approximately 10 minutes of practice is sufficient to allow the procedure to be performed effectively. Furthermore, the system can also transmit videos to smart devices with larger screens, including tablets and desktop

Table 5
Subjective image assessment scores and mean mobile Internet speeds

<table>
<thead>
<tr>
<th>Remote mentor</th>
<th>No. of cases</th>
<th>Mean score (SD)</th>
<th>Mobile Internet speed* (Mbps, mean (SD))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Score 1</td>
<td>Score 2</td>
<td>Score 3</td>
</tr>
<tr>
<td>Physician 1</td>
<td>0</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Physician 2</td>
<td>0</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Physician 3</td>
<td>0</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>All observers</td>
<td>0</td>
<td>2</td>
<td>13</td>
</tr>
</tbody>
</table>

Mbps: megabits per second.

* Measured using BENCHBEE 2.2.9.
computers. Thus, we believe that the use of this system will not necessarily be problematic for a broader population of practitioners.

The high identification rate and diagnostic accuracy for suspected appendicitis in this study might be affected by the fact that this study only included Asian pediatric patients who are usually small and thin. Those for adults and obese pediatric patients could be decreased.

The availability of LTE networks is not yet universal worldwide, although it is rapidly increasing [20]. As mentioned above, a mobile Internet speed of at least 24 Mbps is theoretically required to transmit high-quality, lossless images of 150 kB in size at more than 20 FPS. However, we have already demonstrated that tele-interpretation for suspected pediatric acute appendicitis using this system over a 3rd generation (3G) network with a speed of approximately 5 Mbps can be made feasible by reducing the FPS [unpublished data]. Interpretation for static organs such as the appendix may, in general, require only a low FPS for the transmission of video sequences. We used an LTE network in this study because background videos were transmitted simultaneously with the ultrasound videos. If only ultrasound video sequences were to be used, the use of a 3G network would be feasible for the diagnosis of pediatric acute appendicitis.

There is, in addition, one further consideration regarding the use of this tele-system. There will be situations in which the mobile Internet speed will slow down dramatically in comparison with the maximum rate of the network. During peak hours (usually commuting times), when many people are simultaneously making phone calls, sending text messages, engaging in video communication and/or downloading movies, the resulting slowdown could cause this system to crash.

The small number of cases included in our study and its single-center design prevent us from generalizing its conclusions to all clinical settings. A large, multicenter, randomized controlled study is needed.

5. Conclusion

Telesonography with tele-mentoring between an inexperienced physician and an experienced mentor can be effectively used to diagnose pediatric acute appendicitis in an emergency clinical setting. This approach is viable when an onsite expert is not available. Given that ultrasound mentoring and remote interpretation for acute appendicitis require detailed guidance and the ability to perceive subtle findings, the results of this study support the potential use of this practice for other diseases. This practice would decrease the potential risks of CT radiation for pediatric patients and reproductive women by allowing CT scans to be replaced with ultrasonography in under-resourced regions, even when experts are not available onsite.

Acknowledgments

We thank Alpinion Medical Systems, which developed the tele-ultrasonography system in collaboration with us and provided this system to us free of charge for this study.

References


