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Original Contributions

THE ASSOCIATION BETWEEN OPERATOR CONFIDENCE AND ACCURACY OF ULTRASONOGRAPHY PERFORMED BY NOVICE EMERGENCY PHYSICIANS

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□ **Abstract—The variable accuracy of emergency department (ED) ultrasound described in the literature has limited its utility as the sole imaging modality in critical decision making. Although ultrasound accuracy is highly dependent upon the technical abilities of the operator and conditions unique to each patient, no previous study of ED ultrasound has included estimates of operator confidence. This prospective observational study explores the association between operator confidence and the accuracy of ED ultrasound. Ultrasound was not performed in our ED until a formal training module was instituted. Patients were enrolled prospectively for the first year following the training module if they underwent one of the following ultrasound studies: abdominal examination for intraperitoneal fluid, right upper quadrant examination for gallstones, renal examination for hydronephrosis, pelvic examination for intrauterine pregnancy, abdominal examination for aorta diameter > 3 cm, or cardiac examination for pericardial fluid. In addition, formal ultrasound, computed tomography, magnetic resonance imaging, or an invasive procedure was required as a "gold standard" for each patient. Operators recorded their interpretation of the ED ultrasound and rated their confidence with the analysis before the formal imaging study or procedure. Test performance characteristics for each examination type and for all studies together were determined. The association between operator confidence and accuracy was explored using logistic regression and by determining test performance characteristics with patients stratified by confidence value. A total of 276 ED ultrasound studies were included. There were no significant differences in accuracy between ED attendings and residents. Overall accuracy, sensitivity, specificity, LR+, and LR− were 90%, 92%, 86%, 6.8, and 0.09, respectively. With confidence scores of 9 or 10 (n = 113), these values improved to 96%, 99%, 90%, 9.6, and 0.01, respectively. Logistic regression revealed an association between confidence and ED ultrasound accuracy ($p < 0.001$). It is concluded that a significant association exists between operator confidence and the accuracy of ED ultrasound. High confidence values are associated with clinically useful test performance characteristics. © 2005 Elsevier Inc.**

□ **Keywords—ultrasonography; operator confidence; diagnosis**

INTRODUCTION

Ultrasonography has become standard practice in many emergency departments (EDs) throughout the country, with most residency programs integrating ultrasound training into their curriculum (1–4). Advantages to ED ultrasound include the rapid diagnosis of life-threatening illnesses and decreased lengths of stay in the ED (5–9). In addition, ultrasound can be used in place of more invasive procedures, such as diagnostic peritoneal lavage in the initial evaluation of unstable multiple trauma victims, and can assist in the placement of central venous access catheters (10–15). Despite the successful integration of ultrasound into the routine practice of emergency medicine, the reported test performance characteristics have generally been inadequate for making critical deci-

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sions without formal diagnostic imaging (3,6–9,16–18). As a result, the role of ED ultrasound in clinical practice remains unclear.

Unlike formal radiologist readings for computed tomography (CT), magnetic resonance imaging (MRI), and ultrasound studies, which are generally considered "definitive" for the purpose of clinical decision-making, interpretation of ED ultrasound may be less reliable for a variety of reasons. First, an emergency physician (EP) generally has considerably less experience than an ultrasound technician in performing ultrasonography or a radiologist in interpreting these studies. In addition, ED ultrasound is highly dependent upon the technical abilities of the ultrasonographer as well as the physical characteristics of the patient and the patient's ability to cooperate with the examination (15). All of these have led to lower overall reported values for sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) (3,6–9,16–18). On the other hand, the ED ultrasonographer is in the unique position of being aware of his or her own experience as well as the technical limitations associated with a particular examination. Thus, operator confidence with the study interpretation should be considered when deciding whether to rely exclusively on the ED ultrasound, but has not been investigated previously. We hypothesized that an association exists between operator confidence and ED ultrasound accuracy and that use of an appropriate threshold confidence value could result in clinically useful test performance characteristics.

METHODS

Study Design

This was a prospective, observational study. Waiver of consent was granted by our investigational review board.

Study Setting and Population

This study was conducted in an urban university hospital with approximately 40,000 annual ED visits. Ultrasound was not performed in our ED before the trial period. Thus, the participating physicians were novice sonographers.

Study Protocol

A departmental training program was instituted before the trial, with ED personnel required to be "certified" by completing this program to perform ultrasound. Even after certification, however, physicians were instructed not to rely exclusively on the ED ultrasound but instead to obtain a formal radiographic study for confirmation. The training program included a lecture on ultrasound physics, slide-based instruction on each of the included ultrasound examinations as defined below, and a practicum using live models with positive findings for each examination. In addition to the initial training program, educational resources including an original instruction manual, CD-ROM, and emergency ultrasound textbooks were placed in the ED for reference. Data collection sheets used for the study also included definitions of a positive study result for reference during the ED ultrasound examinations.

Certified resident and attending emergency physicians were instructed to collect data from all eligible ultrasound examinations for 12 months after the initial training program. The following ultrasound studies were included: 1) abdominal ultrasound to determine the presence or absence of intraperitoneal fluid; 2) cardiac ultrasound to determine the presence or absence of pericardial fluid; 3) right upper quadrant abdominal ultrasound to determine the presence or absence of gallstones; 4) pelvic ultrasound (transabdominal or transvaginal) to determine the presence or absence of an intrauterine fetus or gestational sac in a pregnant female; 5) renal ultrasound to determine the presence or absence of hydronephrosis; and 6) abdominal ultrasound to determine whether the aortic diameter is > 3 cm or ≤ 3 cm. Confirmation of ED ultrasound results by formal ultrasonography, CT, MRI, or invasive procedure was also required for inclusion. The invasive procedure had to result in a definitive diagnosis in order to serve as a confirmatory test. A single patient could undergo ultrasound examination by more than one physician if operators were blinded to previous interpretations.

Outcome Measures

Standardized data collection sheets were created for each of the six studies defined above. Collected data included: patient demographics, interpretation of the ED ultrasound with regard to the six specific determinations as defined above, other abnormal findings noted on the examination and a posttest confidence estimate by the physician (on a scale from 1 to 10). In addition, one or more representative images were printed and attached for assessment of image adequacy as determined by our ultrasound coordinator in consultation with a designated ultrasound technician from the radiology department. The formal radiology interpretation or invasive procedure notes were also recorded on the same data collection sheet once the final results were entered into the

medical record. Only invasive procedures in which a definitive diagnosis was rendered were considered. These results were used as the gold standard in determining the correctness of the ED ultrasound interpretation with regard to the six specific determinations as defined above. Data were entered into an Excel (Microsoft Corp., Redmond, WA) spreadsheet for further analysis.

Data Analysis

The overall accuracy, sensitivity and specificity, and likelihood ratios for a positive (LR+) and negative (LR−) test were calculated for all examinations together and following stratification into each of the six ultrasound study types defined above. The primary goal of this analysis was to determine the relationship between operator confidence and the accuracy of ED ultrasound. Logistic regression was performed modeling the following variables: study type, study number, image adequacy as determined by our ultrasound coordinator, the results of the final diagnostic study interpretation (positive or negative), and operator confidence. The study number was defined as the cumulative number of a particular ultrasound study type performed by each physician, stratified into two groups (the first through fifth studies and the sixth study and higher). In addition, test performance characteristics were calculated for all patients stratified by confidence value. Linear regression was used to test for the influence of study month on ED ultrasound accuracy. Finally, incorrect ultrasound determinations were cataloged by examination type and whether they were false positive or negative. StatsDirect™ (StatsDirect Software Inc., Ashwell, UK) was used for all statistical calculations.

RESULTS

In the 12-month study period, a total of 276 eligible ultrasound studies were submitted by emergency physicians for inclusion in the trial. A total of 12/14 full-time attendings performed 54% of studies, and 16/18 residents performed the remaining 46%. This included residents from the second, third, and fourth postgraduate years. None of the participants had substantial prior experience with ED ultrasound. Examination number frequencies are displayed in Table 1.

The total number, percent positive, and test performance characteristics are displayed for all studies stratified by study type (Table 2) and confidence value (Table 3). No statistically significant differences were observed with regard to overall accuracy for attending vs. resident physicians (Table 4). Logistic regression analysis revealed a statistically significant association between operator confidence and accuracy when controlling for examination number, examination type, image adequacy, and formal diagnostic study interpretation (Table 5). No relationship was observed between study month and ultrasound accuracy (r = −0.04; 95% confidence interval [CI] = 10.16 to 0.08; p = 0.494). The incorrect ultrasound determinations are cataloged in Table 6.

Table 1. Examination Number Frequencies for all Ultrasound Examinations Included in this Analysis (n = 276)

Exam #	%
1	30
2	17
3	11
4	7
5	6
6–10	15
11+	15

Note: Examination number was defined as the cumulative number of a particular study type performed by each physician.

DISCUSSION

We document our experience over the first 12 months after the introduction of ED ultrasound in our institution. Although our overall test performance characteristics are similar to previous reports, this analysis is unique for several reasons. We employed a "gold standard" that required every eligible patient to undergo formal ultrasound, CT, MRI, or an invasive procedure. More importantly, we explored the relationship between operator confidence and the accuracy of ED ultrasound using multiple different analytic approaches. Logistic regression revealed operator confidence to be highly associated with overall accuracy while controlling for study type, image adequacy, examination number, and the formal diagnostic study interpretation. In addition, confidence scores of 9 or 10 were present in almost half of all patients and resulted in test performance characteristics that were adequate to support clinical decision-making based solely on the ED ultrasound.

The overall sensitivity values reported here are similar to those presented in previous investigations. Mandavia et al. documented 92%, 96% specificity, 94% PPV, and 95% NPV for 1138 ED ultrasound examinations performed by emergency medicine residents following a standardized training program (3). Their "gold standard," however, was a review of printed images from each examination by an EP experienced in ED ultrasound and a certified ultrasound technician. Lanoix et al. docu-

Table 2. Test Performance Characteristics by Study Type

Exam type	n	% Pos	Accuracy	Sensitivity	Specificity	LR+	LR−
Aorta	11	45	100 (72–100)	100 (48–100)	100 (54–100)	N/A	0.0 (0.0–0.49)
Pericardial fluid	7	71	86 (42–100)	100 (48–100)	50 (1–99)	2.0 (0.7–9.7)	0.0 (0.0–1.3)
IUP	70	74	100 (95–100)	100 (93–100)	100 (81–100)	N/A	0.0 (0.0–0.07)
Hydronephrosis	25	56	84 (64–95)	93 (66–100)	73 (39–94)	3.4 (1.6–9.6)	0.10 (0.02–0.47)
Gallstones	105	59	83 (74–90)	81 (69–90)	86 (72–95)	5.8 (2.9–12.4)	0.22 (0.13–0.37)
Intraperitoneal fluid	58	60	93 (83–98)	100 (90–100)	83 (61–95)	5.8 (2.7–14.1)	0.0 (0.0–0.12)
Total	276	63	90 (86–93)	92 (87–96)	86 (78–92)	6.8 (4.3–11.2)	0.09 (0.05–0.14)

mented an overall sensitivity and specificity of 90% and 89%, respectively, for 230 ED ultrasound examinations performed by EPs after a 4-h training course; they used several different "gold standards," including the results of a formal radiographic study, clinical follow-up, and a radiologist or cardiologist review of examination videotape (16). Interestingly, the accuracy of ED ultrasound was no better with more experienced operators, although the accuracy over time was not explored. Schlager et al. reported an overall sensitivity and specificity of 95% and 98%, respectively, in 132 patients undergoing 11 different types of ED ultrasound examination (17).

Several investigators focused on a particular study type. Durham et al. documented 96% accuracy for ED ultrasound in the evaluation of intrauterine pregnancy (IUP), using review of videotaped examinations and clinical follow-up as the "gold standard" in most patients (8). Mateer et al. studied 148 patients undergoing ED ultrasound for IUP and documented 94% agreement by a gynecologist reviewing videotapes of the procedure; interestingly, the EP interpretation was ultimately determined to be correct based on clinical follow-up in most of the cases in which the gynecologist and EP disagreed (18). This same group observed a dramatic decrease in the rate of missed ectopic pregnancy following institution of a protocol for ED endovaginal ultrasound (19). Blaivas et al. documented a shorter length of stay in the ED for 753 patients undergoing ED ultrasound as compared to 489 patients receiving a formal ultrasound, but they did not attempt to determine accuracy values (5). Others have reported similar findings in patients being evaluated for pericardial tamponade, ectopic pregnancy, and ruptured abdominal aortic aneurysm (6–9). Henderson et al. reported 97% sensitivity for ED ultrasound and plain radiography in 108 patients being evaluated for renal colic using IVP as the "gold standard" (2). Two investigators document improved clinical outcomes with use of ED echocardiography but did not attempt to calculate test performance characteristics (20,21).

Defining an appropriate threshold value for the sensitivity or overall accuracy of ED ultrasound is difficult, and factors such as pretest probability, the severity of the illness in question, and the consequences of a delay to diagnosis must be taken into consideration. A sensitivity value of 93% might be appropriate for the diagnosis of hydronephrosis and renal calculi, but not for a potentially catastrophic disease such as abdominal aortic aneurysm. Conversely, the sensitivity of 99% and LR+ value of 9.6 with higher confidence values of 9 or higher are applicable in the workup of virtually any disease and are consistent with commonly accepted definitions for a clinically useful test (22). Because of our relatively small sample sizes for any one particular study type, the confidence values reported here are somewhat wide, underscoring the need to validate these results with additional studies, potentially through a consortium of EDs. Additional data will allow the threshold confidence value for optimal test performance to be defined and the proportion of eligible studies to be

Table 3. Test Performance Characteristics by Operator Confidence

Confidence	n	% Pos	Accuracy	Sensitivity	Specificity	LR+	LR−
10	75	80	99 (93–100)	100 (94–100)	93 (68–100)	15.0 (3.3–83.6)	0.0 (0.0–0.06)
9	38	63	92 (79–98)	96 (79–100)	86 (57–98)	6.7 (2.4–23.9)	0.05 (0.01–0.24)
8	63	56	89 (78–95)	89 (73–97)	89 (72–98)	8.3 (3.2–24.0)	0.13 (0.05–0.29)
7	32	56	91 (75–98)	94 (73–100)	86 (57–98)	6.6 (2.3–23.6)	0.06 (0.01–0.31)
6	20	60	85 (62–97)	92 (62–100)	75 (35–97)	3.7 (1.5–12.9)	0.11 (0.02–0.53)
5	30	57	77 (58–90)	71 (44–90)	85 (55–98)	4.6 (1.5–16.7)	0.35 (0.15–0.70)
4 or less	4	0	50 (7–93)	N/A	50 (7–93)	0.0 (0.0–3.8)	0.0 (0.0–3.8)
Not noted	14	50	93 (66–100)	86 (42–100)	100 (59–100)	N/A	0.14 (0.03–0.58)
Total	276	63	90 (86–93)	92 (87–96)	86 (78–92)	6.8 (4.3–11.2)	0.09 (0.05–0.14)
7 or higher	208	66	94 (90–97)	96 (91–98)	89 (79–95)	8.4 (4.6–16.4)	0.05 (0.02–0.10)
9 or higher	113	74	96 (91–99)	99 (94–100)	90 (73–98)	9.6 (3.7–27.6)	0.01 (0.0–0.07)

Table 4. Attending vs. Resident Emergency Physician Ultrasounds by Study Type

Exam Type	n	% Pos	Accuracy	*P* Value
Aorta				
Attending	7	43	100	> 0.999
Resident	4	50	100	
Pericardial fluid				
Attending	5	80	80	0.495
Resident	2	50	100	
IUP				
Attending	31	68	100	> 0.999
Resident	39	79	100	
Hydronephrosis				
Attending	15	53	87	0.656
Resident	10	60	80	
Gallstones				
Attending	56	52	80	0.467
Resident	49	67	86	
Intraperitoneal fluid				
Attending	36	61	94	0.606
Resident	22	59	91	
Total				
Attending	150	58	89	0.590
Resident	126	68	91	

determined. In addition, these data were obtained in novice sonographers, and the effect of experience on both confidence and accuracy should be determined.

Multiple factors contribute to confidence in a particular ultrasound examination. Experience is likely important with regard to both confidence and accuracy, justifying the use of a minimum number of examinations for ultrasound certification. We did not, however, observe an association between accuracy and cumulative examination number or study month, although 1 year may not be long enough for novice sonographers to acquire appropriate experience with ED ultrasound. In addition, personality characteristics of the various ultrasonographers were not considered but may affect the relationship between accuracy and confidence. Ultimately, we were unable to control—or even measure—this factor, but our inclusion of multiple emergency physicians of various levels of training may have controlled for variability in personality type to some degree. Furthermore, factors that are independent of operator experience, such as obesity, anatomical variation, excessive bowel gas, failure to cooperate with the examination, and factors specific to study type including gestational age or intra-abdominal fluid volume, may be equally important with regard to both confidence and accuracy.

Table 5. Logistic Regression Model Investigating the Effect of Examination Number, Image Adequacy, Formal Diagnostic Study Interpretation, and Operator Confidence on Accuracy

Parameter	Adjusted OR (95% CI)	*p* Value
Examination number	0.46 (0.18–1.22)	0.120
Image adequacy	4.38 (0.60–32.07)	0.146
Formal study result	1.21 (0.47–3.07)	0.695
Confidence	1.60 (1.22–2.10)	< 0.001

Examination numbers were stratified into the first through the fifth and the sixth and greater for each study type performed by individual physicians. Odds ratios and *p* values were calculated, adjusting for each of the above factors as well as study type.

Table 6. Incorrect ED Ultrasound Interpretations

Examination	n	Median pretest probability	Median confidence value
Pericardial fluid			
False positive	1	4	7
Renal			
False positive	3	8	8
False negative	1	5	5
Gallstones			
False positive	6	8.5	8.5
False negative	12	4	7
Intra-peritoneal fluid			
False positive	4	5	5.5

These data must be viewed in light of the study limitations. Although we were able to enroll almost 300 patients in the study, the use of a more rigorous "gold standard" for each patient limited the sample size, especially with regard to certain study types. This illustrates the need for a multi-center consortium that can provide adequate statistical power to determine whether the application of a confidence threshold allows the safe use of ED ultrasound as a sole imaging modality. Because ultrasound was not performed previously in our department, this study reflects the association between confidence and accuracy in a group of novice sonographers. It is possible that experience increases accuracy and should be explored in future studies. Experience may also influence confidence with a particular study, with inexperienced sonographers susceptible to false elevations in confidence due to an incomplete understanding of the limitations of the modality.

In addition, some form of selection bias may have been present. Although the protocol requested that all patients undergoing formal ultrasound, CT, MRI, or some other confirmatory procedure be enrolled, some EPs may not have submitted ED ultrasound examinations for inclusion. Our physicians did not appear to be selecting examinations with high confidence values for submission, however, as more than half of all examinations included had values below 9. Finally, the pretest probability was not included in our statistical analysis but may play an equally important role in the accuracy of ED ultrasound and should be used in combination with likelihood ratios for clinical decision-making.

Ultimately, however, we believe this study is valuable

in documenting the importance of operator confidence in the accuracy of ED ultrasound. Unlike other imaging modalities used by ED physicians, bedside ultrasonography is both dependent upon—and provides immediate feedback regarding—the skill of the examiner, specific technical characteristics of a particular examination, and the quality of images obtained. Further exploration of this factor may result in appropriate values for sensitivity, specificity, PPV, and NPV to allow reliance on ED ultrasound as a sole imaging modality.

CONCLUSIONS

Previous studies evaluating the accuracy of ED ultrasound have failed to consider operator confidence values despite the technical challenges involved in this procedure and the unique position of the sonographer to judge the technical adequacy of an individual study. Here we document our experience with ED ultrasound over the first 12 months after institution of an ultrasound program. Although our overall test performance characteristics are similar to previous reports, the integration of operator confidence into the analysis and documentation of its relationship to ED ultrasound accuracy are unique. These data support the use of ED ultrasound for clinical decision making in examinations only when associated with a high value for operator confidence.

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