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Ultrasound in Emergency Medicine

LEARNING CURVE OF BEDSIDE ULTRASOUND OF THE GALLBLADDER

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□ **Abstract—Existing guidelines for the number of ultrasounds required before clinical competency are based not on scientific study but on consensus opinion. The objective of this study was to describe the learning curve of limited right upper quadrant ultrasound. This was a prospective descriptive study. Ultrasounds collected over 1 year were reviewed for interpretive and technical errors. Possible errors during bedside ultrasound of the gallbladder include incorrect interpretation, incomplete image acquisition, and improper or poor imaging techniques resulting in poor image quality. The ultrasound image quality was rated on a 4-point scale, with 1 = barely interpretable and 4 = excellent image quality. Required images were rated on an additional 4-point scale, with 4 = all required images were included and 1 = minimal images were recorded. There were 352 patients enrolled by 42 emergency physicians (35 residents and 7 attendings). Gallstones were identified in 13.9% of the patients, and 4.3% of the ultrasounds were indeterminate. Interpretive and technical error rates decreased as the clinician gained experience. The number of poor quality ultrasounds decreased after an average of seven ultrasounds. Inclusion of all required images increased after 25 ultrasounds. Sonographers who had performed over 25 ultrasounds showed excellent agreement with the expert over-read, with only two disagreements, both from a single individual. It was concluded that clinicians are clinically competent after performing 25 ultrasounds of the gallbladder.** © 2009 Elsevier Inc.

□ **Keywords—bedside ultrasound; emergency ultrasound; gallbladder; right upper quadrant; gallstones**

INTRODUCTION

"Emergency ultrasonography" or "bedside ultrasonography" describes limited ultrasound protocols performed at the patient's bedside to answer targeted questions, usually performed by clinicians (1,2). This is in contrast to comprehensive ultrasounds performed by ultrasound technicians and others who explore a wider range of pathologic conditions. For example, an emergency physician may use a limited echocardiogram during a cardiac arrest and then order an echocardiogram by Cardiology once the patient is stabilized. The first echocardiogram was to determine if the heart was beating and the second was to diagnose the wide range of conditions that could lead to cardiac arrest.

Right upper quadrant (RUQ) sonography is commonly performed in the Emergency Department (ED) to determine if a patient has gallstones (3,4). The education required to see gallstones differs from the education required to perform a comprehensive sonographic evaluation of the RUQ, which includes the gallbladder, biliary tree, liver parenchyma, pancreas, right kidney, and adrenal glands. The American College of Emergency Physicians (ACEP) has published guidelines that state a clinician should perform 25 to 50 limited RUQ ultrasounds to be credentialed in emergency ultrasonography of the RUQ (5). The American Institute of Ultrasound in Medicine recommends 300

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total ultrasounds before interpreting ultrasound images (6). These numbers are not based on scientific research and were proposed as a consensus opinion in 2001 and 2003, respectively. To date, there is limited research concerning the learning curves for emergency ultrasound, with most studies focusing solely on interpretive errors (7–9).

Two different types of errors can occur during emergency ultrasonography of the gallbladder: technical and interpretive. Technical errors include: 1) not obtaining all of the proper images and 2) obtaining images with poor quality. Interpretive errors occur when the ultrasound is misread. There has been limited research concerning the errors that occur during emergency ultrasonography of the gallbladder. In this study we examine the technical and interpretive error rates of emergency physicians learning RUQ sonography and compare competency before and after meeting the ACEP-recommended credentialing guidelines.

MATERIALS AND METHODS

The study took place over 12 months in the ED of an urban level 1 trauma center from July 2004 to June 2005. Patients were prospectively enrolled in the study if they received a bedside RUQ ultrasound. Ultrasound images were reviewed weekly in a blinded fashion. The sole exclusion criterion was not recording the ultrasound on videotape. Some individuals had additional imaging after the bedside ultrasound. The need for additional imaging was determined by the attending physician of record.

Education

All clinician sonographers in this study were residents and attending physicians who underwent standardized education in sonography before enrolling patients in this study. Didactic lectures (8 h) covered ultrasound basics, physics of ultrasound, and bedside ultrasonography of the gallbladder. A 1-h lecture dedicated to imaging the RUQ detailed the required images, proper imaging techniques, suggestions for improving imaging, and a review of positive and negative ultrasound images. At least 2 h of hands-on education was performed in small groups or one-on-one skill sessions. The hands-on session focusing on the RUQ demonstrated the imaging techniques discussed during the lectures. The experience level of the sonographers involved in this study ranged from novices with a few ultrasounds to experienced users with hundreds of ultrasounds. Credentialing is defined in this article as successfully performing 25 gallbladder ultrasounds, without regard to a required number of "positive" ultrasounds.

Ultrasound Review and Rating

Ultrasound images were recorded on digital videotape for later review by one of two expert sonographers. Each of the expert sonographers had performed over 1000 ultrasounds and reviewed over 5000 ultrasounds before initiating this study. Ultrasounds were reviewed blinded to the initial read and rated on three separate metrics. The original interpretation was compared to the expert review. The ultrasound image quality was rated on a 4-point scale, with 1 = barely interpretable and 4 = excellent image quality. Required images were rated on an additional 4-point scale, with 4 = all required images were included and 1 = minimal images were recorded (Table 1). The four required images were long axis of the gallbladder and transverse axis of the gallbladder fundus, body, and neck. Agreement (kappa) between the two expert reviewers for 20 additional ultrasounds was excellent for interpretation (1.0), and good for image quality (0.62) and required images (0.62).

Statistics

Comparison of initial read to expert review was performed using a kappa analysis. Data were categorized by post-graduate year (PGY-1, -2, and -3) and pre- or post-credentialing (25 ultrasounds). Between-group comparisons were performed using Fisher's exact test. Unless

Table 1. Rating Scales for Required Images and Image Quality

Required images	
1 of 4	Single image of object of interest and/or all atypical views
2 of 4	Many required images missing and/or multiple atypical views
3 of 4	Most required images present and/or single atypical view
4 of 4	All required images present and all standard views
Image quality	
1 of 4	Poor image quality: few details discernable and/or landmarks not visible
2 of 4	Adequate image quality: some details not visible and/or some landmarks missing
3 of 4	Good image quality and/or most details visible, landmarks visible
4 of 4	Excellent image quality and/or all details clearly visible, all landmarks visible

Table 2. Interpretive Errors of Right Upper Quadrant Ultrasound (US) Images

Experience	Level	Initial Results	Final Results	Reason for US
PGY-3	14 Ultrasounds	(+) gallstone	(−) gallstone	Teaching
PGY-2	18 Ultrasounds	(−) gallstone	(+) gallstone	Teaching
PGY-3	25 Ultrasounds	(−) gallstone	(+) gallstone	Clinical
PGY-3	33 Ultrasounds	(−) gallstone	(+) gallstone	Teaching
PGY-3	38 Ultrasounds	(−) gallstone	(+) gallstone	Teaching
PGY-1	11 Ultrasounds	(−) gallstone	(+) gallstone	Clinical
PGY-3	16 Ultrasounds	(−) gallstone	(+) gallstone	Teaching
Att	15 Ultrasounds	(−) stone (+) sludge	(+) stone (−) sludge	Clinical

Att = attending physician.

otherwise specified, data are provided as the value with 95% confidence interval.

RESULTS

There were 352 patients enrolled by a total of 42 physicians, including 35 residents and 7 attendings. The average experience levels at the beginning of the study period for PGY-1, -2, -3, and attending physicians were 0, 70, 102, 346 (total ultrasounds), respectively, and 0, 4.4, 3.5, 34 (RUQ ultrasounds), respectively. Fifty-two percent of the ultrasounds during the study period were performed by credentialed sonographers who had performed at least 25 RUQ ultrasounds. PGY-3 residents performed most of the RUQ ultrasounds (50.4%), followed by attending physicians (27.5%) and PGY-2 residents (17.8%).

Sixty percent (60.2%) of the patients enrolled in the study were female, with an average age of 42.8 years. Gallstones were identified in 13.9% of the patients, and 4.3% of the ultrasounds were indeterminate. There was no statistical difference in positive ultrasounds (defined as presence of gallstones) between experience levels of sonographers. Ultrasounds were performed 24 h a day, 7 days a week during the course of the study, with 53% performed on nights and weekends when an ultrasound technician was not available in the hospital.

Due to the active ultrasound educational program, a substantial percentage of the ultrasounds performed were for educational purposes only. The majority (60.2%) of the ED ultrasounds were performed clinically in an attempt to diagnose gallstones, with the remainder for educational purposes. The need for additional imaging outside of the ED was determined by the attending of record; 52.3% of the patients underwent additional imaging by computed tomography (CT) (26.7%), ultrasound (16.5%), both CT and ultrasound (6.5%), and other (2.6%).

All ultrasounds were reviewed weekly with specific attention paid to technical and interpretive errors. There was very good agreement between the initial sonographers and the expert reviewer, with an overall kappa of 0.917 (95% confidence interval 0.856–0.978) for the detection of gallstones. Information on patients with interpretive errors is detailed in Table 2. Agreement varied by experience level, with PGY-1 level residents to attendings showing increasing levels of agreement (Figure 1). Agreement also increased once the sonographer was credentialed. The number of required images on a 4-point scale averaged 3.5 for all groups. The percentage of sonographers who included all required images increased as experience increased (Figure 2). The percentage of poor image quality (1 of 4) was higher for PGY-1 sonographers over all other experience groups (13.3% vs. 1.2%, $p = 0.024$). Conversely, credentialed sonographers obtained excellent images (4 of 4) more often than non-credentialed sonographers (54.3 vs. 66.5%, $p = 0.026$) (Figure 3).

DISCUSSION

The literature on errors that occur during emergency (or bedside) ultrasonography has focused almost exclusively on interpretive mistakes. Many studies on other emergency ultrasonography protocols (FAST, cardiac, aorta, renal, uterus, and lower extremity duplex) report interpretive errors as sensitivity and specificity (10–16). There are three previous studies that explore the error rate of bedside RUQ ultrasound. Two prior studies on RUQ ultrasound focused on interpretive errors, with no discussion of technical errors (7,9). Only one abstract has been published examining some of the technical components of emergency ultrasonography (17). Recently, the ACEP board of directors approved a document that lists the images needed for each bedside ultrasound performed in the ED, including RUQ (18).

A number of national groups have recommended credentialing guidelines for the performance of emergency ultrasonography despite the lack of rigorous research in this area. ACEP recommends 25 RUQ ultrasounds, whereas the

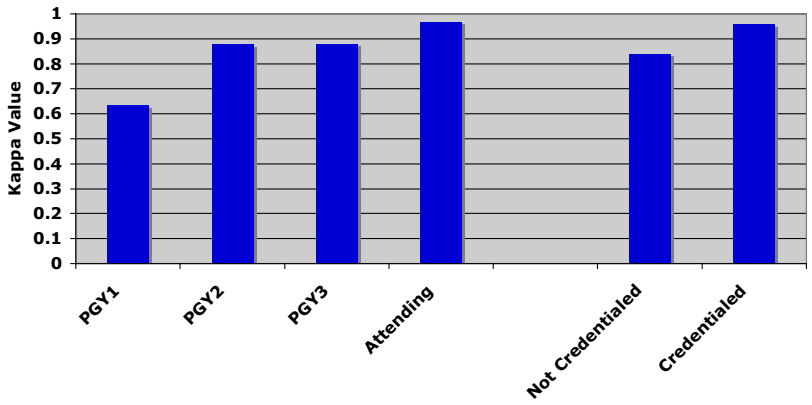

Figure 1. The figure represents the agreement of initial sonographers' interpretation with expert review. Results are categorized by experience level. Sonographers who had completed 25 or more right upper quadrant ultrasounds were considered credentialed.

American Institute of Ultrasound in Medicine recommends a total of 300 (5). Appropriate guidelines should be based on facts and not the impressions of individuals with inherent biases. By their nature, limited RUQ ultrasounds performed at the bedside in the ED are not identical to the ultrasounds performed by ultrasound technicians in the Radiology Department. The skill level to determine if a gallstone is present is not the same as the ability to identify other more subtle findings such as differentiation of focal fatty sparing from neoplastic disease of the liver.

The ability to accurately read RUQ ultrasound images is critical for any physician who interprets these studies, but it is unclear how many ultrasounds an individual must perform before accurately interpreting images of the gallbladder. In this study, we found that all groups except for PGY-1 residents accurately interpreted the ultrasound images. As would be expected, the ability to accurately interpret the images increased as the average number of RUQ ultrasounds increased. PGY-1 residents averaged 6.68 ultrasounds with a kappa of 0.634, whereas PGY-2 residents averaged 20.9 ultrasounds with a kappa of 0.879. With the exception of one sonographer who misinterpreted two ultrasounds after performing over 30 ultrasounds, all other interpretive errors occurred in individuals who had performed 25 or less. Previous studies have implied that performing 10 ultrasounds may be sufficient, but a more recent study supports 30 ultrasounds before obtaining clinical competency (7,9). Both of these studies focus on interpretive errors only, with no discussion of technical errors.

Unlike most Radiology Departments, where ultrasound images are acquired by technicians, the ability to accurately and completely obtain emergency ultrasound

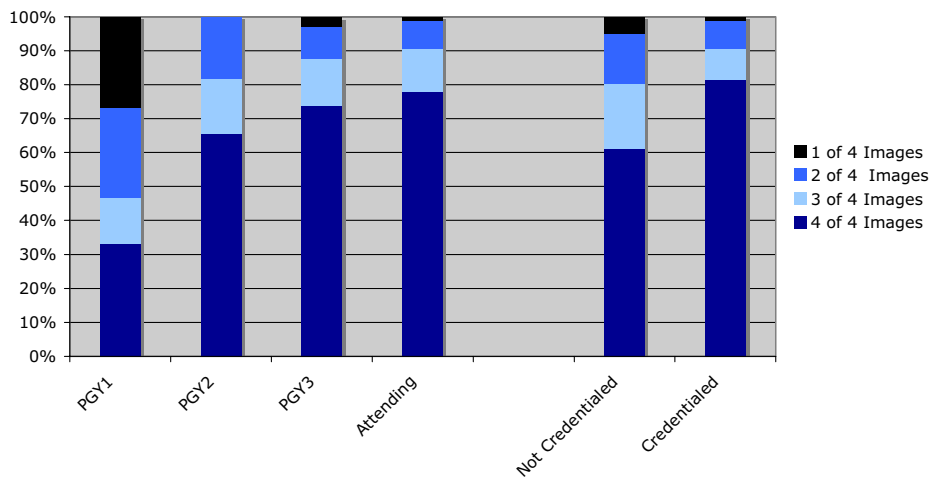

Figure 2. The figure represents the number of required images submitted by sonographers with results separated by experience level. Sonographers who had completed 25 or more right upper quadrant ultrasounds were considered credentialed.

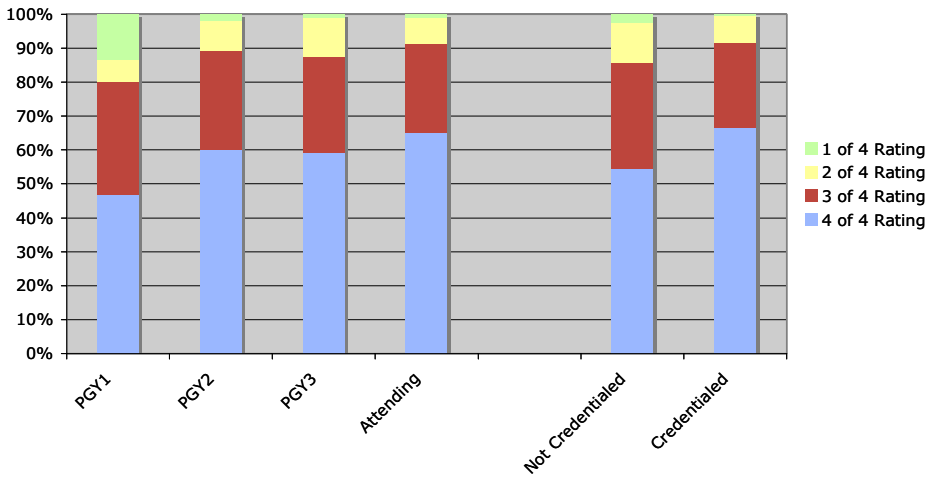

Figure 3. The figure represents the image quality with results separated by experience level. Images were rated on a 4-point scale: 1 = poor image quality, barely interpretable; 2 = adequate image quality; 3 = good image quality; 4 = excellent image quality. Sonographers who had completed 25 or more right upper quadrant ultrasounds were considered credentialed.

images resides with the clinician. This technical skill requires an attention to obtaining the correct images as well as clear images that demonstrate all necessary landmarks. Not obtaining all the required images can easily result in missing pathology or mistaking artifact for pathology that does not exist. Because the patients in the ED are not fasting before presentation, there are times when it is impossible to visualize the entire gallbladder, but every attempt should be made. In this study, only groups that averaged 25 or more ultrasounds (credentialed physicians) demonstrated the ability to obtain most of the required images (3 or 4 out of 4) $>$ 90% of the time.

Many factors impact image quality, some of them outside of the control of the sonographers. Body habitus and fasting state are two major factors beyond the control of the sonographer that result in the degradation of image quality, but obtaining good ultrasound images is also a skill that develops over time. A 3 or a 4 on our 4-point scale allowed easy interpretation of all ultrasound images. Image quality rated as a 2 meant that the decreased image quality potentially impacted the ability of the sonographer to detect pathology. Image quality of a 1 was so poor as to make interpretation of the images extremely challenging. Most ultrasounds were a 3 or 4 at all levels of experience, with even PGY-1 residents imaging over 80% of patients at this level. The percentage of poor ultrasounds decreased significantly after the first year (26% to 1.3%, $p = 0.031$). The percentage of excellent images improved after 25 ultrasounds (67% vs. 54%, $p = 0.026$).

All three types of errors (interpretive, image quality, and image inclusion) improved as the sonographers gained experience. The ACEP emergency ultrasound credentialing guidelines suggest that 25 ultrasounds are sufficient to be clinically competent in limited bedside ultrasonography. However, this is not based on hard science. In our study, we found that performing 25 ultrasounds led to over 80% of the ultrasounds being technically complete, with over 90% of them rated as excellent or good image quality. An argument could be made that 80% of complete ultrasounds is not ideal, but it is hard to say what percentage of non-fasting emergent ultrasounds should have 100% of required images. In some patients it may be impossible to obtain all of the images. Sonographers who had performed over 25 ultrasounds showed excellent agreement with the expert review, with only 2 disagreements, both from a single individual.

Limitations

One possible limitation is that this manuscript does not include a gold standard for the detection of gallstones (e.g., ultrasound by radiology technician). Although this missing data would provide a sensitivity and specificity for the ultrasounds performed in our ED, this was not the purpose of the study. Multiple previous studies have explored the sensitivity and specificity of bedside ultrasonography compared to ultrasounds performed in the Radiology suite. The authors of this manuscript felt that examining the separate technical and interpretive components of the ultrasound provided the information needed to comment on the learning curves of emergency physicians. Stated another way, we wanted to see if they missed seeing gallstones that were evident on their own images. Comparing whether they saw gallstones on their

images to whether an ultrasound technician saw gallstones on a separate set of images confuses technique and interpretation. The comparisons performed in this manuscript isolate the educational components (interpretation and image acquisition) of performing ultrasonography in the ED.

Another limitation relates to the reported findings of the ultrasound. Some sonographers would argue that ultrasound of the RUQ should include identification of findings other than gallstones (e.g., sonographic Murphy's sign, peri-cholecystic fluid, wall thickening, dilatated common bile duct). However, there are no sonographic findings that are sufficient to diagnose cholecystitis without physical examination findings. The presence (or absence) of gallstones was chosen as the sonographic finding to track educational errors as it is considered the primary sonographic finding for ultrasound of the gallbladder in our ED.

CONCLUSION

Our data support the performance of 25 ultrasounds before clinical competency. Image quality improved faster than inclusion of all necessary images.

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