The Effect of Bedside Ultrasonographic Skin Marking on Infant Lumbar Puncture Success: A Randomized Controlled Trial

Jeffrey T. Neal, MD*; Summer L. Kaplan, MD; Ashley L. Woodford, BS; Krisha Desai, BS; Joseph J. Zorc, MD, MSCE; Aaron E. Chen, MD

*Corresponding Author. E-mail: jeffreytneal@gmail.com, Twitter: @jeffreytneal.

Study objective: Lumbar puncture is a commonly performed procedure, although previous studies have documented low rates of successful completion in infants. Ultrasonography can visualize the anatomic landmarks for lumbar puncture and has been shown in some studies to reduce the failure rate of lumbar puncture in adults. We seek to determine whether ultrasonography-assisted site marking increases success for infant lumbar punctures.

Methods: This was a prospective, randomized, controlled trial in an academic pediatric emergency department (ED). We enrolled a convenience sample of infants younger than 6 months between June 2014 and February 2016 and randomized them to either a traditional lumbar puncture arm or an ultrasonography-assisted lumbar puncture arm. Infants in the ultrasonography arm received bedside ultrasonography of the spine by one of 3 study sonographers before lumbar puncture, during which the conus medullaris and most appropriate intervertebral space were identified and marked. The lumbar puncture was then performed by the predetermined ED provider. Our primary outcome was successful first-attempt lumbar puncture. Subjects were considered to have a successful lumbar puncture if cerebrospinal fluid was obtained and RBC counts were less than 1,000/mm^3. All outcomes were assessed by intention-to-treat analysis.

Results: One hundred twenty-eight patients were enrolled, with 64 in each arm. No differences between the 2 arms were found in the baseline characteristics of the study subjects and providers, except for sex and first-attempt position. The first-attempt success rate was higher for the ultrasonography arm (58%) versus the traditional arm (31%) (absolute risk difference 27% [95% CI 10% to 43%]). Success within 3 attempts was also higher for the ultrasonography arm (75%) versus the traditional arm (44%) (absolute risk difference 31% [95% CI 15% to 47%]). On average, performing bedside ultrasonography on 4 patients (95% CI 2.1 to 6.6) resulted in 1 additional successful lumbar puncture.

Conclusion: Ultrasonography-assisted site marking improved infant lumbar puncture success in a tertiary care pediatric teaching hospital. This method has the potential to reduce unnecessary hospitalizations and exposures to antibiotics in this vulnerable population. [Ann Emerg Med. 2017;69:610-619.]

Please see page 611 for the Editor's Capsule Summary of this article.

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0196-0644/$-see front matter

http://dx.doi.org/10.1016/j.annemergmed.2016.09.014

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INTRODUCTION

Background

Lumbar puncture is a frequently performed invasive procedure in children to evaluate cerebrospinal fluid in potentially life-threatening neurologic disorders, such as meningitis. The traditional technique involves palpation of anatomic landmarks (ie, superior borders of the posterior iliac crest, which lie in parallel with the L4 spinous process) followed by a "blind" stick of the selected L3 to L4 or L4 to L5 interspinous space. Although successful obtainment of cerebrospinal fluid is important for accurate diagnosis and to reduce unnecessary pain and anxiety, lumbar punctures in children are often unsuccessful. Factors that have been associated with lumbar puncture success include patient age (<12 weeks), use of local anesthetic, and early stylet removal.[1,2] In another study, risk factors for traumatic or unsuccessful lumbar punctures were identified as less physician experience, lack of local anesthetic use, age younger than 3 months, advancement of the spinal needle with stylet in place versus stylet removed, and increased patient movement.[3] Family member presence does not affect lumbar puncture success rates.[4] According to several pediatric

Editor's Capsule Summary

What is already known on this topic

Lumbar puncture is difficult to perform on infants.

What question this study addressed

Does the use of ultrasonography-assisted site marking increase success rate for infant lumbar puncture?

What this study adds to our knowledge

In this randomized controlled trial with 128 children, the use of bedside ultrasonographic marking by 2 individuals was associated with a 27% absolute improvement in success of lumbar puncture.

How this is relevant to clinical practice

This study suggests that ultrasonography-assisted site marking improves infant lumbar puncture success, although it remains to be seen how generalizable the results are.

studies, the reported rate of unsuccessful lumbar puncture (defined as obtaining no cerebrospinal fluid or obtaining a traumatic puncture) can be as high as 40% to 50%.[2,5,6]

Bedside ultrasonography possesses the ability to visualize the anatomic landmarks of lumbar puncture, including the subarachnoid space and conus medullaris in infants. In the adult literature, the effect of ultrasonography assistance on lumbar puncture success is equivocal.[7-11] In the pediatric population, ultrasonography has been used to determine optimal patient positioning for lumbar puncture,[12] to increase confidence of the lumbar puncture insertion site,[13] to help disclose the reason for a failed lumbar puncture,[14] and to mark the lumbar puncture insertion site.[15] In simulation, it has been demonstrated that physicians inexperienced with ultrasonography can easily obtain the requisite anatomic images for lumbar puncture.[16] Few studies have investigated the effect of bedside ultrasonography on lumbar puncture success rate in pediatric patients.[17] To our knowledge, no randomized studies have been published on the use of ultrasonography for infant lumbar puncture. In theory, through visualization of anatomic landmarks and marking of the most appropriate insertion site, ultrasonography-assisted site marking could affect lumbar puncture success.

Importance

Increasing the proportion of successful lumbar punctures with ultrasonography assistance has many implications. First, it would reduce pain and discomfort through reduction of total attempts and total procedure time. Second, it could significantly reduce the rate of unnecessary hospitalizations, additional interventional procedures, and antibiotic use. Third, it would offer a significant cost savings through improvement of the diagnostic and management process. In one recent retrospective study of low-risk infants aged 28 to 60 days, those who had unsuccessful lumbar punctures were hospitalized more frequently and had higher median hospital charges than those with successful lumbar punctures, despite similar serious bacterial infection rates.[18]

Goals of This Investigation

The goals of this investigation were to determine the effect of bedside ultrasonography-assisted site marking on the proportion of successful infant lumbar punctures (on first attempt and within 3 attempts) compared with the traditional approach. In addition, we sought to determine whether the ultrasonography intervention decreased hospitalization length of stay. We hypothesized that ultrasonography-assisted site marking would increase the proportion of successful lumbar punctures and therefore decrease length of stay.

MATERIALS AND METHODS

Study Design and Setting

We performed a prospective, nonblinded, randomized, controlled trial in an urban academic pediatric emergency department (ED) that has more than 90,000 pediatric patients per year and is staffed with medical students, nurse practitioners, trainees, and attending physicians. Trainees included residents of various specialties (pediatrics, medicine-pediatrics, emergency medicine, family medicine, and psychiatry) and pediatric emergency medicine fellows. There were no specific lumbar puncture training efforts in place, aside from standard hospital credentialing policy for procedures, during the entirety of this study. The institutional review board approved this study.

Selection of Participants

We recruited a convenience sample of infants aged zero to 6 months during a 20-month period from June 2014 to February 2016. Eligible patients were drawn from the study site ED. Inclusion criteria were infants aged 6 months or younger and receiving a lumbar puncture. Research assistants screened patients on the ED tracking board for eligibility. Exclusion criteria included known spinal cord abnormality, such as tethered cord, or parents who were non-English speaking. Sampling of patients was limited to study sonographer availability, given that the study arm was revealed only after randomization. As per institutional protocol, verbal consent for lumbar puncture was obtained by the provider, and written informed consent was subsequently obtained by a study investigator before enrollment.

Interventions

A block randomization sequence was generated with random-sized blocks before the start of the study to ensure that treatment groups were evenly distributed throughout the study duration. The sequence was kept in a password-secured spreadsheet and was not available to the study investigators. Allocation concealment occurred through storage in sealed envelopes containing premarked group assignment and study numbers. During the study period, any medical student, nurse practitioner, trainee, or attending physician was eligible to perform the lumbar puncture; however, to minimize potential bias, the clinician performing the lumbar puncture was identified before randomization. Once the subject was consented and enrolled, the next envelope in line was selected by a research assistant to assign the subject to a treatment arm. For patients randomized to the traditional lumbar puncture arm, no additional intervention was made and clinicians proceeded with lumbar puncture based on the traditional landmark approach. For patients randomized to the ultrasonography-assisted lumbar puncture arm, bedside ultrasonography was performed with a Mindray M7 (Mindray North America, Mahwah, NJ) linear high-frequency transducer before lumbar puncture to identify anatomic landmarks (Figure 1) and to mark the insertion site.

The patient was placed in the lateral decubitus or sitting position (depending on provider preference), with the spine flexed as if planning for lumbar puncture. The termination of the conus medullaris was identified and marked on the skin with a surgical marking pen with a long line perpendicular to the spine. The optimal interspinous level below the conus (widest subarachnoid space) was identified in the longitudinal plane and centered on the screen image, and another short mark was made adjacent to the center of the probe; the probe was then reoriented into the transverse plane at the level of this mark, the spinal canal was centered on the screen, and a short mark was again made at the center of the probe. With the probe removed, these 2 short marks were extended and intersected, making a target cross. The interspace level was confirmed by counting the corresponding vertebral bodies superiorly from the sacrum. The depth from the skin surface to the thecal sac at the marked interspace level was measured and recorded. The research assistant recorded the total time from initial probe placement until skin marking. If abnormal anatomy, such as a low-lying conus, was visualized, the lumbar puncture was aborted. The clinician performing the lumbar puncture was then provided a diagram with the skin markings (Figure 2), as well as the depth and instructions to direct his or her first attempt at the marked interspace. There was no interrater reliability of any measurements performed because the information was provided in real time. Subsequent attempts were allowed by clinician discretion based on the ultrasonography information and clinical judgment. No change in the patient positioning was allowed unless the puncture was unsuccessful on the first attempt.

Three study sonographers performed the ultrasonography (a pediatric emergency medicine board-certified physician and director of the study site emergency ultrasonography program [A.E.C], a senior pediatrics resident [J.T.N.], and a medical student [K.D.]). The director had additional training in emergency and advanced emergency ultrasonography. The

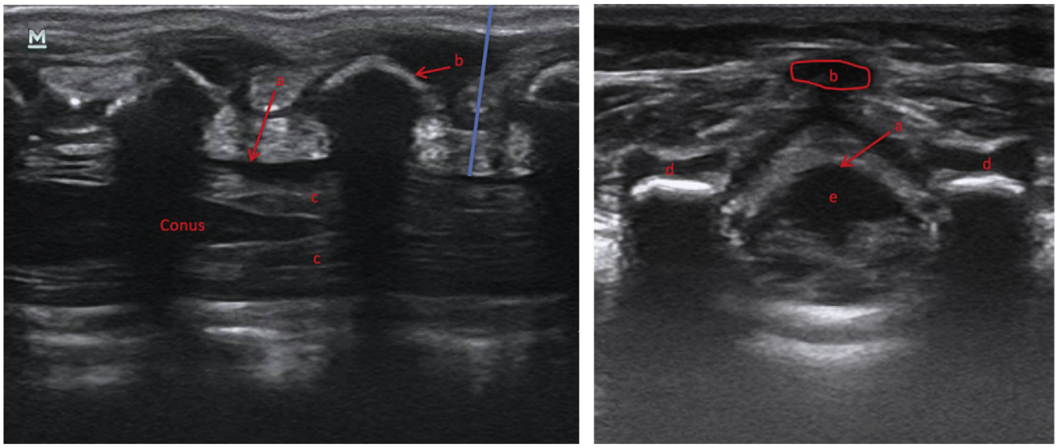

Figure 1. Identification of anatomic landmarks with bedside ultrasonography. Longitudinal plane (left) vs transverse plane (right); dura (a), spinous process (b), cauda equina (c), transverse process (d), subarachnoid space (e); example of depth measurement (blue line).

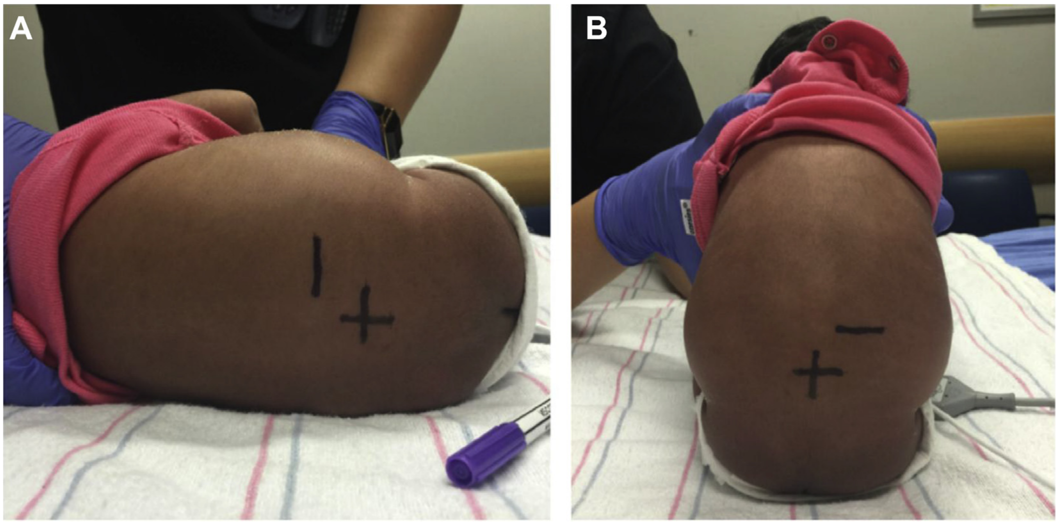

Figure 2. Ultrasonographic skin marking. Clinicians performing the LP were handed a diagram that described the following skin markings: a large straight line marking the termination of the conus and a cross marking the intervertebral space and midline for the first attempt. The images above demonstrate these markings in *A*, the lateral decubitus; and *B*, sitting position.

trainees completed a beginner ultrasonography technique course and successful identification of anatomic landmarks on at least 5 infant patients. The medical student sonographer had no previous experience with point-of-care ultrasonography but also completed a 2-day ultrasonography course. Each sonographer reviewed the visualization and marking procedure with the principal investigator before the first study ultrasonograph in order to standardize the technique. All images and clips were reviewed with a board-certified pediatric radiologist for feedback and quality control. To our knowledge bedside ultrasonography was not being clinically used at the study site for infant lumbar puncture in the ED.

Table 1. Patient characteristics.*

Characteristic	Traditional Arm, n=64	Ultrasonography-Assisted Arm, n=64
Age, days	29 (14, 45)	24 (9, 34)
Sex, male†	30 (46.9)	45 (70.3)
Race		
White	24 (37.5)	35 (54.7)
Black	26 (40.6)	16 (25.0)
Asian	5 (7.8)	1 (1.6)
Other	9 (14.1)	12 (18.8)
Weight, kg	4.2 (3.3, 4.7)	3.9 (3.5, 4.4)
Gestational age, wk‡	39.0 (37.0, 40.0)	39.2 (37.7, 40.0)
Maximum temperature, °C (°F)	38.1 (100.6) (37.4, 38.6 [99.3, 101.5])	38.2 (100.8) (37.6, 38.8 [99.7, 101.8])
Time LP performed		
Day (8 AM to 8 PM)	48 (75.0)	47 (73.4)
Night (after 8 PM to before 8 AM)	16 (25.0)	17 (26.6)
Bolus received	30 (46.9)	30 (46.9)
First-attempt position†		
Lateral decubitus	54 (84.4)	62 (96.9)
Sitting	10 (15.6)	2 (3.1)

LP, Lumbar puncture.
*Values represent median (IQR) and frequency (percentage).
†Statistically significant difference.
‡If documented as full term, analyzed as 40.0 weeks.

Methods of Measurement

Baseline demographic and clinical characteristics were collected (Table 1). These characteristics and additional information, including recent antibiotic therapy, history of lumbar puncture (within the previous 72 hours), and spinal cord abnormality (by history), were recorded by a research assistant on a standardized datasheet on the date of enrollment.

In regard to the lumbar puncture procedure, all clinicians who attempted it recorded patient positioning (sitting versus lateral decubitus), provider training level, and self-reported previous lumbar puncture experience (stratified into groups of zero, 1 to 10, 11 to 20, 21 to 50, and >50) for each attempt. It is standard practice at the study institution to use topical lidocaine for all infant lumbar punctures.

A follow-up chart review by the lead research assistant was performed on each patient after hospital discharge. Additional information was recorded, including length of hospitalization, length of receipt of antibiotics, and need for further interventional procedures such as repeated lumbar puncture and sedation. After the final patient was enrolled and data collection was complete, the data were downloaded from REDCap and thoroughly checked for missing variables. Any patients with missing variables had an additional chart review.

To calculate our sample size, we assumed a baseline neonatal lumbar puncture success rate of 60% (based on previous studies demonstrating a failure rate of up to 40%).[2,5,6] Using calculations for the comparison of 2 proportions, we estimated a sample size of 128 (64 per group) needed to detect an absolute 20% improvement with a power of 0.8 and α of .05.

Outcome Measures

Our primary outcome was a successful first-attempt lumbar puncture, defined as cerebrospinal fluid obtained with RBC counts less than 1,000/mm^3 because this was the most commonly cited definition of traumatic tap in the literature.[19,20] An unsuccessful lumbar puncture was also defined as obtaining no cerebrospinal fluid ("dry tap") or insufficient cerebrospinal fluid for cell counts. Given the diagnostic and treatment ambiguity inherent in both situations (no cerebrospinal fluid or traumatic fluid obtained), we decided to include these together as unsuccessful lumbar punctures. If 2 tubes of cerebrospinal fluid were sent for cell counts, the tube with the fewest RBCs (regardless of order) was used for analysis.

Our secondary outcomes included lumbar puncture success within 3 attempts. The same provider or another clinician could perform additional attempts at the same level as the marking or by provider discretion, keeping in mind the marked level of the conus and the ultrasonography information provided. An attempt was defined as removal and reinsertion of a spinal needle. Redirection of the spinal needle beneath the skin did not constitute an additional attempt. A provider change was not counted as a de novo attempt, but rather as subsequent attempts after the first provider. An additional secondary outcome included lumbar puncture success, defined as RBC count less than 10,000/mm^3, given the different provider thresholds of a "traumatic tap."

Primary Data Analysis

Descriptive statistics were used to report baseline and demographic characteristics between the 2 study arms. For purposes of data analysis, we reviewed patient and provider characteristics for the first lumbar puncture attempt only, irrespective of the number of additional attempts, because the rates of traumatic lumbar puncture increase with subsequent attempts.[6] All outcomes were assessed by intention-to-treat analysis.

To assess our primary and main secondary outcomes, we calculated absolute risk differences, risk ratios, and 95% confidence intervals (CIs) where indicated. We investigated for any correlation between sonographer and lumbar puncture success, as well as provider experience (dichotomized to $\leq$10 lumbar punctures and >10 lumbar punctures) and lumbar puncture success. All analyses were performed with Stata (version 13.0; StataCorp, College Station, TX).

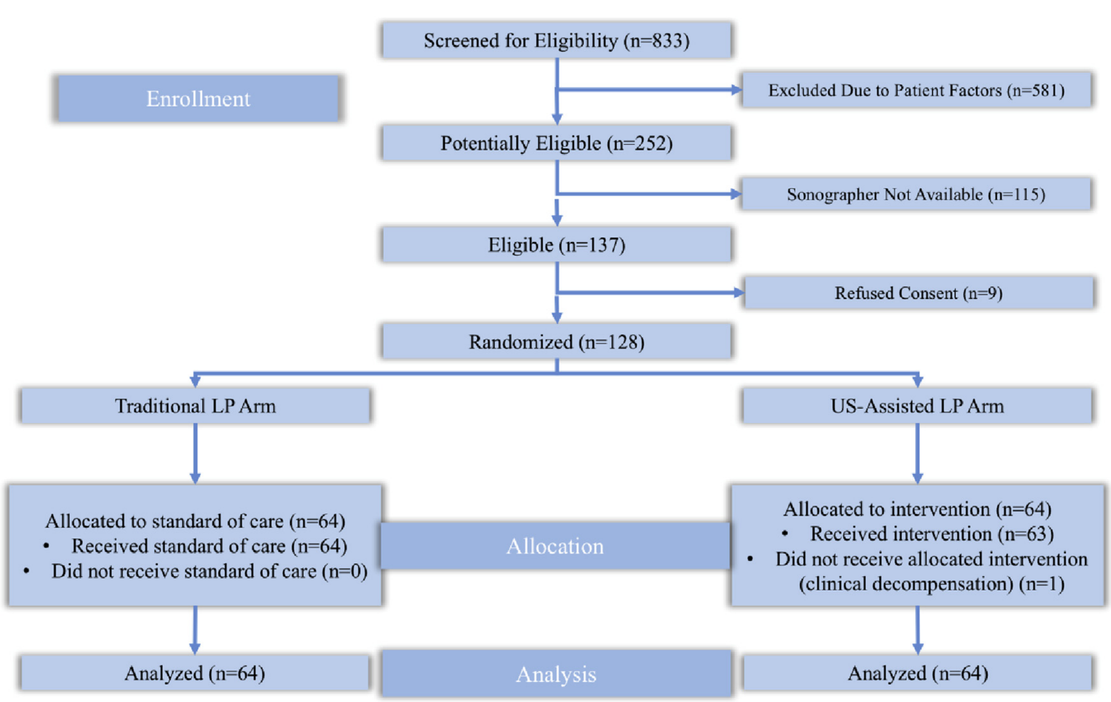

Figure 3. CONSORT flow diagram.

RESULTS

Characteristics of Study Subjects

One hundred twenty-eight patients were enrolled, 64 to the traditional lumbar puncture arm and 64 to the ultrasonography-assisted lumbar puncture arm (Figure 3). One patient in the ultrasonography arm had clinical decompensation after consent and enrollment, but before the lumbar puncture attempt, and did not receive a lumbar puncture. Therefore, the patient was considered as having had an unsuccessful lumbar puncture per our intention-to-treat analysis. The majority of patients received a lumbar puncture for a febrile neonate evaluation, whereas 3 patients received one for a seizure evaluation. Three study sonographers performed all of the ultrasonography on the patients. Investigator 1 (A.E.C.) performed 36 ultrasonographs, investigator 2 (J.T.N.) performed 25, and investigator 3 (K.D.) performed 2.

Sixty-three patients received ultrasonography before lumbar puncture. The median depth to the spinal canal was 0.92 cm (range 0.54 to 1.34 cm). Of the 62 patients with the time of skin marking recorded, the average time from probe contact to the skin marking was 5 minutes 17 seconds. A board-certified pediatric radiologist reviewed all ultrasonography images and clips. No abnormalities concerning for low-lying conus were noted. One ultrasonograph was deemed a technically limited scan because the saved images did not demonstrate the conus.

The median age of the patients in the study was 26 days (range 3 to 179 days). Seventy-five of the patients (58.6%) were male infants. Baseline characteristics of the study subjects and providers (Tables 1 and 2, respectively) were similar between groups, with the exception of sex and first-attempt position. We found a higher proportion of male infants (70% versus 47%) and fewer first attempts in the sitting position (3% versus 16%) in the ultrasonography arm compared with the traditional arm. One hundred seven total clinicians performed the 127 study lumbar punctures. Most clinicians performed 1 lumbar puncture, whereas the highest number of lumbar punctures performed by any one clinician was 3.

Table 2. Provider characteristics.*

Characteristic	Traditional Arm, n=64	Ultrasonography-Assisted Arm, n=64
First-attempt provider		
Medical student	4 (6.3)	1 (1.6)
Nurse practitioner	12 (18.8)	10 (15.9)
PGY1 resident	11 (17.2)	8 (12.7)
PGY2 resident	10 (15.6)	13 (20.6)
PGY3 resident	13 (20.3)	22 (34.9)
PGY4/5 resident	6 (9.4)	5 (7.9)
PEM fellow	6 (9.4)	3 (4.8)
Attending physician	2 (3.1)	1 (1.6)
First-attempt provider LP experience†		
0	3 (4.8)	2 (3.2)
1–10	32 (51.6)	29 (46.8)
11–20	10 (16.1)	14 (22.6)
20–50	10 (16.1)	14 (22.6)
>50	7 (11.3)	3 (4.8)

PGY, Postgraduate year; *PEM*, pediatric emergency medicine.
*Values represent frequency (percentage).
†Two subjects from each group had missing data for LP experience.

Main Results

Success on the first attempt was greater for the ultrasonography arm (58%) versus the traditional arm (31%) (absolute risk difference 27% [95% CI 10% to 43%]) (Table 3). Success within 3 attempts was greater for the ultrasonography arm (75%) versus the traditional arm (44%) (absolute risk difference 31% [95% CI 15% to 47%]). On average, 4 patients would require ultrasonography assistance to obtain 1 additional successful lumbar puncture on both first attempt (95% CI 2 to 10) and within 3 attempts (95% CI 2 to 7). With ultrasonography-assisted site marking, there was 1 less median lumbar puncture attempt per patient overall.

There were different proportions of the causes of unsuccessful lumbar puncture in each arm (Table E1, available online at http://www.annemergmed.com). Of the 35 unsuccessful lumbar punctures in the traditional arm, 11 (17.2%) were "dry," 21 (32.8%) were traumatic by RBC count definition, and 3 (4.7%) had insufficient fluid for cell counts. Of the 15 unsuccessful lumbar punctures in the ultrasonography arm, 4 (6.3%) were dry, 10 (15.6%) were traumatic, and 1 (1.6%) was not performed because of patient decompensation.

Provider experience did not affect first-attempt lumbar puncture success (Table E2, available online at http://www.annemergmed.com). When providers were stratified according to previous lumbar puncture experience, first-attempt success was 41% for providers with 10 or fewer lumbar punctures and 52% for those with greater than 11 (risk ratio=1.2 [95% CI 0.8 to 1.7]). The effect of ultrasonography-assisted site marking was greater for the less experienced providers (32.4% versus 20.6% increase in lumbar puncture success over traditional). Although a trend toward increased success with increased experience was evident, the results were not significant. Of the 61 cases that progressed beyond the first attempt, 43 (14 in the ultrasonography arm, 29 in the traditional arm) had a change in provider on subsequent attempts. A higher-level provider change was made on the second attempt 9 and 14 times in the ultrasonography and traditional groups, respectively.

Table 3. Primary and secondary outcome.

Outcome	Traditional Arm, n=64	Ultrasonography-Assisted Arm, n=64	ARD (95% CI), %
Success on first attempt (RBC count <1,000/mm^3)	20 (31.3)	37 (57.8)	26.6 (10.0 to 43.2)
Success within 3 attempts (RBC count <1,000/mm^3)	28 (43.8)	48 (75.0)	31.3 (15.1 to 47.4)
Success on first attempt (RBC count <10,000/mm^3)	23 (35.9)	40 (62.5)	26.6 (9.9 to 43.3)
Success within 3 attempts (RBC count <10,000/mm^3)	36 (56.3)	52 (81.3)	25.0 (9.5 to 40.5)
Median overall attempts, No.	2	1	–1 (–1.4 to –0.6)

ARD, Absolute risk difference.

There was no difference in provider lumbar puncture success in the ultrasonography arm according to the sonographer. Success on first attempt was 59.5% versus 56.0%, and success within 3 attempts was 64.9% and 60.0% when the ultrasonography was performed by sonographers 1 and 2, respectively. There was no evidence of increasing success over time with the study sonographers. Sonographer 3 was not included in the analysis because of the limited number of scans performed.

The median hospital length of stay was similar between the 2 groups (48.1 versus 46.0 hours in the traditional and ultrasonography arms, respectively), but the difference of 2.1 hours was not significant (95% CI –10.5 to 14.7 hours). The median length of antibiotics treatment was also similar between the 2 groups (25.0 versus 26.8 hours in the traditional and ultrasonography arms, respectively), but the difference of 1.8 hours was not significant (95% CI –7.4 to 3.4 hours). During hospitalization, 8 patients in the traditional arm who had initial unsuccessful lumbar punctures underwent a repeated lumbar puncture. Seven of these repeated attempts were with interventional radiology and 2 required sedations. One lumbar puncture was delayed after an ultrasonograph demonstrated a large spinal hematoma. Two patients in the ultrasonography arm required a repeated lumbar puncture (one was the patient who never had an initial lumbar puncture because of clinical decompensation in the ED, and one was performed after the initial lumbar puncture culture grew *Escherichia coli*). One lumbar puncture was with interventional radiology and required sedation.

LIMITATIONS

Our study has several limitations. First, although this was a randomized trial, providers were not blinded, and therefore it was evident which patients had received ultrasonography before lumbar puncture. The simple knowledge that ultrasonography was performed or the presence of a target marking may have increased the confidence of the provider,[13] especially with less experienced trainees. The study could have been improved if a skin marking based on palpation landmarks had been performed for patients in the traditional arm. Nevertheless, conus position and depth to the spinal canal would not be available according to palpation alone.

Second, the lumbar puncture technique was not standardized for optimal success because we thought standardization might affect provider preferences. Per the study institution protocol, all patients received topical lidocaine. However, data on advancement of the lumbar puncture needle with or without stylet in place were not collected. Because early stylet removal has been associated with increased success,[1,3] it is unclear whether this occurred more frequently in the ultrasonography arm and could have biased the results.

Third, there were baseline differences in sex and first-attempt lumbar puncture position between the groups. We believe these occurred because of random chance, and neither was associated with the primary outcome. A recent randomized controlled trial demonstrated no difference in infant lumbar puncture success rates according to positioning.[21]

Fourth, our study was conducted at an academic pediatric ED, where trainees perform the majority of procedures. Because lumbar puncture has become less frequently performed, the practical experience of our trainees has decreased. In our study group, approximately 4% of lumbar punctures were performed by trainees without any experience and nearly 50% were performed by trainees with limited experience (only 1 to 10 previous lumbar punctures). It is common practice in the study institution to provide supervision of junior residents during procedures. Given that the majority of providers were inexperienced with lumbar puncture, it is likely they had a supervising physician in the room. Despite this fact, we observed a low proportion of success in our control group, which could have artificially inflated the absolute difference between the control and the ultrasonography arm. Therefore, our findings may not be generalizable to other settings in which providers have more experience with lumbar puncture and may have higher success rates when using the traditional palpation method.

Fifth, all study ultrasonography was performed by 3 study investigators, potentially limiting generalizability to other practices and institutions with less experience with point-of-care ultrasonography; however, 2 sonographers had limited previous ultrasonography training, suggesting that these techniques may be easily taught.

DISCUSSION

To our knowledge, our study is the first randomized controlled trial to evaluate the effect of ultrasonography assistance on infant lumbar puncture; infants are a population that historically experiences a higher rate of unsuccessful lumbar punctures. In the adult literature, the results are equivocal, with one study showing improved success with ultrasonography assistance and another showing no effect.[9,10] In pediatrics, one recent study performed with patients younger than 18 years did not demonstrate a reduced rate of traumatic lumbar puncture and number of lumbar puncture attempts with the use of ultrasonography[17]; however, the mean age of patients in this study was 68 months, a much older population than in our study. Ultrasonographic penetration into the spinal canal decreases with increasing age and calcification of the spinous processes, and this may have negated many of the benefits of ultrasonography observed in young infants. With ultrasonography-assisted skin marking, we observed a 27% (95% CI 10% to 43%) increase in first-attempt lumbar puncture success and a 31% (95% CI 15% to 47%) increase in success within 3 attempts compared with traditional palpation in our population of infants aged zero to 6 months.

We observed a high proportion of overall unsuccessful and traumatic traditional lumbar punctures in our study population (56% and 44% within 3 attempts when defining as RBC counts <1,000 and <10,000/mm^3, respectively), although not substantially different from reported trainee rates in the literature.[22,23] This is likely a factor of the teaching hospital site, where a trainee was the first-attempt provider in 97.6% of the lumbar punctures. Previous studies have demonstrated that interns are ill prepared for lumbar puncture and success rates are poor,[22,24] and perhaps simulation may increase confidence and success rates.[25,26] Nevertheless, although our study was underpowered to detect such a difference, our results also demonstrated that provider experience did not have a significant effect on lumbar puncture success, which has been previously demonstrated.[6]

Ultrasonography can provide valuable information for infant lumbar puncture that is not readily available with traditional palpation techniques.[12-14] Because of incomplete ossification of the structures surrounding the spinal canal, landmarks are more easily visualized in infants than in adults. Studies have shown that the depth from the skin to the subarachnoid space can be easily measured by ultrasonography.[27-29] Demonstration of the expected insertion depth may improve provider confidence and success rates by more accurate localization of the subarachnoid space. The most important benefit of ultrasonography, however, is likely in the actual marking for the insertion site. Studies have shown increased variability of the estimated interspinous space with landmark- versus ultrasonography-based approaches,[30-32] and it is possible that this variability can decrease success rates because the width of the subarachnoid space varies by location. Furthermore, the ultrasonographic marking gives the location of the midline, and because epidural vessels can be seen laterally to the canal space both anteriorly and posteriorly (Figure 4), it is likely that better estimations of midline would lead to decreased numbers of traumatic lumbar punctures. Last, demarcation of the termination of the conus medullaris ensures the safety of repeated attempts in alternate interspaces.[33]

Additional research could further evaluate this technique of using ultrasonography to assist lumbar puncture in children and explore other groups of patients and providers, especially given the limitations of our study. It would be helpful to evaluate the generalizability of ultrasonography assistance to the provider performing the lumbar puncture, given the lack of experienced sonographers in low-resource settings. In addition, we chose to mark the location in advance, although some studies have investigated the dynamic use of ultrasonography during performance of the lumbar puncture.[14,34] At most institutions, this is usually performed by interventional radiology under sedation and is not practical in a busy pediatric ED.

Our study evaluated the effect of ultrasonography-assisted site marking on infant lumbar puncture success. Many additional measurements such as subarachnoid space width, interspinous space distance, needle entry angle, and depth to the spinal canal can easily be

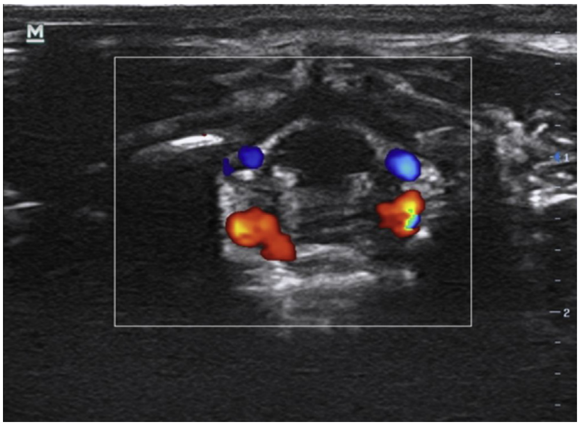

Figure 4. Epidural vessels.

undertaken to evaluate the correlation between any of these measurements and infant lumbar puncture success. Failed lumbar punctures lead to higher rates of hospitalization and higher hospital costs in this vulnerable age group,[18] and any method improving success rates would be beneficial.

In conclusion, this study found an increase in lumbar puncture success rates compared with usual clinical practice for infants randomized to receive ultrasonography-assisted skin marking before the procedure in an academic pediatric ED.

The authors acknowledge Michael C. Monuteaux, ScD, of Boston Children's Hospital for his guidance on the statistical analysis of the data; Rachel G. Rempell, MD, for her review and revision of the article; and all of the academic associate research assistants for their help in the recruitment of the patients for this study.

Supervising editors: Jocelyn Gravel, MD; Steven M. Green, MD

Author affiliations: From the Division of Emergency Medicine, Boston Children's Hospital, Boston, MA (Neal); and the Department of Radiology (Kaplan) and the Division of Emergency Medicine (Woodford, Desai, Zorc, Chen), Children's Hospital of Philadelphia, Philadelphia, PA.

Author contributions: JTN and AEC conceived the study, designed the trial, submitted the appropriate clinical trials paperwork, and supervised the conduct of the trial and data collection. JTN, ALW, KD, and AEC undertook recruitment of participating patients and acquisition and management of data, including quality control. SLK provided protocol advice and facilitated review of ultrasonography images. JJZ provided additional protocol advice, including statistical recommendations. JTN drafted the article, and all authors contributed substantially to its review and revision. AEC takes responsibility for the paper as a whole.

All authors attest to meeting the four ICMJE.org authorship criteria: (1) Substantial contributions to the conception or design of the work; or the acquisition, analysis, or interpretation of data for the work; AND (2) Drafting the work or revising it critically for important intellectual content; AND (3) Final approval of the version to be published; AND (4) Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Funding and support: By *Annals* policy, all authors are required to disclose any and all commercial, financial, and other relationships in any way related to the subject of this article as per ICMJE conflict of interest guidelines (see www.icmje.org). The authors have stated that no such relationships exist.

Publication dates: Received for publication June 15, 2016. Revisions received August 16, 2016, and August 26, 2016. Accepted for publication September 8, 2016. Available online November 14, 2016.

Presented at the 19th annual Society of Academic Emergency Medicine Mid-Atlantic Regional Research Forum, February 2015, Washington, DC; at the American Institute of Ultrasound in Medicine annual convention, March 2015, Lake Buena Vista, FL; as a poster at the Pediatric Academic Societies annual meeting, April 2015, San Diego, CA; at the Society for Academic Emergency Medicine annual meeting, May 2015, San Diego, CA; and at the American Academy of Pediatrics national conference and exhibition, October 2016, San Francisco, CA.

Trial registration number: NCT02133066

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IMAGES IN EMERGENCY MEDICINE

(continued from p. 575)

DIAGNOSIS:

Four-part comminuted right proximal humerus fracture-dislocation with humeral head impaction into the thoracic cavity. The patient underwent right-sided video-assisted thoracoscopic surgery, with removal of the humeral head from the thoracic cavity, evacuation of the hemothorax, and right shoulder hemiarthroplasty.

Intrathoracic displacement of the humeral head is a rare complication of high-energy trauma.[1] The majority of cases involve a 4-part humeral head fracture, as with this patient. Four-part fractures carry a high risk of avascular necrosis and usually require hemiarthroplasty. The mechanism of humeral head dislocation into the thorax is unclear. It is postulated that the dislocation occurs when an extreme external force is applied while the shoulder is in abduction, causing an anterior or inferior displacement of the humeral head medially into the thoracic cavity. The humeral shaft is then leveraged against the ribs, resulting in the humeral head's being trapped in the chest.[2-5] Associated thoracic injuries are similar to any penetrating chest trauma—rib fractures, pneumothorax, hemothorax, and hemopneumothorax—and often require urgent intervention.

Author affiliations: From the Department of Emergency Medicine, Oregon Health & Science University, Portland, OR.

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Table E1. Breakdown of lumbar puncture outcome in traditional versus ultrasonography arms.

LP Outcome	Traditional Arm (%), n=64	Ultrasonography Arm (%), n=64
"Dry"	11 (17.2)	4 (6.3)
Traumatic (>1,000 RBCs)	21 (32.8)	10 (15.6)
Insufficient for counts	3 (4.7)	0
Not performed	0	1 (1.6)
Successful*	29 (45.3)	49 (76.6)

*Success regardless of number of attempts. For the traditional arm, 10 of the total LPs required greater than 3 attempts, 1 of which was ultimately successful according to cell count definition (the remainder were "dry" or traumatic). For the ultrasonography arm, 3 of the total LPs required greater than 3 attempts, 1 of which was ultimately successful as well.

Table E2. Effect of provider experience on successful first-attempt lumbar puncture.

LP Provider Experience*	Traditional Arm (%), n=62	Ultrasonography Arm (%), n=62	Total (%)
≤10	9 (25.7)	18 (58.1)	27 (40.9)
>10	11 (40.7)	19 (61.3)	30 (51.7)
Total	20 (32.3)	37 (59.7)	57 (46.0)

*Two subjects from each group had missing data for LP experience.