Ultrasound elastography in obstetrics

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Disclosures

- Equipment loan and technical support from Siemens Healthineers and GE Healthcare
- Consultant for Siemens Healthineers
- Leadership roles in the Quantitative Imaging Biomarkers Alliance of the Radiological Society of North America
- Member of American Institute of Ultrasound in Medicine
- Consultant to the Society of Abdominal Radiology

Learning outcomes

1. Explain the motivation for using ultrasound elastography in obstetrics

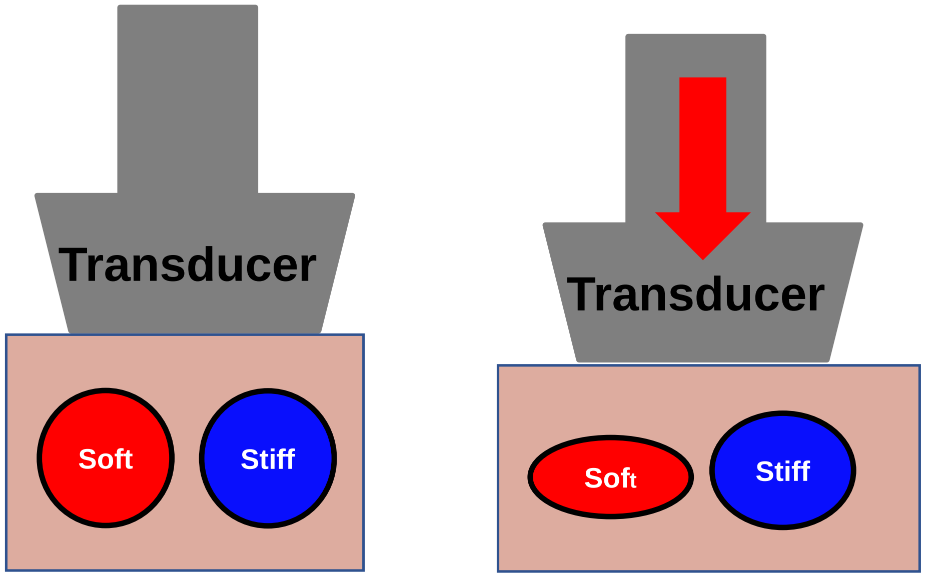
2. Provide examples of strain and shear wave elastography in the uterus, placenta, and cervix

3. Identify possible ways in which you can contribute to advance the clinical application of ultrasound elastography in obstetrics

Review: Ultrasound elastography

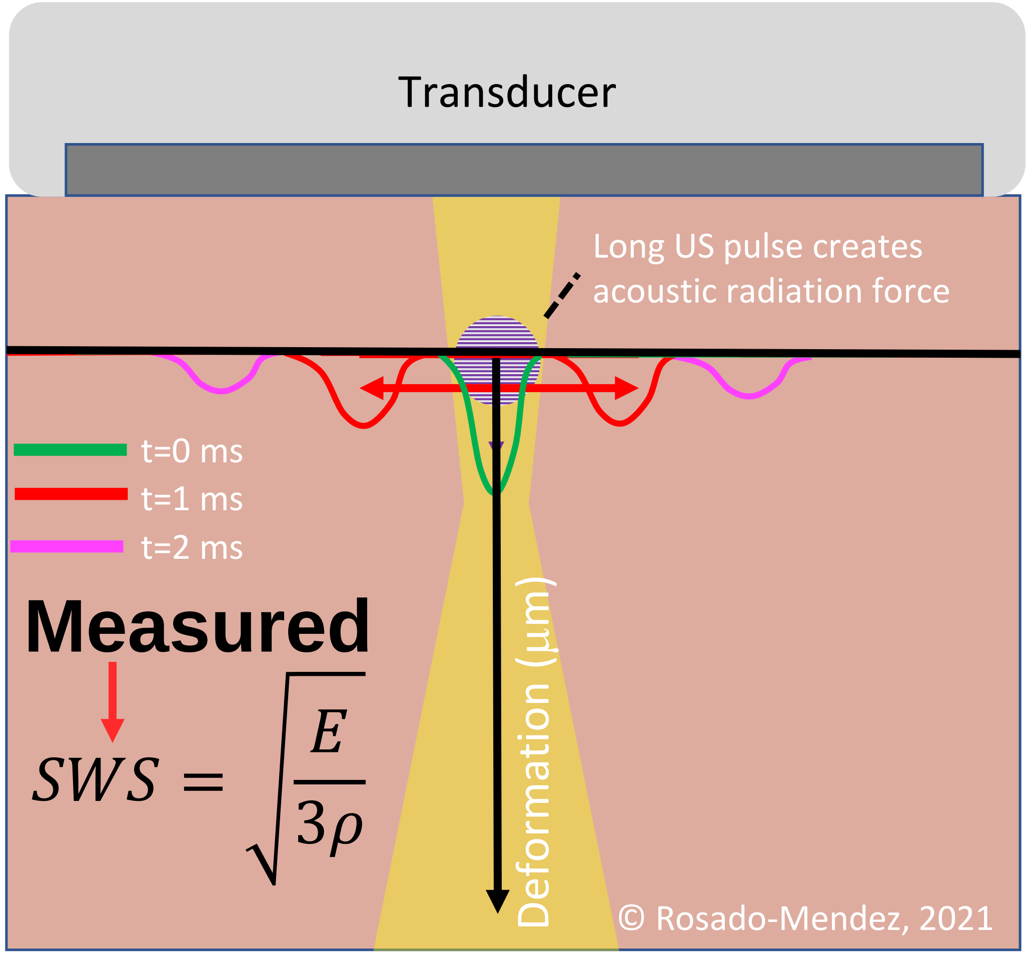
Strain Elastography

Elastic modulus $E = \dfrac{Stress}{Strain}$ ← **Measured**



Pre-compression **Post-compression**

Shear Wave Elastography

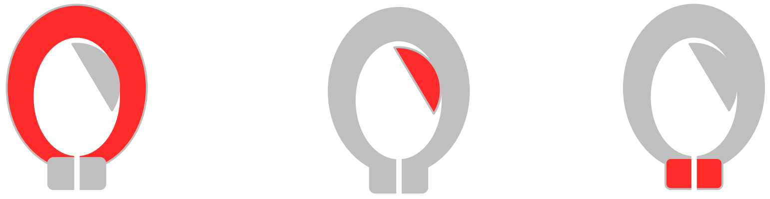


Shear wave speed $SWS = \sqrt{\dfrac{E}{3\rho}}$

Shiina et al. Ultrasound Med Biol 2015; 41(5):1126-47
Sarvazyan et al. Current Medical Imaging. 2011;7(4):255-82.

Why elastography in obstetrics?

- Pregnancy and parturition require a delicate synchrony of physiological changes of maternal and fetal tissues, including their mechanical properties
- Pathological alterations of these changes can increase the risk of complicated pregnancies
- Elastography allows characterizing non-invasively these changes and monitoring them through gestation



Uterus **Placenta** **Cervix**

Review of anatomy and physiology

Example of application of elastography

Challenges

How you can contribute

https://my.clevelandclinic.org/health/articles/22303-obstetrician
https://www.britannica.com/science/obstetrics

Uterus: anatomy and physiology

- Muscular organ that houses the developing fetus and participates in fetal nourishment
- Three layers forming the uterine wall:
  - Internal: endometrium
  - Medial: myometrium
  - External: Perimetrium
- During pregnancy, the uterine wall expands and decreases in thickness while remaining in a passive non-contractile state maintained by elevated levels of progesterone
- Hormonal changes close to term change the uterus to a contractile state to start labor

www.britannica.com
https://www.ncbi.nlm.nih.gov/books/NBK559304/
https://www.ncbi.nlm.nih.gov/books/NBK557575

Uterus: application of elastography

- **Intended application:** Assessment of risk of uterine rupture in the context of trial of labor after Cesarean delivery
- **Study goal:** Evaluate the correlation between stiffness of lower uterine segment assessed with SWE (in vivo and ex vivo) and tensile stress-strain analysis (TSSA)
- **Findings:** poor correlation between TSSA and in vivo SWE. Moderate to good correlations between TSSA and ex vivo SWE
- **Conclusion:** Further development needed before clinical translation

Seliger et al. Eur. J. Obst. Gyn. Rep. Biol. 2018, 225: 172-180

Pearson correlation of SWE [95% Confidence interval] with complex elastic modulus measured with ex vivo TSSA

	Siemens Acuson S3000 9L4	Siemens Acuson S3000 4C1	Philips Epiq 7G C5-1	Canon Aplio 500 375BT
In vivo	0.16 [-0.33, 0.58], p=0.533	0.25 [-0.24, 0.64], p=0.315	0.19 [-0.25,0.57], p=0.385	0.10 [-0.40 0.56], p=0.696
Ex vivo	0.57 [0.18, 0.80], p=0.007	0.37 [-0.07, 0.69], p=0.10	0.22 [-0.22,0.59], p=0.158	0.78 [0.48 0.92], p<0.001

24 samples of women going through C-section

Placenta: anatomy and physiology

- Main link between fetus and mother
- Disc-shaped, sponge-like organ that connects to the fetus through the umbilical cord
- Formed by infiltration of fetal cells (trophoblasts) into the endometrium and remodeling of maternal spiral arteries
- Functions:
  - Maternal recognition of pregnancy
  - Implantation
  - Exchange of nutrients and gas
  - Immune protection
  - Endocrine action

https://www.ncbi.nlm.nih.gov/books/NBK551634/
https://www.ncbi.nlm.nih.gov/books/NBK538332/

Placenta: applications of elastography

Spiliopoulous et al. Arch. Gyn. Obs. 2020, 302: 1103-1112

- **Intended application:** Evaluation of placental stiffness in the context of pre-eclampsia
- **Study goal:** Quantification of placental stiffness in healthy controls and pre-eclamptic patients
- **Findings:**
  - ➢ Stiffness in 23 pre-eclamptic patients:
    - 26.36 ± 14.1 kPa 3rd trimester
  - ➢ Stiffness in 24 healthy controls
    - 10.43 ± 7.6 kPa 3rd trimester
  - ➢ Significant effects of body mass index (BMI)
- **Other studies:** Edwards et al. confirmed confounding effects of BMI and gestational weight gain in uncomplicated pregnancies

Edwards et al. Placenta 2020, 99:79-88

Cervix: anatomy and physiology

- Cylindrical-shaped structure with central canal that connects uterus to vagina
- Highly organized collagenous composition provides mechanical strength to support growing fetus
- Gradually remodels during pregnancy towards a ripened state that allows a vaginal delivery
- Other components:
  - Smooth muscle
  - Fibroblasts
  - Epithelial cells
  - Blood vessels

Feltovich and Carlson, Seminars in Perinatology 2017, 41: 477-484
www.britannica.com

Cervix: strain elastography

- **Intended applications:**
  - ✓ Prediction of risk of premature labor
  - ✓ Assessing success of induction of labor
- **Main limitations:**
  - No consensus on how to standardize application of external compression
  - Limited to qualitative or semi-quantitative analysis due to unknown stress distribution
  - Lack of reference tissue to which cervical strain can be compared
- **Strategies to overcome:**
  - ➢ Use of internal physiological motion
  - ➢ Reference cap of known stiffness on transducer to serve as reference

Woźniak et al., Ginekologia Polska. 2015; 86(6):442-447

Prediction of spontaneous preterm labor with strain elastography applied between 18-22 weeks of gestation

Technique	Area under the ROC curve (95% CI)
Strain elastography (red and yellow colors)	0.84 (0.76-0.92)
Cervical length	0.68 (0.78-0.69)

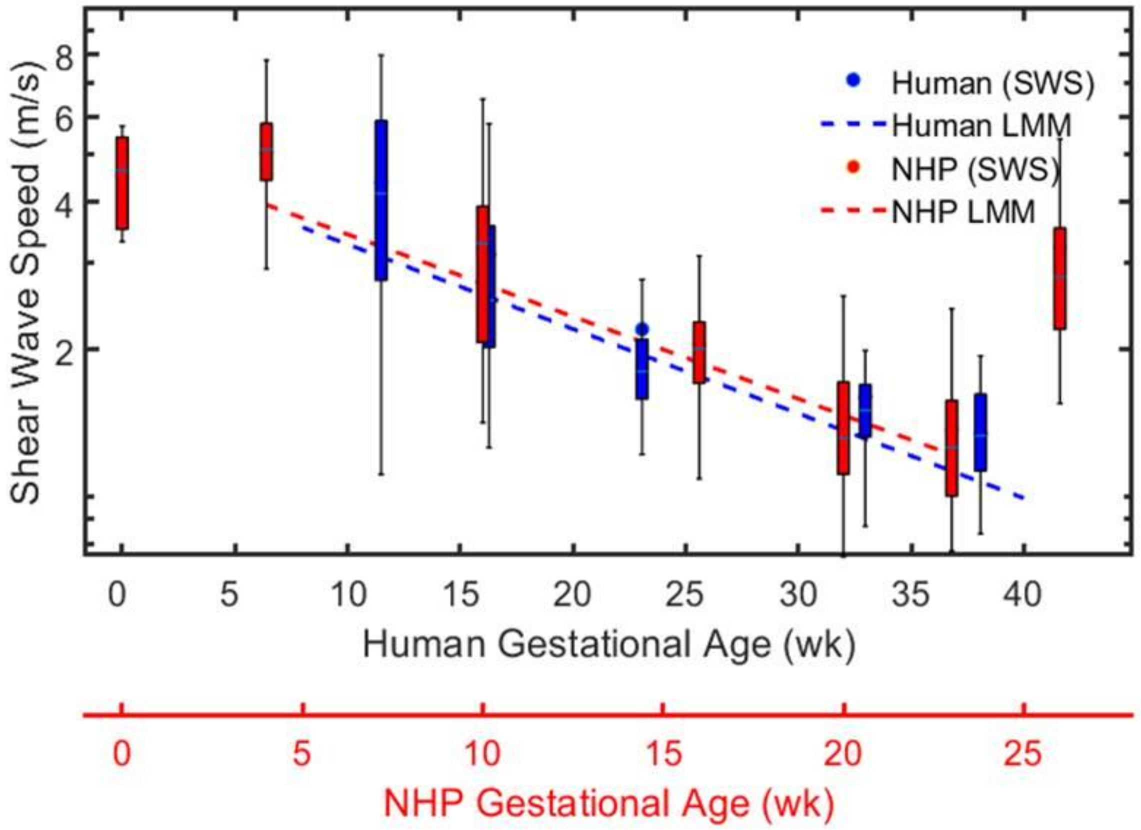
Swiatkowska-Freund and Preiss, International journal of women's health. 2017;9:245
Feltovich and Carlson, Seminars in Perionatology 2017, 41: 477-484

Cervix: shear wave elastography

- **Intended applications:**
  - ✓ Prediction of risk of premature labor
  - ✓ Assessing success of induction of labor

Hernández-Andrade et al., JPM,2014	**Carlson et al., TUFFC,2014**
Peralta et al., PLoS One, 2015	**Muller et al. UMB 2015**
Rosado-Mendez et al., UMB,2017	**Huang et al., TUFFC, 2015**
Carlson et al. UMB,2018	**Carlson et al. UMB,2018**
Rosado-Mendez et al., PMB,2018	**Carlson et al. Interface Focus, 2019**
O'Hara et al., UMB, 2019	**O'Hara et al., JUM, 2020**

Other…



Rosado-Mendez and Hall, Quantitative Imaging in Ultrasound, AIP Publishing, 2021
Rosado-Mendez et al. Ultras. Med. Biol. 2018;44(3):515-521
Carlson et al., Interface focus. 2019;9(5):20190030

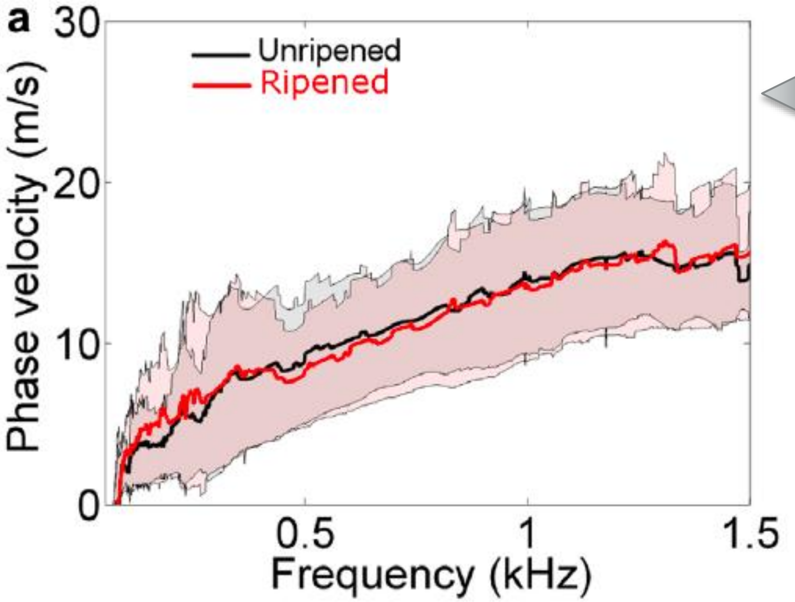
Cervix: shear wave dispersion

The cervix is not a homogeneous, isotropic, or purely elastic material

Structural heterogeneity

Viscoelastic components

Shear wave dispersion

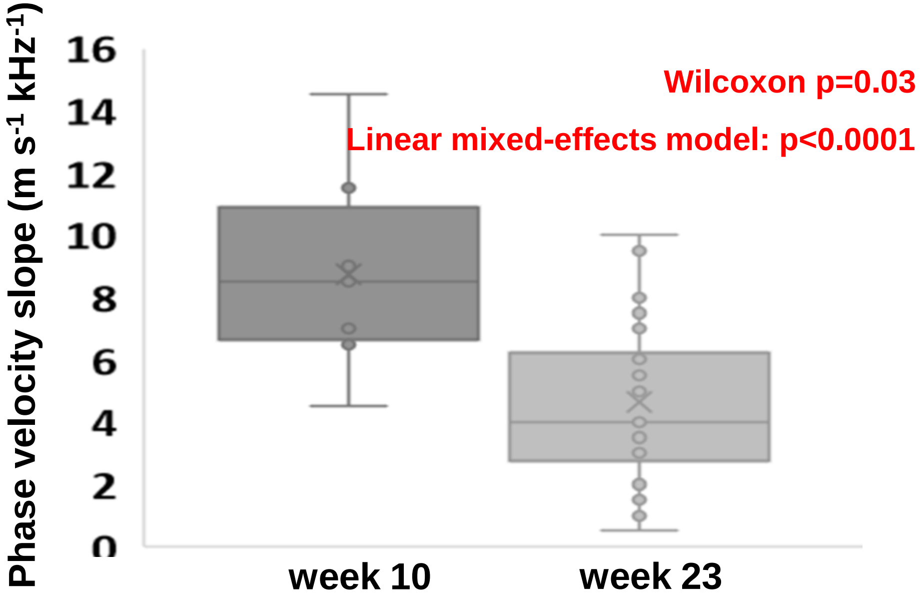


27 Rhesus hysterectomy samples

Cervical ripening induced in n=13 with 200 μg misoprostol

18 pregnant Rhesus macaques

SWEI applied at weeks 10 and 23 of the 24.3-week-long gestation



Rosado-Mendez et al., Ultras. Med. Biol 2017, 43(4):790-803
Torres et al., Frotiers in Physics 2021,15 (8):606664

Challenges of ultrasound elastography in obstetrics

- Oversimplification of and misconceptions about the formation and interactions of acoustic and shear waves with tissue
- Limited understanding of physical, biological, and technical confounders
- Lack of standardized protocols, particularly regarding the application of external force in strain elastography
- Limited understanding of safety risks of the exposure of the fetus to acoustic radiation forces

World Federation of Ultrasound in Medicine and Biology

More preclinical studies investigating the impact of acoustic radiation forces on the fetus are needed to assess the ALARA (As Low As Reasonably Achievable) principle in the context of imaging techniques using acoustic radiation forces, like SWE

Shiina et al. Ultrasound Med Biol 2015; 41(5):1126-47
Edwards et al. Placenta 2020, 99:79-88

POSSIBLE WAYS TO CONTRIBUTE

- Connect with potential collaborators in obstetrics and establish effective communication channels
- Discuss advantages, limitations, and safety aspects of each elastography modality with obstetricians in the context of specific applications
- Design protocols for the application of elastography techniques, adopting metrology approaches that allow to identify sources of systematic error and variability

Thank you

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