



# Real Time Needle Integrated Ultrasound Imaging

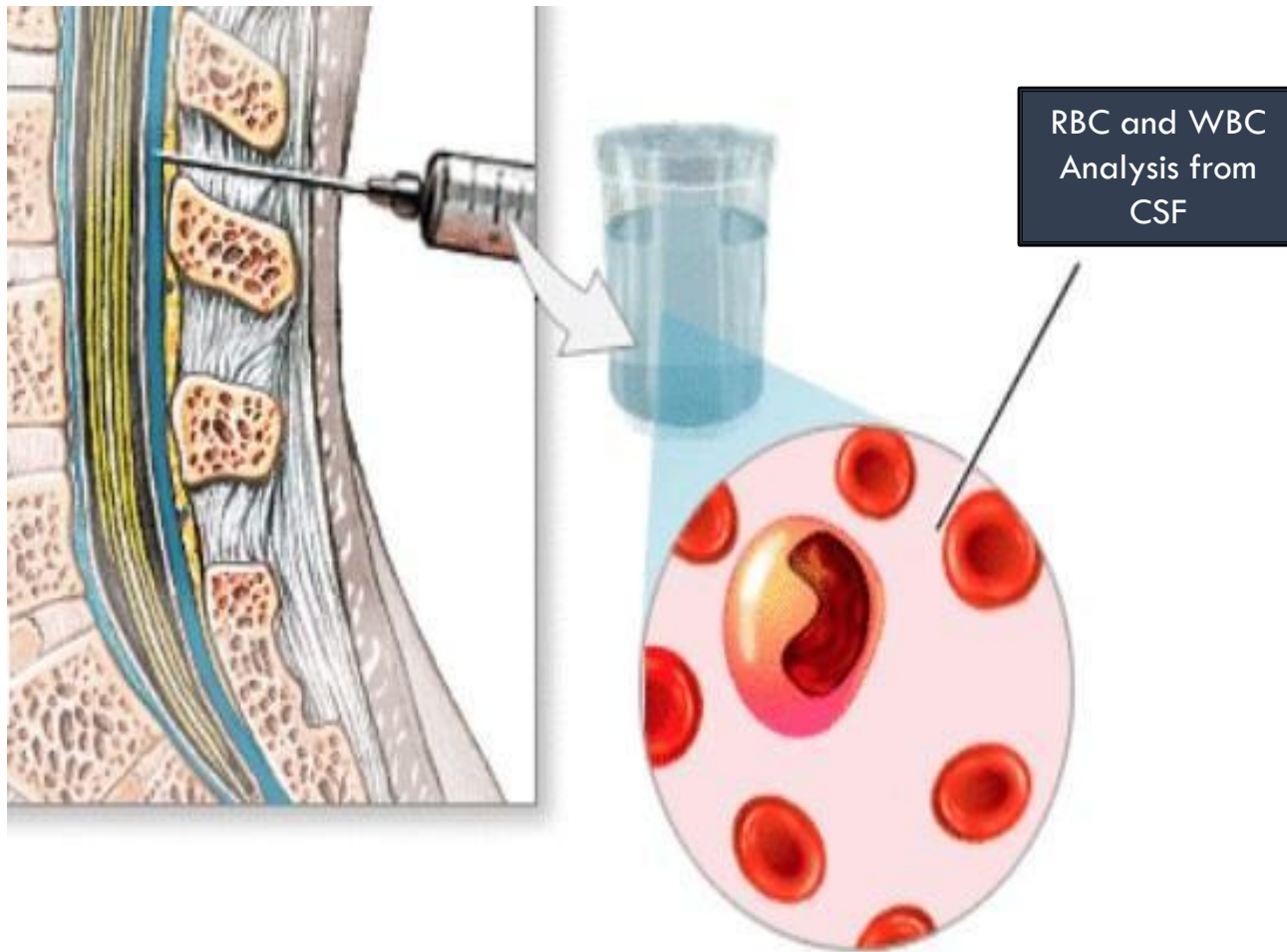
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**Undergraduate Student:** Ernest Scalabrin



# WHAT IS CEREBROSPINAL FLUID?



- CSF is a clear fluid that bathes the brain and the spinal cord
- It protects the brain against impact, removes waste, and provides nutrients to the central nervous system

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SOLUTION

# WHY IS CSF COLLECTED?

Every year, **700,000** diagnostic and therapeutic lumbar punctures are performed to collect CSF for:

Meningitis



Inflamed meninges



Leading cause of encephalitis

Viral Infections



Subarachnoid bleeding

Hemorrhage



Hydrocephalus

Intracranial Pressure

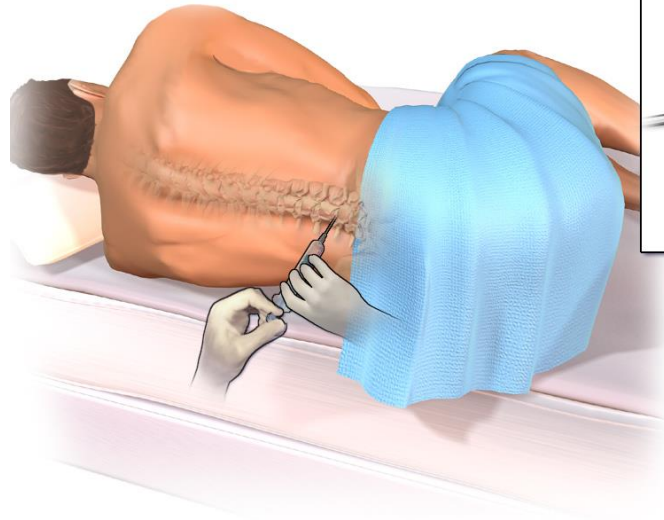
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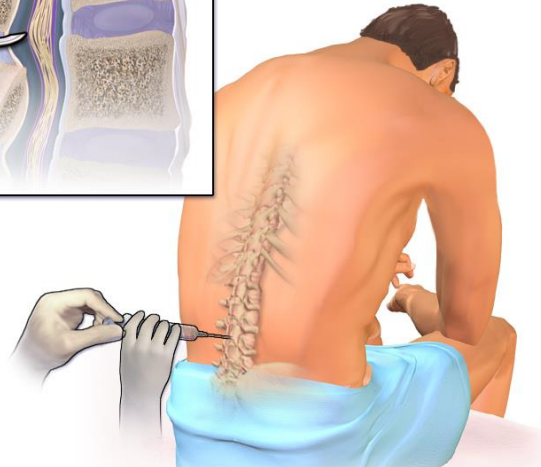
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# How Is CSF Collected?

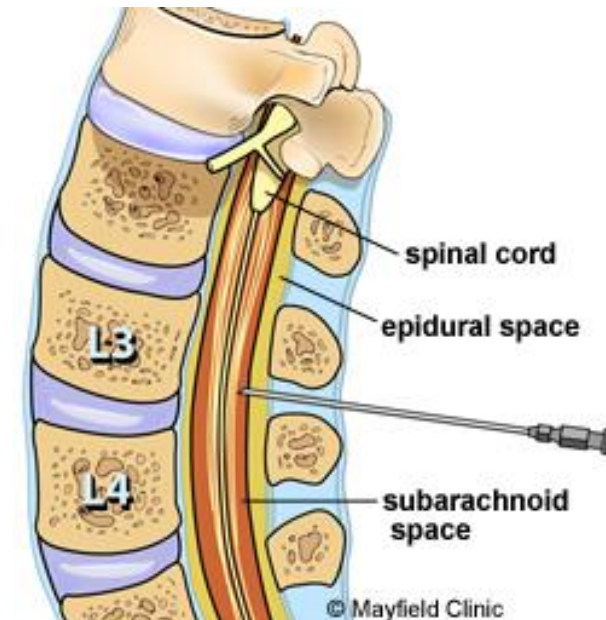
## Lumbar Puncture



Lying Position



Sitting Position



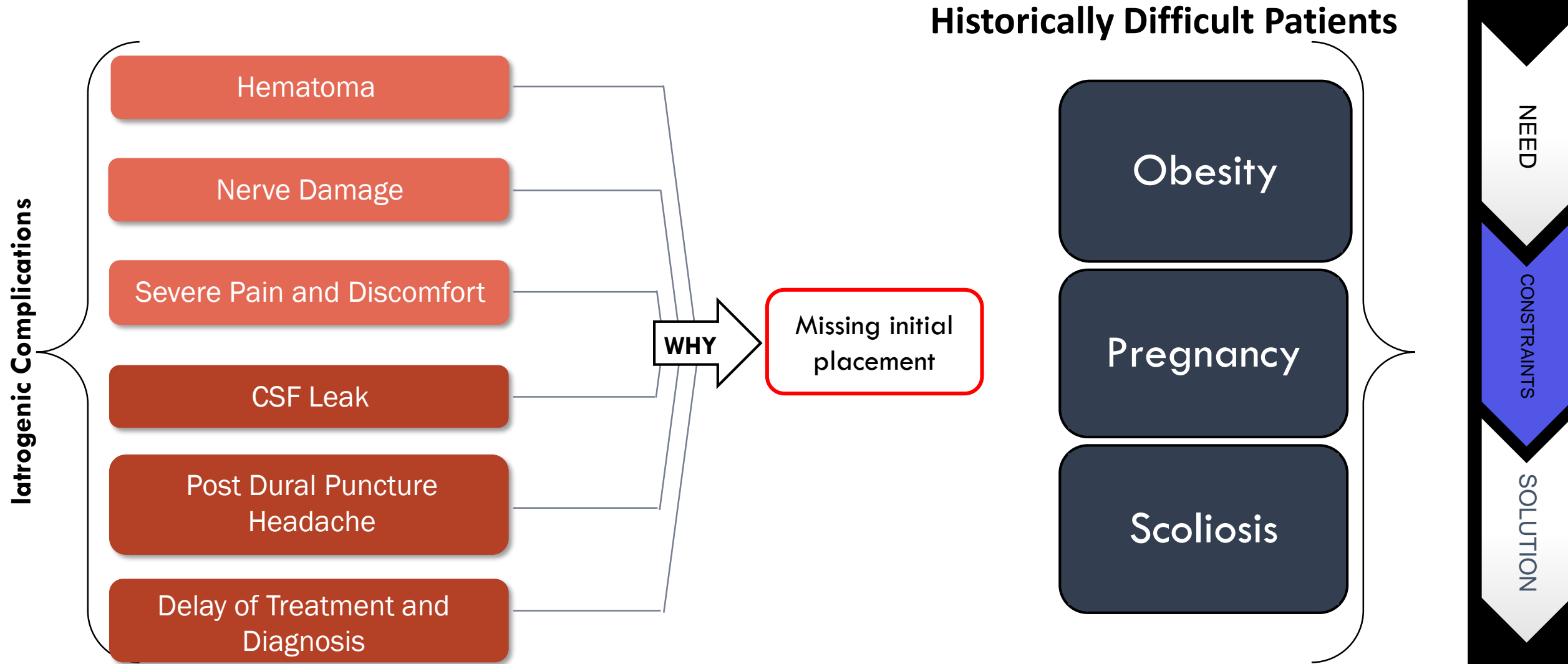
- CSF is located in the subarachnoid space of the spine
- Collected via Lumbar Puncture, navigation of a collection needle to subarachnoid space
  - Physicians must avoid blood vessels, nerves, and bone without visibility

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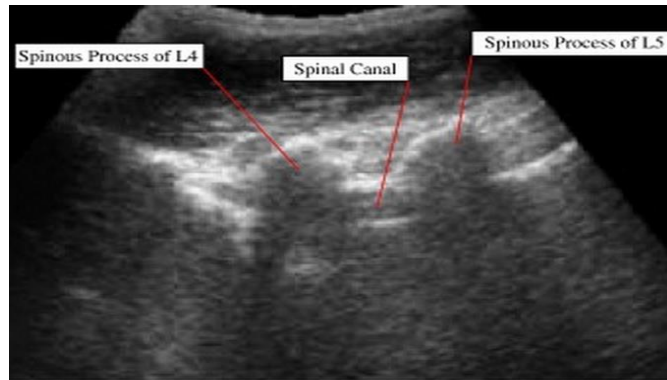
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# WHY SHOULD LUMBAR PUNCTURES BE IMPROVED?



## Static: pre-procedure

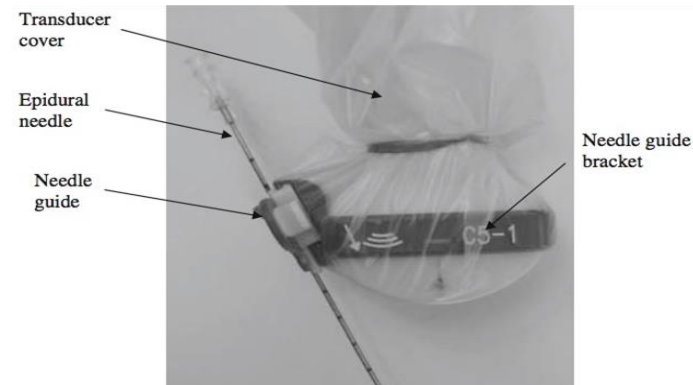


Success inversely related to BMI

Patient movement requires rescan

Wide cone of view results in shadowing

## Dynamic: intra-procedure

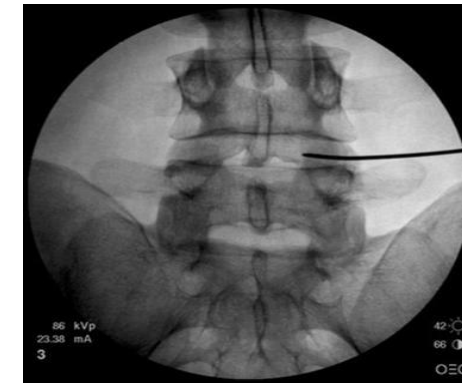


Significantly longer needle (12.5 cm)

Spinous process prevents needle visualization

Difficult to keep needle in plane of beam

## Fluoroscopic



Expensive (~\$7500)

Booked the following day

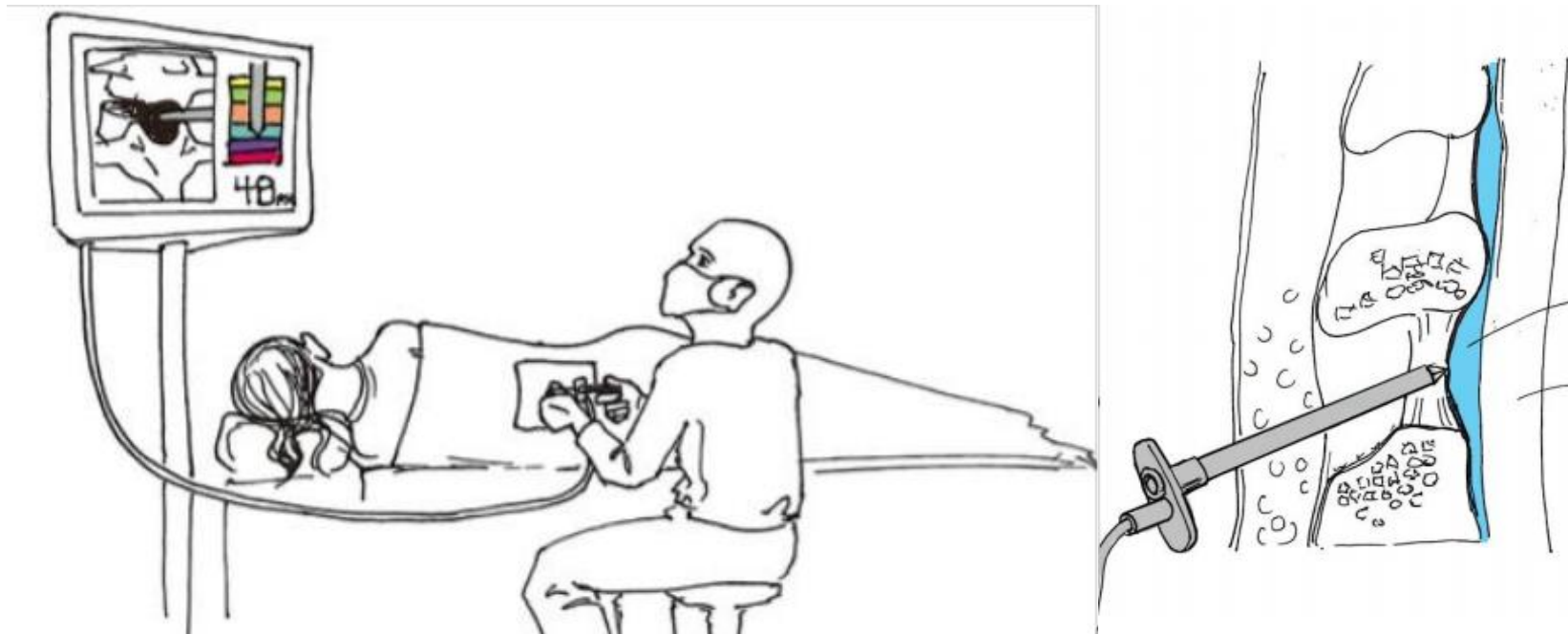
Contraindicated for pregnant patients

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# OUR SOLUTION



Device will provide:

- Improved image quality through sub-dermal imaging
- Dynamic guidance to allow the correct placement of the needle on the first attempt
- Reduced rate of iatrogenic complications

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## Disposable Needle-Embedded Ultrasound Probe



Fits within the standard 14G introducer needle



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# CURRENT PROTOTYPE

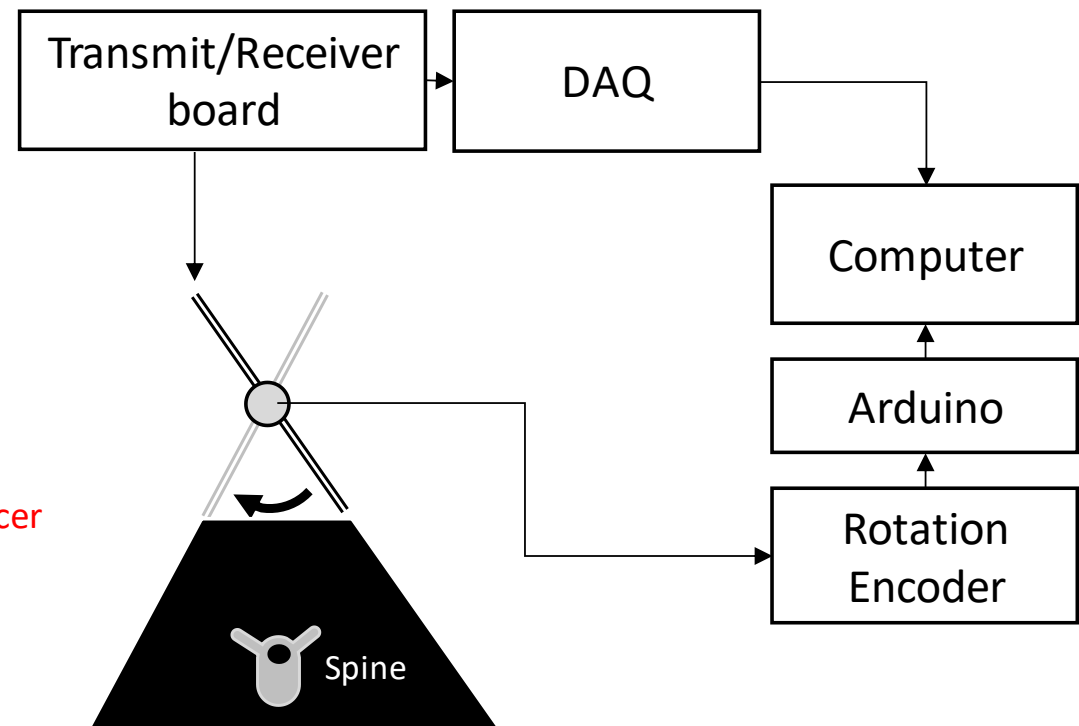
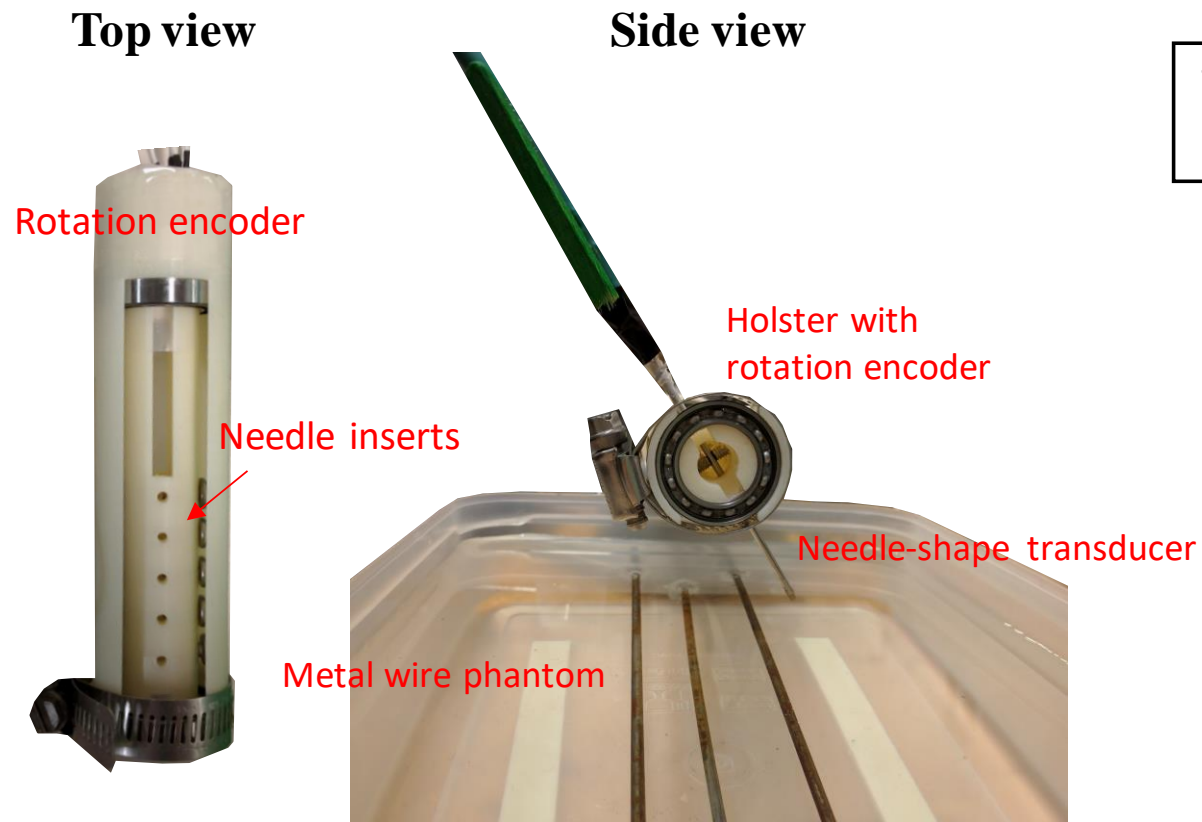


Figure Credit: Kai Zhang

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# BACK PROJECTION BASED SYNTHETIC APERTURE FOCUSING

$$y_{bf}(m, n) = \sum_e y_{bf_e}(m, n, e),$$

**Conventional delay-and-sum**

$$y_{bf}(m, n, e) = y_{pre}(d, e),$$

$$d^2 = m^2 + n^2.$$

**Back projection SAF**

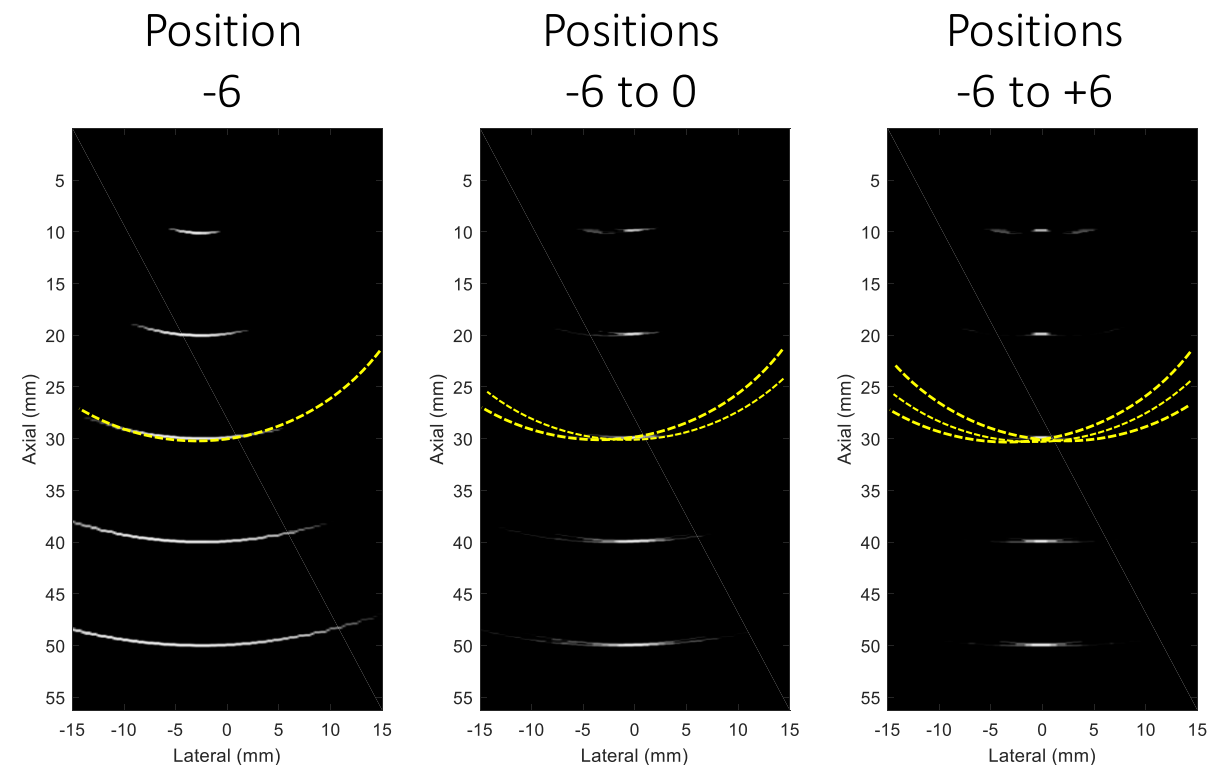


Figure Credit: Kai Zhang

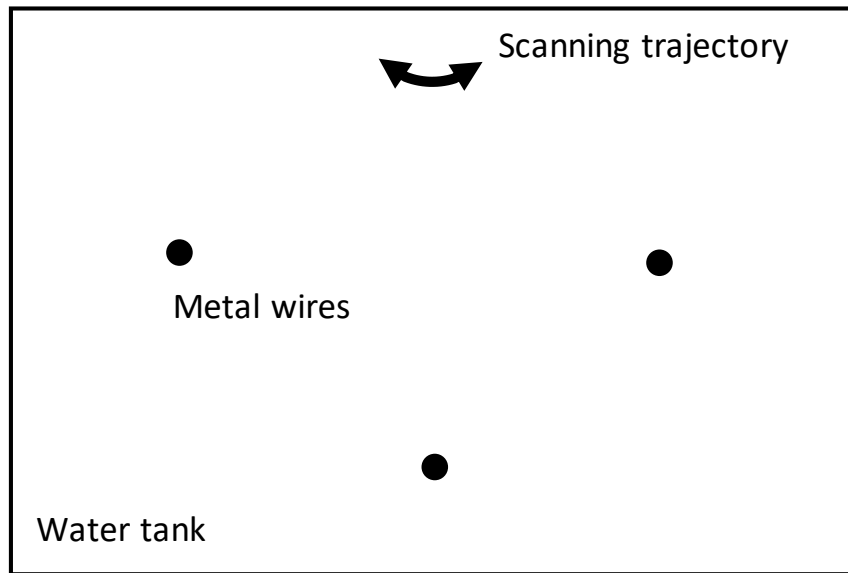
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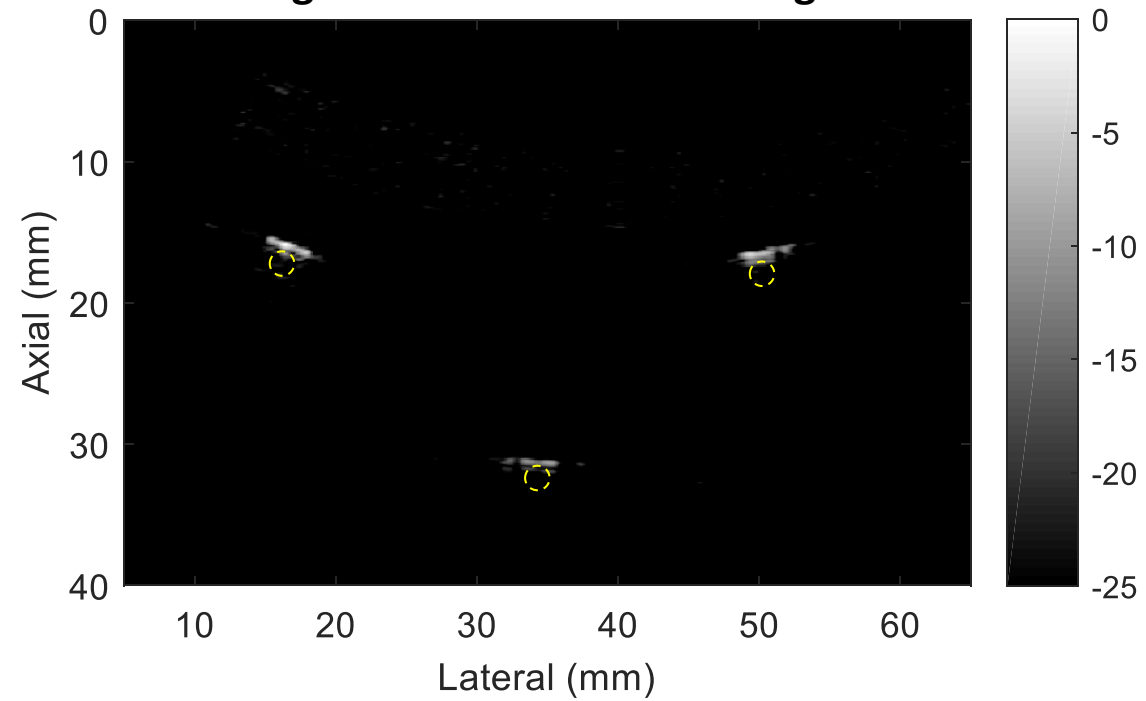
SOLUTION

# REAL TIME BEAMFORMING

### Phantom design



### Single element STRATUS image



**Synthetic Tracked Aperture Ultrasound (STRATUS)**

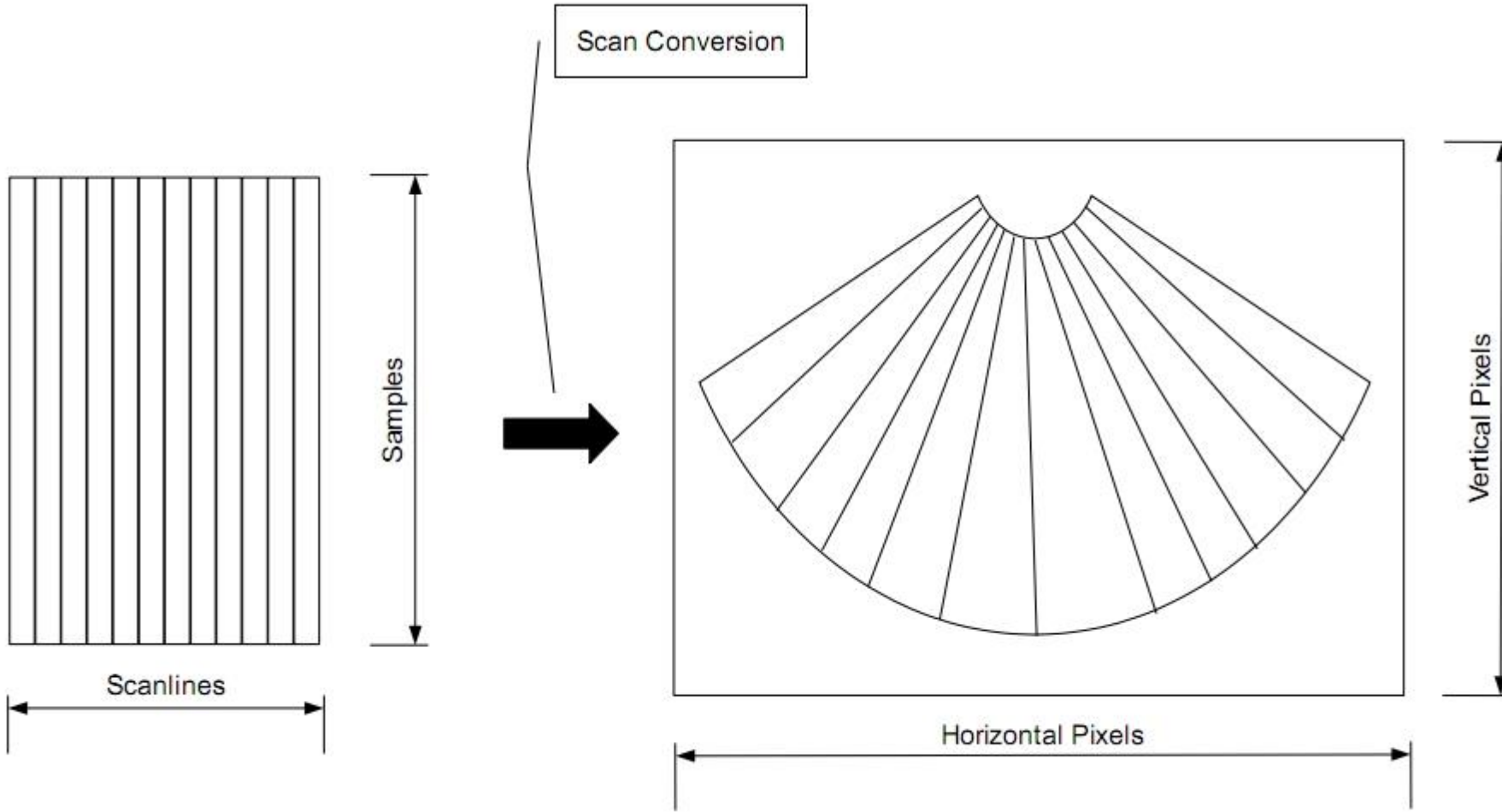
Figure Credit: Kai Zhang

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# SCAN CONVERSION



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# OFF LINE PROCESSING RESULT



Video Credit: Mateo Paredes,  
Kai Zhang

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# CURRENT LIMITATIONS

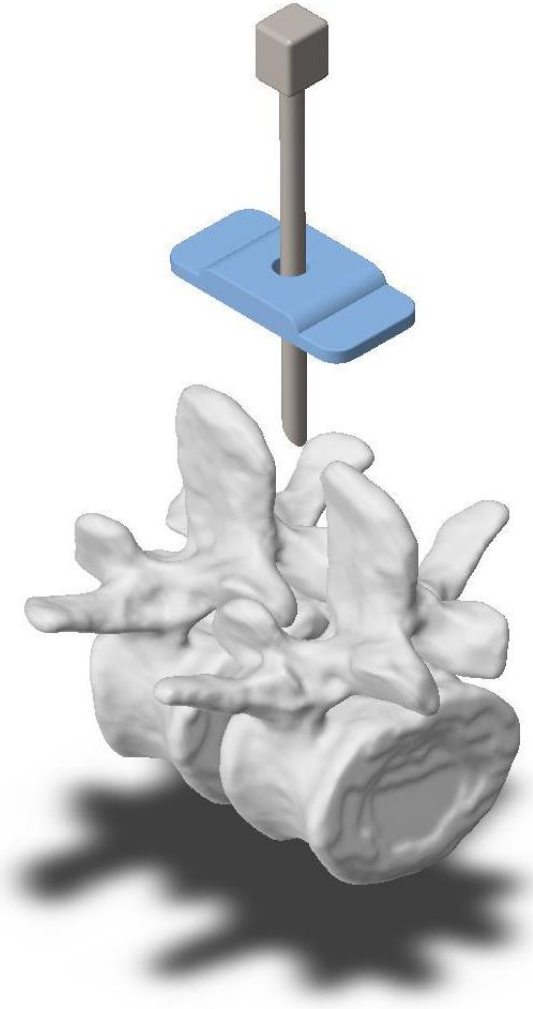
Limitation	Impact	Need
Beamforming/Scan conversion are not real time	Moderate – inconvenient for physician	Implement real time algorithm to link beamforming and scan conversion
No quantitative depth tracking	High – Obese patients have >8cm of adipose tissue	Implement depth tracking capability
Holster is very large and must be fixed to patient	High – very bulky and impractical for clinical use	Miniaturize angle tracking apparatus
Speed is not ideal	Moderate – Slows imaging and clinical results	Convert code to C++
No cross correlation of A-lines to B-mode image	Moderate – No way to orient once sweeping stops	Implement Cross correlation algorithm

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# IDEAL MECHANICAL DESIGN



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# DELIVERABLES

Task	Priority	Completion Date
C++ Translation and Speed Optimization	Minimum Deliverable	3/24/17
Beamform & Scan Conversion Integration	Expected Deliverable	3/24/17
Needle Depth Tracking	Maximum Deliverable	4/30/17

NEED

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# MILESTONES

Task	Priority	Completion Date
<b>Beamform &amp; Scan Conversion Integration</b>	<b>Expected Deliverable</b>	<b>3/24/17</b>
Study Literature		2/25/17
Understanding the Code		3/1/17
Beamforming		2/27/17
Scan Conversion		3/1/17
Able to Implement Existing Algorithm		3/6/17
Add real time scan conversion visualization in Matlab		3/17/17
Backprojection Reconstruction		3/24/17

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# MILESTONES

Task	Priority	Completion Date
<b>Needle Depth Tracking</b>	<b>Maximum Deliverable</b>	<b>4/30/17</b>
Acquire images of wire phantom		3/31/17
Attempt to use cross correlation to measure depth		4/6/17
Fabricate needle with side shooting element (or mechanical or optical tracking)		4/13/17
Integrate side shooting signal into algorithm		4/30/17

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# DEPENDENCIES

Unknown	Estimated Likelihood	Resolution Plan
Cross Correlation	Moderate (depending on anatomical effects)	Resort to mechanical or optical depth tracking. Implement side shooting element.

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# READING LIST

- [1] Armon C., Evans R. W., "Addendum to assessment: prevention of post-lumbar puncture headaches," *Neurology* 65, 510-512 (2005).
- [2] American Society for Healthcare Risk Management, "Risk Management Handbook for Health Care Organizations", Jossey-Bass, 5 (2009).
- [3] Edwards C., Leira E. C., and Gonzalez-Alegre P., "Residency Training: A Failed Lumbar Puncture Is More about Obesity than Lack of Ability," *Neurology* 84(10), e69-72 (2015).
- [4] Shah K. H., Richard K. M., et al., "Incidence of traumatic lumbar puncture," *Academic Emergency Medicine* 10(2), 151-4 (2003).
- [5] Ahmed S. V., Jayawarna C., and Jude E., "Post lumbar puncture headache: Diagnosis and management," *Postgraduate Medical Journal* 82(273), 713-716 (2006).
- [6] Shaikh F., Brzezinski J., Alexander S., Arzola C., Carvalho J. C., Beyene J., and Sung L., "Ultrasound imaging for lumbar punctures and epidural catheterisations: systematic review and meta-analysis," *BMJ* 346 (2013).
- [7] Brook A. D., Burns J., Dauer E., Schoendfeld A. H., and Miller T. S., "Comparison of CT and Fluoroscopic Guidance for Lumbar Puncture in an Obese Population with Prior Failed Unguided Attempt," *Journal of NeuroInterventional Surgery* 323-27 (2013).
- [8] Engedal T. S., Ørding H., Vilholm O. J., "Changing the needle for lumbar punctures," *Clinical Neurology and Neurosurgery* 130, 74-79 (2015).
- [9] Tamas U., Abolmaesumi P., Jalal R., Welch M., Ayukawa I., Nagpal S., Lasso A., Jaeger M., Borschneck D., Fichtinger G., and Mousavi P., "Spinal Needle Navigation by Tracked Ultrasound Snapshots," *IEEE Transactions on Biomedical Engineering* 59(10), 2766-72 (2012).
- [10] Moore J., Clarke C., Bainbridge D., Wedlake C., Wiles A., Pace D., and Peters T., "Image Guidance for Spinal Facet Injections Using Tracked Ultrasound," *Medical Image Computing and Computer-Assisted Intervention*, (2009).
- [11] Chen E. C. S., Mousavi P., Gill S., Fichtinger G., Abolmaesumi P., "Ultrasound guided spine needle insertion," *Proc. SPIE* 7625, 762538 (2010).
- [12] Najafi M., Abolmaesumi P., Rohling R., "Single-Camera Closed-Form Real-Time Needle Tracking for Ultrasound Guided Needle Insertion," *Ultrasound in Medicine and Biology*, 41(10), 2663-2676 (2015).
- [13] Wang X. L., Stolka P. J., Boctor E., Hager G., Choti M., "The Kinect as an interventional tracking system," *Proc. SPIE* 8316, 83160U (2012).
- [14] Nagpal S., Abolmaesumi P., Rasouljan A., et al., "A multi-vertebrae CT to US registration of the lumbar spine in clinical data," *Int. J. CARS* 10(9), 1371-81 (2015).
- [15] Jensen J. A., Nikolov S. I., Gammelmark K. L., Pedersen M. H., "Synthetic aperture ultrasound imaging," *Ultrasonics* 44(22), e5-e15 (2006).
- [16] Zhang H. K., Cheng A., Bottenus N., Guo X., Trahey G. E., Boctor E. M., "Synthetic Tracked Aperture Ultrasound (STRATUS) Imaging: Design, Simulation, and Experimental Evaluation," *Journal of Medical Imaging* 3(2), 027001 (2016).
- [17] Bottenus N., Long W., Zhang H. K., Jakovljevic M., Bradway D. P., Boctor E. M., Trahey G. E., "Feasibility of Swept Synthetic Aperture Ultrasound Imaging," *IEEE Transactions on Medical Imaging* 35(7), 1676-1685 (2016).

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# REFERENCES

1. Armon C, Evans RW. Addendum to assessment: prevention of post-lumbar puncture headaches. *Neurology* 2005; 65: 510– 512
2. American Society for Healthcare Risk Management (n.d.). *Risk Management Handbook for Health Care Organizations* (Vol. 1).
3. Edwards, Cory, MD, Enrique C. Leira, MD, MS, and Pedro Gonzalez-Alegre, MD, PhD. "Residency Training: A Failed Lumbar Puncture Is More about Obesity than Lack of Ability." *American Academy of Neurology* (2015): n. pag. Print.
4. Shah KH, Richard KM, et al. Incidence of traumatic lumbar puncture. *Academic Emergency Medicine*
5. Ahmed, S. V., Jayawarna, C., & Jude, E. (2006, November). Post lumbar puncture headache: Diagnosis and management. *Postgraduate Medical Journal*, 82(273), 713-716.
6. Ultrasound imaging for lumbar punctures and epidural catheterisations: systematic review and meta-analysis
7. Brook, A. D., J. Burns, E. Dauer, A. H. Schoendfeld, and T. S. Miller. "Comparison of CT and Fluoroscopic Guidance for Lumbar Puncture in an Obese Population with Prior Failed Unguided Attempt." *Journal of NeuroInterventional Surgery*, 2013, 323-27.
8. Changing the needle for lumbar punctures: Results from a prospective study
9. Ungi, Tamas, Purang Abolmaesumi, Rayhan Jalal, Mattea Welch, Irene Ayukawa, Simrin Nagpal, Andras Lasso, Melanie Jaeger, Daniel Borschneck, Gabor Fichtinger, and Parvin Mousavi. Spinal Needle Navigation by Tracked Ultrasound Snapshots. *IEEE Transactions on Biomedical Engineering*, Oct. 2012. Web.
10. Moore, John, Colin Clarke, Daniel Bainbridge, Chris Wedlake, Andrew Wiles, Danielle Pace, and Terry Peters. Image Guidance for Spinal Facet Injections Using Tracked Ultrasound. *Medical Image Computing and Computer-Assisted Intervention*, 2009. Web.
11. Chen, Elvis C. S.; Mousavi, Parvin; Gill, Sean; Fichtinger, Gabor; Abolmaesumi, Purang. Ultrasound guided spine needle insertion. *Medical Imaging 2010: Visualization, Image-Guided Procedures, and Modeling*, edited by Kenneth H. Wong, Michael I. Miga, Proceedings of SPIE, Volume 7625, 762538, 2010.
12. Single-Camera Closed-Form Real-Time Needle Tracking for Ultrasound-Guided Needle Insertion. Najafi, Mohammad et al. *Ultrasound in Medicine and Biology*, Volume 41, Issue 10, 2663 - 2676
13. Xiang L. Wang ; Philipp J. Stolka ; Emad Boctor ; Gregory Hager ; Michael Choti; The Kinect as an interventional tracking system. *Proc. SPIE* 8316, *Medical Imaging 2012: Image-Guided Procedures, Robotic Interventions, and Modeling*, 83160U (February 23, 2012); doi:10.1117/12.912444.
14. Nagpal, S., Abolmaesumi, P., Rasouljan, A. et al. *Int J CARS* (2015) 10: 1371. doi:10.1007/s11548-015-1247-5
15. Jørgen Arendt Jensen, Svetoslav Ivanov Nikolov, Kim Løkke Gammelmark, Morten Høgholm Pedersen, Synthetic aperture ultrasound imaging, *Ultrasonics*, Volume 44, Supplement, 22 December 2006, Pages e5-e15, ISSN 0041-624X.

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