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Original Contributions

ULTRASONOGRAPHIC MEASUREMENT OF AORTIC DIAMETER BY EMERGENCY PHYSICIANS APPROXIMATES RESULTS OBTAINED BY COMPUTED TOMOGRAPHY

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☐ **Abstract—To assess agreement between emergency physicians' measurements of abdominal aortic diameter using ultrasound in the Emergency Department (ED) and measurements obtained by computed tomography (CT), a double-blinded, prospective study was conducted. The study enrolled a convenience sample of patients over 50 years of age presenting to the ED and scheduled to undergo CT scan of the abdomen and pelvis. Before CT scan, each patient received an ultrasound from a resident or attending emergency physician measuring anterior-posterior aortic diameter transversely at the approximate level of the superior mesenteric artery (SMA), longitudinally midway between the SMA and the iliac bifurcation, and transversely approximately 1 cm above the iliac bifurcation. Two radiologists blinded to the ultrasound measurements then independently measured aortic diameters at the corresponding anatomical points as imaged by CT. The ultrasonographic measurements were then compared with an average of the two CT measurements. Forty physicians enrolled a total of 104 patients into the study. Ultrasonographic measurements of aortic diameter were slightly smaller than those obtained by CT scan, with a difference of means of −0.39 cm (95% CI −0.25 to −0.53) at the level of the SMA, −0.26 cm (95% CI −0.17 to −0.36) on longitudinal view, and −0.11 cm (95 % CI −0.01 to 0.22) at the bifurcation. At the level of the SMA, the difference in measurements by ultrasound and CT would be expected to be less than 1.41 cm, 95% of the time. At the bifurcation, we expect 95% of the differences to be less than 1.05 cm. Agreement was closest on longitudinal view, with 95% of the differences expected to be less than 0.94 cm. Participating physicians estimated the time required to complete their ultrasound studies to be less than 5 min in a majority of cases. In conclusion, ultrasonographic measurement of aortic diameter by emergency physicians rapidly and effectively approximates measurements obtained by CT scan.** **© 2005 Elsevier Inc.**

☐ **Keywords—abdominal aorta; computed tomography; emergency physicians; measurement; ultrasound**

INTRODUCTION

Ruptured abdominal aortic aneurysm (AAA) claims approximately 8700 lives per year in the United States (1). The overall incidence of AAA has increased over the past few decades in spite of a downward trend in mortality from coronary and cerebrovascular disease (1,2). Current estimates of the prevalence of AAA in persons over the age of 50 years range from 1% to 5% (3–6).

In the non-acute setting, early detection of AAA is imperative to improve long-term survival. Rupture of aneurysms less than 4 cm in diameter is a rare occurrence, but the expansion rate and the risk of rupture increase exponentially over time once the diameter of the AAA exceeds that measurement (7,8). Importantly, as many as two-thirds of AAAs go unrecognized before rupture, with overall mortality rates approaching 90%

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once this disaster has occurred (3,9–12). If, on the other hand, AAA is diagnosed early and repair undertaken at the appropriate elective time, patients' long-term survival approximates that of the general population (13,14).

The importance of ultrasonography in the detection of AAA is well established. Studies in the radiologic literature cite a sensitivity of ultrasound for the detection of AAA between 95% and 98% with results typically reproducible within 0.6 cm (2,15–19). A recent study by Kuhn et al assessed the ability of emergency physicians to diagnose AAA qualitatively in the appropriate clinical setting and postulated that Emergency Department (ED) ultrasonography performed by emergency physicians can be an effective screening instrument for identifying patients with AAA and ensuring appropriate treatment and follow-up (20). With this in mind, we set out to evaluate, prospectively and quantitatively, the degree to which ultrasonographic measurements of aortic diameter at prespecified anatomic points and planes by emergency physicians agree with corresponding measurements obtained by computed tomography (CT) scan.

MATERIALS AND METHODS

We conducted a double-blinded, prospective study using a convenience sample of patients presenting to our ED to evaluate the ability of emergency physicians to measure abdominal aortic diameter with ultrasound. An institutional review board examined and approved the study protocol before the initiation of any patient enrollment.

The study enrolled patients aged 50 years or older presenting to the ED with a complaint of abdominal pain and scheduled for abdominal and pelvic CT scan with intravenous contrast as part of their clinical evaluation. All resident and attending physicians were asked to enroll patients in the study on a 24 h, 7 day per week basis, and enrollment was based on random convenience according to the practical constraints of patient care in a busy urban ED. The participating ED receives approximately 55,000 visits per year drawn from a predominantly urban patient population. As the home institution for a residency in Emergency Medicine, the ED is staffed by attending physicians and by resident physicians engaged in training at the second through fourth postgraduate year level. During the time of this study, each resident participated annually in formal didactic and hands-on teaching in ultrasonography that included at least 2 h of lecture and 3 h of in-service training in basic transabdominal techniques. Patients were studied initially over a 14-month period before an institution-wide freeze on all research activity precluded further patient enrollment for 9 months. Following this, patients were once again entered into the study over a 12-month span.

Before undergoing abdominal and pelvic CT scan, each enrolled patient received an ultrasound examination to measure the diameter of the abdominal aorta at prespecified anatomical sites, from either an attending or resident Emergency Medicine physician. Each physician entering a patient into the study performed the ultrasound without direct supervision. Two radiologists, both blinded to the ultrasound results, then independently measured aortic diameter on the subsequent CT scan at sites agreed upon before the initiation of the overall investigation and corresponding to the measurements obtained ultrasonographically in the ED. Patients were excluded from the study if a risk existed of substantive deterioration in clinical status over the time needed to complete the ultrasound or if the patient declined to participate.

All of the ultrasounds were performed using a Toshiba 140-A model with color flow Doppler capability. Physicians enrolling patients in the study were asked to utilize ultrasound to identify two anatomic points along the abdominal aorta: the take-off of the superior mesenteric artery (SMA) and the iliac bifurcation. They were then expected to measure aortic anterior-posterior diameter with the ultrasound transducer in transverse orientation at the level of the SMA and at a point estimated as 1 cm above the iliac bifurcation. An additional measurement was taken with the transducer in longitudinal orientation between the SMA and bifurcation (2,7,21–23). Ultrasonographic measurements were taken from inner wall to inner wall. CT measurements, on the other hand, were taken from outer wall to outer wall in accordance with the standard practice within the field of Radiology. Physician ultrasonographers recorded their results both on a specified data sheet and by generating a photographic reproduction of the images obtained. Patients were asked to provide estimates of their height and weight and, where possible, this information was recorded. Physicians were asked to report their level of training and an estimate of the time needed to complete their attempts at the three measurements on a scale of less than 5 min, 5–10 min, 10–15 min, and greater than 15 min.

The subsequent CT studies were helical scans with 5–8 mm collimation. Using calipers, each radiologist independently measured aortic diameter at the designated anatomic sites while blinded to both the ultrasound measurements and the measurements made by the other participating radiologist. CT measurements from each radiologist were averaged, with the ultrasound measurements being compared with that average for data analysis.

Data were entered into Microsoft Excel for Windows

(Microsoft Corporation, Redmond, WA). Agreement, or lack thereof, between measurements obtained by ultrasound and CT was assessed on the basis of difference and variability in congruence with the technique described by Bland and Altman (24). By this method, the mean difference between ultrasound- and CT-measured diameters serves as the estimated bias, or the systemic difference between the two modalities, and the standard deviation of the differences represents random variability around that mean. Ninety-five percent limits of agreement were calculated as the mean difference +/− (1.96 × SD), signifying the range within which the difference between CT and ultrasound measurements of aortic diameter would be expected to fall 95% of the time (24,25). Scatter plots of that data for each anatomical site were generated and are presented herein. Analyses of differences were two-tailed utilizing SPSS for Windows, Version 10.0.1 (SPSS Inc., Chicago, IL), with *t*-tests for paired samples statistics and significance generated along with 95% confidence intervals where appropriate. Fisher's exact test was utilized to generate negative and positive predictive values for ultrasound to identify AAA when compared with measurements obtained by CT.

RESULTS

A total of 104 patients participated in the study. The average patient age was 68.6 years (range 50 to 99 years, SD 10.4), and 51% of those enrolled were male. Height and weight were recorded for 71 patients (68.3%). For each of these, body mass index (BMI) was calculated as height in meters squared divided by weight in kilograms, with values 25 or greater defined as overweight and those equal to or greater than 30 defined as obese in the United States according to the National Center for Health Statistics (NCHS) (26). The average body mass index (BMI) for this portion of the study population was 27.3 with a range of 17 to 51 and a SD of 6.4. Among those for whom a BMI was calculated, 60.6% met criteria for being overweight, and 32.4% were obese. In comparison, National Center for Health Statistics (NCHS) statistics for the year 2000 report that 64% of the general adult population is overweight, and 30% is obese (26).

Forty physicians enrolled patients into the study. Three attending physicians entered a total of 31 patients, 18 physicians at the fourth post-graduate year level entered a total of 30 patients, 18 physicians at the third post-graduate year level entered a total of 26 patients, and 11 physicians at the second post-graduate year level of training entered a total of 17 patients. Physicians participating in the study identified and measured anterior-posterior (AP) aortic diameter at the level of the SMA in 100 of the 104 enrolled patients (96.2%). AP measurements on longitudinal view were taken in 103 patients (99.0%). AP measurements at the designated point above the iliac bifurcation were recorded for 98 patients (94.2%). Failure to record a measurement for a particular anatomical point on the data sheet was presumed to be due the participating ultrasonographer's failure to identify the aorta for measurement at that site.

Estimates of the time needed to complete the measurement attempts were listed for 97 of the 104 patients (93.3%). Sixty-seven of the patient entries (69.1%) were listed as requiring less than 5 min to complete, 27 of the cases (27.8%) required an estimated 5 to 10 min to complete, and 3 cases (3.1%) were recorded as necessitating between 10 and 15 min (3.1%). No study was listed as lasting more than 15 min.

Five patients in this group (4.8%) were diagnosed with AAA by CT, with AAA defined as either an infrarenal abdominal aortic diameter greater than 3.0 cm or a suprarenal to infrarenal ratio of aortic diameter greater than 1.5. ED ultrasound correctly identified AAA in each of these 5 cases. In addition, 4 patients over the course of the study period presented with clinical signs of a ruptured AAA that was subsequently diagnosed by an emergency physician-performed ultrasound. They were excluded from the study because they proceeded directly to the operating suite without CT scan being performed. Findings at laparotomy confirmed the diagnosis in each of these cases. One case occurred in which the ED ultrasound measurements significantly exceeded the values obtained by CT at all three designated measuring points. A review of the patient's hospital record and the recorded ultrasound image revealed that the structure measured by the participating physician was in fact the inferior vena cava in which a Greenfield filter had been placed. This case was included in the determination of positive and negative predictive powers of ultrasound in diagnosing AAA when compared with CT scan. Because the ultrasound measurements in this case were of a structure other than the aorta, they were not incorporated into the analysis of agreement between ultrasound and CT. Two other instances of ED ultrasound yielding measurements that would have falsely identified AAA when compared with the corresponding CT measurements occurred, once at the level of the SMA, and once on the longitudinal view. No ultrasounds that were falsely negative for AAA were generated in the study. Positive and negative predictive values for ED ultrasound for diagnosing AAA at each measuring site are presented in Table 1.

Table 2 contains comparative mean data for the two imaging modalities at each anatomic site with 95% CI.

Bland-Altman plots of the difference between each averaged CT measurement of abdominal aortic diameter and the corresponding ED ultrasound measurement

Table 1. Positive and Negative Predictive Values for AAA by ED Ultrasound as Compared with CT

	Positive predictive value (95% CI)	Negative predictive value (95% CI)
SMA	0.00 (0.00–0.46)	0.99 (0.94–0.99)
Longitudinal	0.67 (0.22–0.96)	0.99 (0.94–0.99)
Bifurcation	0.80 (0.28–0.99)	1.00 (0.96–1.00)

against the averaged measurements of the two modalities are presented in Figures 1, 2, and 3. At the level of the SMA, the limits of agreement were −1.01 to 1.79 cm. The difference between CT measurement of aortic diameter and ultrasound measurement by emergency physicians at this site would therefore be expected to be less than 1.41 cm (1.96 × SD) 95% of the time. The limits of agreement for longitudinal measurements were −0.68 to 1.20 cm, indicating that measurement differences between the two modalities at this site should be less than 0.94 cm 95% of the time. Lastly, at the bifurcation the limits of agreement ranged from −0.94 to 1.16, signifying that measurement differences between CT and ultrasound at that level of the aorta would be expected to be less than 1.05 cm 95% of the time.

Data comparing ultrasound values to those obtained by CT at all points of measurement for physicians at each level of training are presented in Table 3.

DISCUSSION

A number of factors render the direct comparison of aortic diameter measurement by ultrasound with that by CT to be problematic. There is no gold standard for measuring aortic diameter. Static CT images may overestimate true aortic diameter in vessels that are oblique to the axial imaging plane (25,27). Moreover, interobserver variability in measurements obtained by CT alone has been reported to range from 0.28 to 0.7 cm (15,16,25,28). At the same time, interobserver variability in measurements obtained by ultrasound are reported in the literature to range from 0.22 to 1.55 cm in the hands of experienced ultrasonographers (15,16,18,29,30). Precise correlation between the two modalities is not possible because of the real time variation in aortic diameter according to systolic and diastolic phases of pulsatile flow through the vessel and the simple fact that exact matching of the anatomic points and planes of measurement is not possible when moving from one imaging modality to the other. Some lack of agreement between measurements by the two imaging modalities is therefore inevitable and well-reported in the literature (15,16,19,25).

Overall, aortic diameters obtained by ED ultrasound in this study slightly underestimated the corresponding measurements by CT, a phenomenon noted frequently in the literature (16,17,31). Several factors may account for this. As noted above, the ED ultrasounds performed in this study measured aortic diameter from inner wall to inner wall, whereas CT measurements were from outer wall to outer wall. In our experience, newly trained ultrasonographers tend to isolate the interface between the aortic lumen and inner wall as a more easily identified measuring point than the transition from the outer aortic wall to surrounding adventitial tissue, a factor that has been cited in the literature on ultrasonography based (22,32–34). This practice has been criticized as dangerous based on the theory that an intralumenal clot within a clinically significant AAA might confound an inexperienced ultrasonographer into measuring a pseudolumen and thus generating a falsely low measurement of overall aortic diameter. Our goal in this study, however, was to compare the measurements obtained by relatively inexperienced emergency physicians performing unsupervised ultrasounds with results obtained by CT. Consideration for the overall thickness of the aortic wall at two points in the span of vessel diameter must therefore factor into any difference in results. In addition, the potential exists for CT to overestimate actual aortic diameter for the reasons outlined earlier.

Still, our data indicate that emergency physicians at varied levels of training can measure abdominal aortic diameter rapidly using ultrasound in the ED with results that show reasonable agreement with measurements obtained by CT. The majority of the ultrasound studies were estimated to have been performed within 5 min, highlighting the rapidity with which this useful clinical information can be gained in the ED setting. Agreement between ultrasound and CT scan was poorest at the level of the SMA. However, agreement between ED ultra-

Table 2. Comparison of US versus Averaged CT Measurement Means

	Mean of averaged CT measurements	Mean of US measurements	Relative difference	95% CI
SMA	2.24 cm	1.85 cm	0.39 cm	0.25 to 0.53
Longitudinal	2.00 cm	1.74 cm	0.26 cm	0.17 to 0.36
Bifurcation	1.83 cm	1.72 cm	0.11 cm	0.01 to 0.22

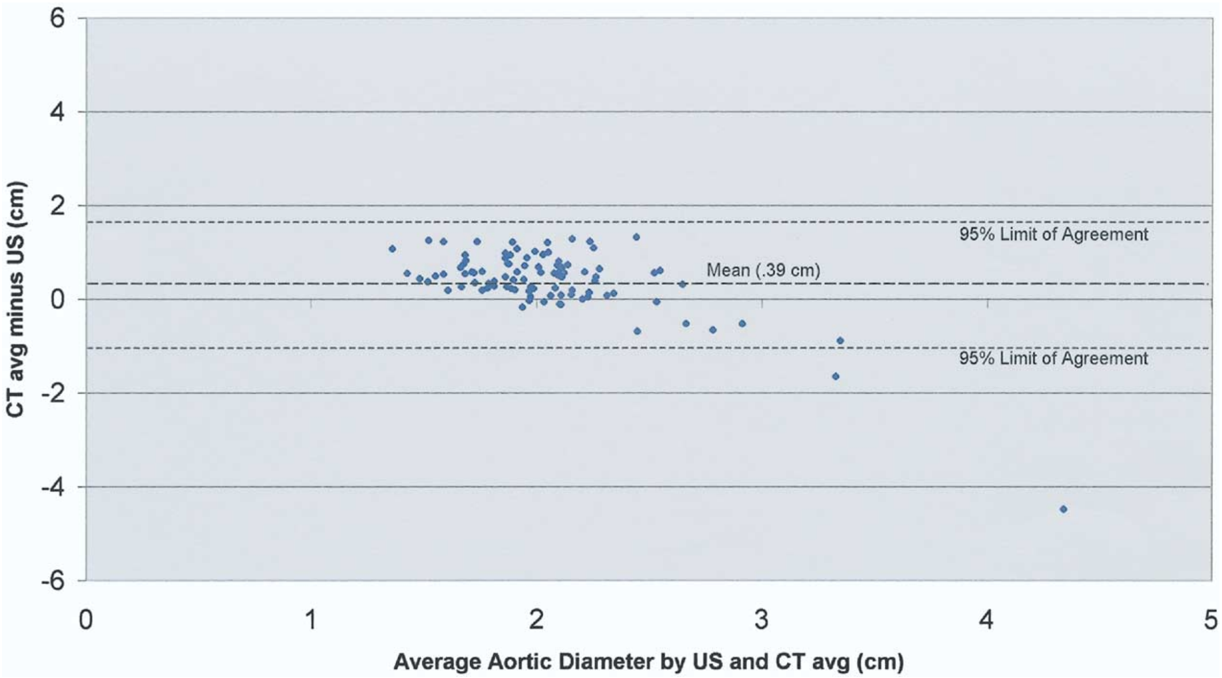

Figure 1. Measurement difference vs. mean aortic diameter (SMA).

sound and CT scan was greatest with regard to measurements performed longitudinally and on transverse view just above the iliac bifurcation where the diagnosis of AAA is most critical. At these two sites, our data indicate that measurements obtained by ED ultrasound would fall within 0.94 cm and 1.05 cm, respectively, of the corresponding CT scan measurements 95% of the time.

Is this degree of agreement acceptable in the clinical setting? A 1-cm discrepancy between imaging modalities may be considered unacceptable in tracking

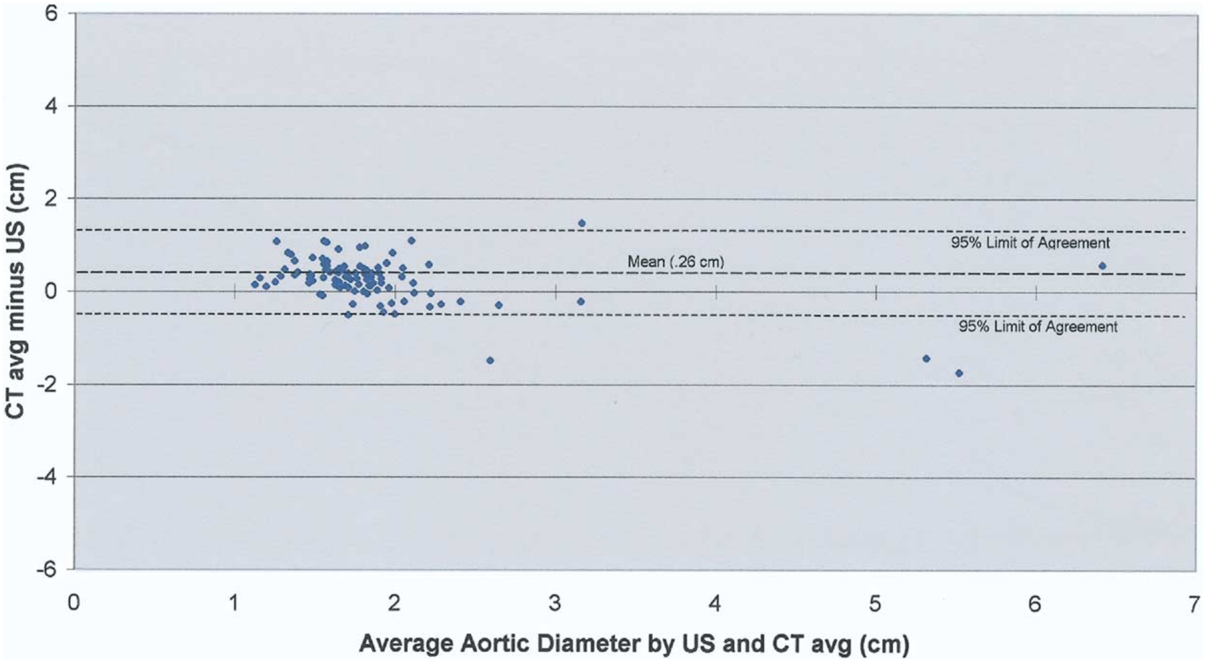

Figure 2. Measurement difference vs. mean aortic diameter (longitudinal).

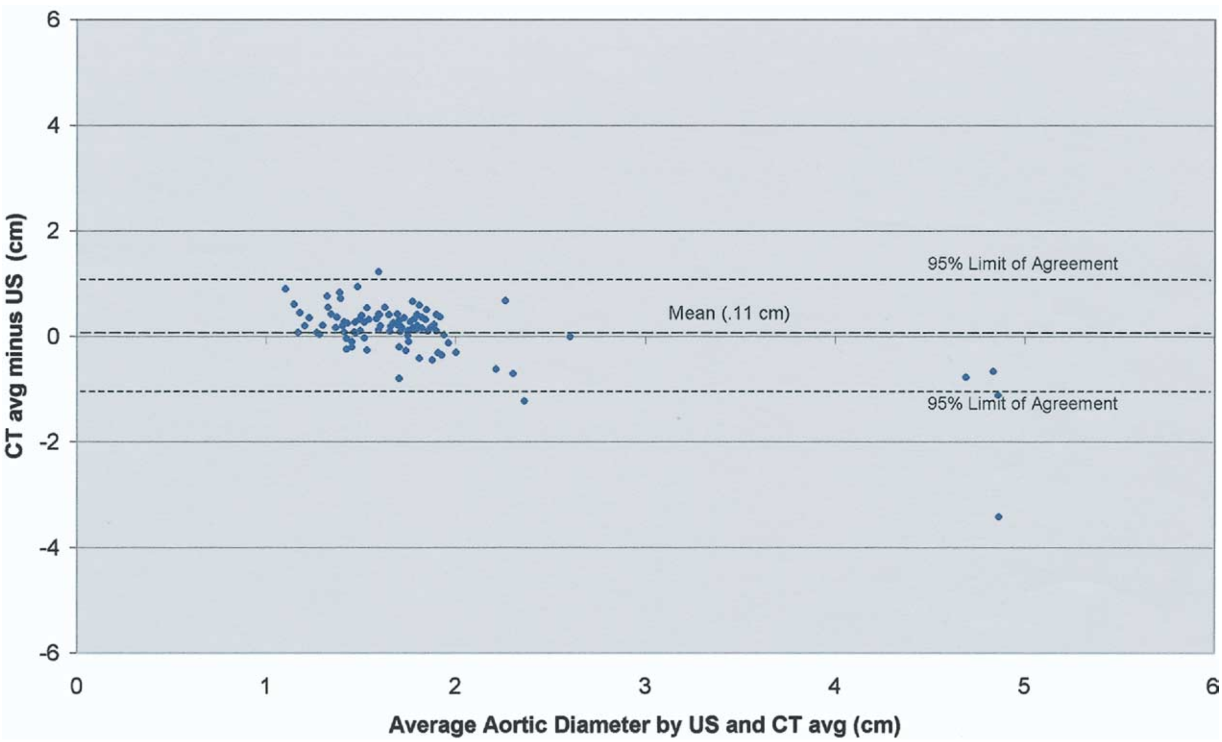

Figure 3. Measurement difference vs. mean aortic diameter (bifurcation).

the rate of expansion for a known AAA. In the ED, however, the primary goal is the simple identification of an aneurysmal aorta for the purposes of immediate surgical intervention, further diagnostic imaging, or appropriate referral for longitudinal surveillance. It is important to note that the ultrasounds performed as part of this study identified 5 out of 5 patients eventually proven to meet anatomic criteria for AAA by CT scan. An additional 4 patients presenting to our ED with clinical signs of ruptured AAA during the study period were diagnosed with AAA by ED ultrasound but did not meet enrollment criteria because they did not receive a CT scan and were instead taken directly and emergently to Surgery. Intraoperative findings confirmed the diagnosis of ruptured AAA in all four cases. False-positive diagnoses of AAA would have been made on the basis of the ED ultrasound in three of our patients, and this phenomenon occurred most frequently with images taken at the level of the SMA. Each of the three patients, by nature of the study protocol, were deemed clinically stable and allowed to proceed to CT, however, where the potential diagnosis of AAA could be further pursued. Nevertheless, this factor, along with the lesser degree of agreement between ultrasound and CT at this level, would indicate the ultrasound measurements taken at the level of the SMA should be interpreted with great caution.

Lastly, it should be noted that 4.8% of the patients enrolled in this study met diagnostic criteria for AAA on the basis of ultrasound performed within the ED. This finding approximates and perhaps slightly exceeds the prevalence reported by other investigators for this condition among the elderly in the United States (3–6). We therefore concur with the assertion by Kuhn et al. that the potential exists for emergency physicians to participate in the screening of elderly

Table 3. Comparison of US vs. Average CT Scan Results by Level of Training

	# Measurements (SMA, longitudinal, and bifurcation)	Mean of differences, US vs. CT avg.	95% CI	Correlation
PGY-2	39	−0.38 cm	−0.46 to −0.28 cm	.469
PGY-3	75	−0.30 cm	−0.44 to −0.16 cm	.727
PGY-4	87	−0.01 cm	−0.34 to 0.15 cm	.538
Attending	97	−0.16 cm	−0.27 to −0.05 cm	.745

patients for this potentially fatal condition when they present to the ED (20). A structured analysis of the potential cost-benefit of such a screening mechanism is warranted.

LIMITATIONS

This study is limited by the fact that patients were enrolled on a convenience basis. The realities of practice within a busy acute care setting and the 24 h, 7 day per week nature of Emergency Medicine precluded any assurance of enrolling 100% of those patients who met inclusion criteria for the study. A potential selection bias therefore exists, with regard to both those physicians who took the initiative to enter patients in the study and which patients may have been picked for inclusion. Our study population showed wide variation in body mass index, but the convenience basis of enrollment raises the possibility that patients who proved too difficult to scan were simply not entered. Consequently, our results can only be applied to situations in which emergency physicians are able to confidently identify the abdominal aorta by ultrasound. More study is required to determine what percentage of *all* attempted ED ultrasound measurements of the abdominal aorta meet with success.

Although the percentage of patients identified with AAA in our study population approximated the prevalence of this condition among the general populace, the fact that only 5 such patients were included for statistical analysis limits the conclusions that can be drawn regarding emergency physicians' ability to accurately measure by ultrasound aortas that are abnormally dilatated by aneurysm when compared with CT. The results of this study with respect to the negative predictive value of ED ultrasound in the diagnosis of AAA, however, suggest that emergency physicians are capable of utilizing ultrasound effectively to rule out AAA in the appropriate clinical setting. A larger study population that captures a much greater number of patients with AAA is needed to generate meaningful direct comparison of ED ultrasound measurements of aneurysms, in particular with measurements obtained by CT.

Further study is also needed to delineate the optimum time period in which emergency physicians can learn to perform accurate ultrasonographic measurement of the abdominal aorta. Limited in-service training enabled the participating physicians in this study to demonstrate good measurement ability using ultrasound when compared to CT. However, physicians participating in this study were stratified according to their level of training in Emergency Medicine, not with respect to how many actual prior aortic ultrasounds each had performed. The potential influence of any one participant's prior ultrasound experience on the results of this study could therefore not be determined. Further elucidation of how measuring capability may improve over time for specific individuals with varied prior ultrasound experience at various levels of Emergency Medicine training may provide useful information regarding the most effective and time-efficient means of imparting competency to emergency physicians.

CONCLUSIONS

Emergency physicians are capable of measuring abdominal aortic diameter by ultrasound in the ED quickly and with an accuracy that agrees with measurements obtained by CT sufficiently to provide useful clinical information.

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