Ultrasound imaging aids the learning of the landmark technique for lumbar puncture in novice learners in a secure training environment [version 1; peer review: 2 approved with reservations]

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Abstract
Background: Performing a lumbar puncture (LP) is a key skill to master for doctors in the emergency department (ED), but the level of success and rate of complications still differs considerably. Studies have shown that LP is attempted at a different level than intended in 30% of cases when the classical landmark technique is used. Ultrasound-assisted LP can reduce the risk of failed LP, possible by its ability to visualize the relevant anatomy of the spine, but only a few studies have considered its potential in learning environments with novice learners.

Methods: Medical students and first-year trainee doctors who had never performed a LP in a clinical setting were asked to locate and mark the exact location of where to insert the needle when performing a LP by first using the classical landmark technique secondly by use of ultrasound. Corrections of the marked locations were registered for each attempt. Each participant marked three different healthy volunteers in both sitting and laying positions.

Results: The accuracy in LP by landmarking as a total of correct markings (“unchanged”) vs. a total of incorrect markings (“changed”) improved significantly in both the sitting (p = 0.028) and lying positions (p=0.002). All participants were positive about the use of ultrasound when learning how to identify the correct LP marking, mostly because of improved understanding of the anatomical structures and improved confidence in the succeeding attempts.

Conclusion: Ultrasound can assist and potentially increase the learning of landmark techniques in novice learners in a secure training environment. Visualizing the underlying anatomical structures of the landmark technique in this way can add a second level of security for the learner for the future practice of LP.
Keywords
lumbar puncture, ultrasound guidance, novice learners

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Author roles: Lundsgaard RS: Conceptualization, Data Curation, Formal Analysis, Investigation, Methodology, Project Administration, Resources, Supervision, Validation, Visualization, Writing – Original Draft Preparation, Writing – Review & Editing

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**Introduction**

Performing a lumbar puncture (LP) is a key skill to master for medical doctors in the emergency department (ED) for diagnosing severe conditions such as life-threatening meningitis or subarachnoid hemorrhage (Evans et al., 2018; Stewart et al., 2014). The standard procedure, using anatomical landmarks to identify the correct intervertebral level, has not changed since it was developed in 1891 (Doherty & Forbes, 2014). However, even though LP is a core skill, the level of success and rate of complications still differs considerably between doctors (Evans et al., 2018), and studies have shown that LP is attempted at a different level than intended in 30% of attempts when the classical landmark technique is used (Duniec et al., 2013; Evans et al., 2018).

Newer techniques to improve accuracy and rate of success when performing LP have been developed but have not yet become a new standard of care (Evans et al., 2018; Peterson et al., 2014; Stewart et al., 2014). Ultrasound-assisted LP can reduce the risk of failed LP in some cases, suggesting the ability to visualize the relevant anatomy of the spine may contribute to its success (Shaikh et al., 2013).

Consequently, interest has been growing in the use of ultrasound in LP, but its cost-effectiveness has been questioned, especially due to increasing time to perform the procedure and the need for dedicated training in the ultrasound equipment (Duniec et al., 2013; Peterson et al., 2014; Pisupati et al., n.d.; Shaikh et al., 2013).

Contrastingly, to the growing the increased attention mentioned above, only a few studies have explored the effect of using LP when teaching LP to medical students and novice medical doctors (Grau et al., 2003). Even though ultrasound has demonstrated the potential to improve learning curves in more experienced doctors performing spinal procedures (Grau et al., 2003), so far only the classic landmarks technique is taught at Danish medical schools.

This study aims to explore how the untrained use of ultrasound affects the ability of inexperienced LP performers to identify the intended intervertebral level in LP procedure using the classical landmark technique. The study focuses on novice doctors and medical students with no prior experience or training in using ultrasound.

**Methods**

**Subjects**

Medical students and first-year trainee doctors who had never performed a LP in a clinical setting were recruited by direct contact of R.S.L. in the ED of a Nyköbing Falster Hospital, a rural hospital in Eastern Denmark. Each participant performed three non-invasive sessions (drawing with a surgical pen) on three different healthy volunteers (medical professionals and students at the site). The volunteers were also recruited by direct contact of R.S.L. in the ED.

A total of six medical students and six first-year training doctors were included in the study. Each participant (learner) marked locations for LP by landmark and ultrasound on three different volunteers sitting and laying down. As the result of each marking was registered as changed or unchanged location (by ultrasound) this generated a total of 72 datasets, six for each participant (learner).

**Subject direction**

No specific instruction about LP procedure was given before enrolling, but participants were asked to go through to the hospital’s procedural guidelines about LP and study the relevant anatomy if needed. None of the participants had any experience in using ultrasound. The research was exempted from ethical approval by the Regional Ethics Committee, Zealand, Denmark. Participants and volunteers were verbally instructed and written informed consent was obtained on-site. Data were anonymized.

**Location**

Sessions were performed in an available patient room in the ED using a regular hospital bed.

Before the procedure, each participant was briefly interviewed on how to perform LP, to make sure their theoretical knowledge was solid. All participants were rated as having equivalent knowledge, and all participants expressed the intervertebral space of L3-L4 as their aim when performing the LP by landmark technique.

**Landmark technique**

Each participant was asked to locate and mark the exact location of where to insert the needle when performing a LP. The location was marked using a surgical marker. Each participant marked the volunteer as the volunteer was first sitting down and then lying down. Each mark was given a number and was visible during the entire session. The marks were afterward removed with 85% ethanol skin disinfectant. Each participant marked three volunteers, (e.g. A, B and C) consecutively. Volunteers were used for more than one, but not all participants due to feasibility of the study. A total of 15 volunteers were included.

**Ultrasound-assisted marking**

After locating the intended intervertebral level of the LP in both sitting and lying position, the participant was handed the linear probe of the Philips Sparq Ultrasound System with “Simplicity Mode” enabled. Only the linear probe (Philips L12-3) was mounted to the ultrasound workstation. On the Philips Sparq, “Simplicity Mode” was enabled as standard and only the depth setting was adjusted during the session. Adjustment of the depth setting was done by the investigator when asked for. The ultrasound workstation was placed on the opposite side of the bed then the participant and the screen was adjusted to either the left or right side of the volunteer depending on participant preference. The participant was now asked to locate the intervertebral space of L3-L4 using the ultrasound workstation and linear probe as a guide. An ultrasonic gel was applied to the probe before handing it to the participant. No additional instruction on reading the ultrasonic image was given (Speer et al., 2013).

The location found using ultrasound was rated as being “correct” and secondly controlled by the investigator R.S.L. R.S.L. is...
an experienced clinician with more than 5 years of practice in LP. It was recorded whether the participant chose a different location for spinal access when using ultrasound (“changed”) or was satisfied with the area already marked (“unchanged”).

Qualitative assessment
Qualitative data in the form of spontaneous comments about the learning experience was gathered in the form of informal conversation during the sessions. Qualitative data were written down as keywords in Danish by the R.S.L. and transcribed afterward.

Statistical analysis
The sample size was calculated using ClinCal online software. Power was set to 85% and alpha 0.05; population was 70% and study group 30%. P values were calculated using Student’s t-test with Microsoft Excel (2016) software (Barath & Rosner, 1992).

Results
Success rate of identifying correct LP location
All ultrasound markings were found (by investigators control) to be at the intended intervertebral level (L3/L4).

Success rate by participants of LP markings is shown in Table 1 (sitting: S1, S2, S3 and lying down L1, L2, L3). The mean success rate of LP by landmarks only was 21%. The first attempt (S1) had a success rate of 0%.

The improvement of accuracy in LP marking is shown in Table 2 as a total of correct markings (“unchanged”) vs. a total of incorrect markings (“changed”) for each attempt (S1, S2, S3)

<table>
<thead>
<tr>
<th>Participant</th>
<th>Sitting 1</th>
<th>Laying 1</th>
<th>Sitting 2</th>
<th>Laying 2</th>
<th>Sitting 3</th>
<th>Laying 3</th>
<th>Success rate using landmark only (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participant 1</td>
<td>Changed</td>
<td>Changed</td>
<td>Changed</td>
<td>Changed</td>
<td><strong>Unchanged</strong></td>
<td>Changed</td>
<td>17</td>
</tr>
<tr>
<td>Participant 2</td>
<td>Changed</td>
<td>Changed</td>
<td>Changed</td>
<td><strong>Unchanged</strong></td>
<td>Changed</td>
<td>Changed</td>
<td>17</td>
</tr>
<tr>
<td>Participant 3</td>
<td>Changed</td>
<td>Changed</td>
<td>Changed</td>
<td>Changed</td>
<td>Changed</td>
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<td>0</td>
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<tr>
<td>Participant 4</td>
<td>Changed</td>
<td>Changed</td>
<td>Changed</td>
<td>Changed</td>
<td><strong>Unchanged</strong></td>
<td>Changed</td>
<td>17</td>
</tr>
<tr>
<td>Participant 5</td>
<td>Changed</td>
<td>Changed</td>
<td><strong>Unchanged</strong></td>
<td>Changed</td>
<td><strong>Unchanged</strong></td>
<td><strong>Unchanged</strong></td>
<td>50</td>
</tr>
<tr>
<td>Participant 6</td>
<td>Changed</td>
<td>Changed</td>
<td>Changed</td>
<td>Changed</td>
<td>Changed</td>
<td><strong>Unchanged</strong></td>
<td>0</td>
</tr>
<tr>
<td>Participant 7</td>
<td>Changed</td>
<td>Changed</td>
<td><strong>Unchanged</strong></td>
<td>Changed</td>
<td><strong>Unchanged</strong></td>
<td><strong>Unchanged</strong></td>
<td>50</td>
</tr>
<tr>
<td>Participant 8</td>
<td>Changed</td>
<td>Changed</td>
<td>Changed</td>
<td>Changed</td>
<td><strong>Unchanged</strong></td>
<td>Changed</td>
<td>17</td>
</tr>
<tr>
<td>Participant 9</td>
<td>Changed</td>
<td>Changed</td>
<td>Changed</td>
<td>Changed</td>
<td><strong>Unchanged</strong></td>
<td>Changed</td>
<td>17</td>
</tr>
<tr>
<td>Participant 10</td>
<td>Changed</td>
<td>Changed</td>
<td>Changed</td>
<td>Changed</td>
<td>Changed</td>
<td>Changed</td>
<td>0</td>
</tr>
<tr>
<td>Participant 11</td>
<td>Changed</td>
<td><strong>Unchanged</strong></td>
<td><strong>Unchanged</strong></td>
<td><strong>Unchanged</strong></td>
<td><strong>Unchanged</strong></td>
<td><strong>Unchanged</strong></td>
<td>67</td>
</tr>
<tr>
<td>Participant 12</td>
<td>Changed</td>
<td>Changed</td>
<td>Changed</td>
<td>Changed</td>
<td>Changed</td>
<td>Changed</td>
<td>0</td>
</tr>
</tbody>
</table>

| Unchanged (n) | 0 | 1 | 2 | 2 | 6 | 4 |
| Changed (n) | 12 | 11 | 10 | 10 | 6 | 8 |
| Unchanged (%) | 0 | 8 | 17 | 17 | 50 | 33 |

<table>
<thead>
<tr>
<th>Volunteer</th>
<th>N</th>
<th>Unchanged</th>
<th>Changed</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sitting 1</td>
<td>12</td>
<td>0</td>
<td>12</td>
<td>0.028</td>
</tr>
<tr>
<td>Sitting 2</td>
<td>12</td>
<td>2</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Sitting 3</td>
<td>12</td>
<td>6</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Laying 1</td>
<td>12</td>
<td>1</td>
<td>11</td>
<td>0.002</td>
</tr>
<tr>
<td>Laying 2</td>
<td>12</td>
<td>2</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Laying 3</td>
<td>12</td>
<td>4</td>
<td>8</td>
<td></td>
</tr>
</tbody>
</table>
and L1, L2, L3). Markings of LP by landmark improved significantly in both sitting (p = 0.028) and lying positions (p=0.002).

All participants chose to change at least one of three marks when using ultrasound. Especially the marks in the first session (S1 + L1) was altered by most participants.

### Participant perception

All participants expressed positivity on the use of ultrasound when learning how to identify the correct LP marking. Half of the participants would consider using ultrasound in the same manner when teaching procedures to colleagues and students in the future. The main reasons for this were: improved understanding of the anatomical structures and improved confidence in the succeeding attempts. Keywords can be found in Dataset 1 (Lundsgaard, 2018).

### Discussion

The precision on marking the correct location for LP using the landmark technique only increased markedly in the novice learners between sessions. This finding complies with the finding of Grau et al. (2003), who found that ultrasound significantly improved the learning curves in spinal procedures. This study did not specifically seek to explore the possible reasons for the improved learning. However, the participants verbally expressed that the ultrasound aided their understanding of the anatomical structures and served as a “quality check” when learning the procedure. These findings are in line with previous work suggesting that one of the strengths in using ultrasound for LP is the visualization of anatomy, e.g., in complex patients, such as the elderly or patients with high BMI (Ansari et al., 2014; Peterson et al., 2014; Pisupati et al., n.d.; Shaikh et al., 2013).

The success rate of correct location by landmark technique only in our participants was lower (21%) than in studies of more experienced doctors (Duniec et al., 2013), corresponding to the low level of our participants’ clinical experience. As the participants were novices with an initial success rate of 0%, the ultrasound aided their learning from the beginning, potentially reducing the risk of forwarding failure and the need for unlearning inexpedient techniques, which is both stressful and challenging to the learner (Heydari et al., 2017; Rushmer & Davies, 2004). Using ultrasound clinically on a regular basis might be out of scope for most novice doctors, but as a simple training aid, it opens new opportunities.

This study concludes that putting an ultrasonic probe in the hand of novice learners in a secure training environment may be highly beneficial, and could add a second level of security for the learner for the future practice of the landmark LP technique.

### Data availability

Dataset 1. Raw data LP markings and keywords identified during discussions surrounding use of ultrasound in lumbar puncture. Please note that keywords are in Danish. https://doi.org/10.5256/f1000research.16133.d216926 (Lundsgaard, 2018).

### Grant information

The author declare that no grants were involved in supporting this work.

### References


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Thank you for the opportunity to read your interesting work on evaluating US-guided lumbar puncture in the training of students and young doctors.

Despite the interesting read, I have to make some comments.

In general
- Reading your paper, I understand that the markings where the LP should be performed improve after using ultrasound. I'm not sure how this demonstrates that ultrasound aids/“may be highly beneficial”/adds a second level of security in learning. What is the first level of security?
- Also, it is not clear to me if the marking is always correct after using ultrasound. US may often change the marking, but are the markings 100% correct after correcting?
- How do you define a secure training environment? It is stated in the title and discussion to be secure. But what elements contribute to this security?
- Please check spelling and grammar for readability. For instance the use of “laying” in both tables and the methods section. “Liner probe”

Abstract
- Please be more exact in the abstract. For instance the methods section of the abstract. It is not clear to me that the markings are sometimes changed based on ultrasound.

Introduction
- Second last paragraph: “using LP when teaching LP...” might not be correct.

Methods section
- In what time period was the study performed? Since US is adopting progressively among (young) doctors, this is relevant information.
- Maybe you could provide the reader with some more information about the volunteers:
age, BMI, previous illnesses (or the absense thereof).
- Inclusion/exclusion criteria of learners and volunteers? - Especially since you state the interviews that were held to determine the theoretical knowledge of the learners.
- How can you expect medical students and young doctors with apparently no experience with US imaging to identify the L3/L4 intervertebral space? Especially since "No additional instruction on reading the ultrasonic image was given." -- Also, some more explanation is needed why you refer to the paper by Speer 2013.
- Power calculation was based on what previous study results? Some explanation is needed here.
- Student's T-test? compared the number of correct markings without and with ultrasound. But these are paired dichotomous values. Perhaps a McNemar's test (or ANOVA?) is a far more appropriate test. Please consult a statistician on this matter.

Results
- To my understanding you have determined the success rate of the landmark technique by letting the learners check with ultrasound? In other words: if all marks remain unchanged after US, the score would be 100% correct. In the methods section you described the investigator to judge all US markings to be "correct" or not. But these data are not reported in the results section or discussion. I suppose the sentence "All ultrasound markings were found ..." should be expanded with a confidence interval? What does current literature say about the accuracy of determining the correct intervertebral space by experienced clinicians? Is it always 100% correct?
- Please consider adding some descriptive statistics and confidence intervals?
- You didn't compare the accuracy of the landmark technique between sessions. Did the learners perform better in the second session when compared to the first? And in the third? I feel this information is vital since this might demonstrate any learning effect and thus substantiate the title.
- It might have been interesting to know how incorrect markings were distributed between too low and too high.

Discussion
- "Using ultrasound clinically on a regular basis might be out of scope..." - this depends on the time and place where novice doctors are employed. Times are a changing!

Thank you again for reading your interesting paper. I feel it still needs some work, though.

Is the work clearly and accurately presented and does it cite the current literature?
Partly

Is the study design appropriate and is the work technically sound?
Partly

Are sufficient details of methods and analysis provided to allow replication by others?
Partly

If applicable, is the statistical analysis and its interpretation appropriate?
No

Are all the source data underlying the results available to ensure full reproducibility?
Partly

**Are the conclusions drawn adequately supported by the results?**

Partly

**Competing Interests:** No competing interests were disclosed.

**Reviewer Expertise:** Ultrasonography in Prehospital and Emergency Medicine

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.
paramedian etc) when marking the spinal levels. So I think we need more information on the same.

5) Usually these scans are done using the curvilinear probe due to depth requirement but it is stated that they used liner probe, hence again the question of the selection criteria of volunteers need to explained

6) It is stated that total of 15 volunteers used. so what the provision made to account for the difference between the volunteers scanned in the analysis?

7) It states that RSL decided the marking as correct or not, again the reader need to have a more description re what is meant by correct position how was it determined?

Is the work clearly and accurately presented and does it cite the current literature?
Partly

Is the study design appropriate and is the work technically sound?
Partly

Are sufficient details of methods and analysis provided to allow replication by others?
Partly

If applicable, is the statistical analysis and its interpretation appropriate?
I cannot comment. A qualified statistician is required.

Are all the source data underlying the results available to ensure full reproducibility?
Partly

Are the conclusions drawn adequately supported by the results?
Partly

Competing Interests: No competing interests were disclosed.

We confirm that we have read this submission and believe that we have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however we have significant reservations, as outlined above.
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