KAUNAS UNIVERSITY OF TECHNOLOGY

Prediction of Tissue Strain Response to External Pressure Using Subject Characteristics in Compression Ultrasonography

Justina Grajauskaitė[1], Rimvydas Eitminavičius[1], Rytis Jurkonis[1], Andrius Sakalauskas[2], Vaidotas Marozas[1], Andrius Rapalis[1]

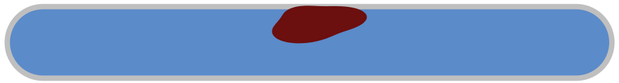
[1] Biomedical Engineering Institute, Kaunas University of Technology
[2] UAB “Telemed” Ultrasound Medical Systems

2026, Tallinn



Motivation

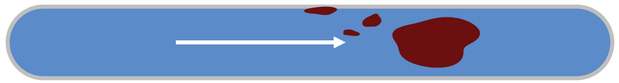
What is deep vein thrombosis (DVT)?



1

Clot forms

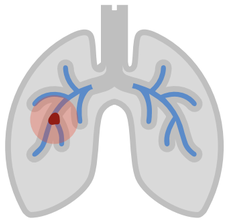
A blood clot forms in a deep vein of the leg



2

Clot breaks off

The clot travels with the blood towards the lungs



3

Pulmonary embolism

The clot blocks blood flow in the lungs and can be fatal

DVT is the third-leading cardiovascular cause of death, after myocardial infarction and stroke[1].

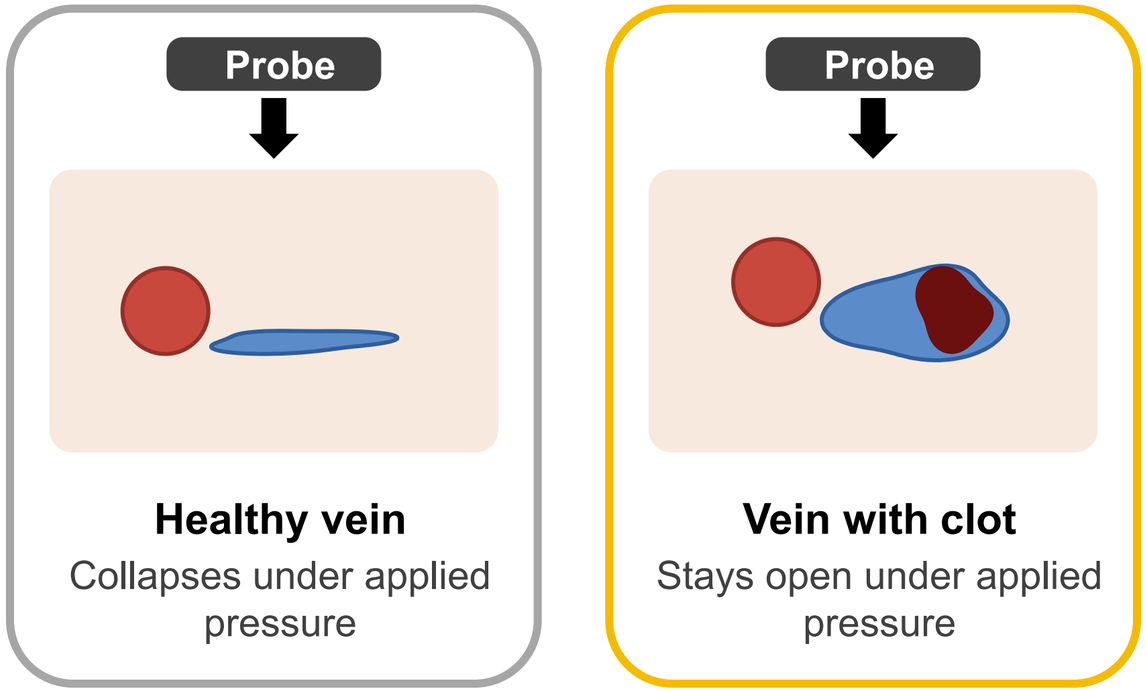
Timely, accessible diagnosis is essential

[1] S. Z. Goldhaber, H. Bounameaux, Pulmonary embolism and deep vein thrombosis, Lancet, 379(9828):1835–1846, 2012

Diagnosis and Challenge

Standard clinical test

Compression ultrasonography is used to diagnose DVT



Operator-dependent
Each sonographer applies and adjusts pressure by feel

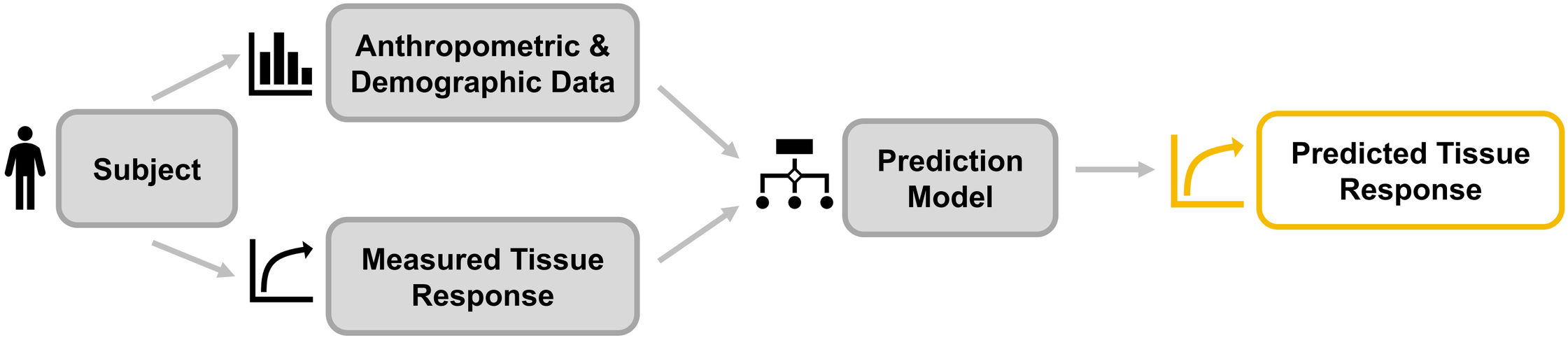
Need for controlled compression
The same conditions for every examination

Automated compression
An actuator applies pressure, guided by ultrasound

Hypothesis and Aim of the Study

Automated compression relies on feedback from the tissue, which responds differently in each person.

It is hypothesized that subject characteristics carry information about the individual soft-tissue response to compression.



We aim to predict the tissue response to compression from subject characteristics.

Methods

Experimental Setup

Instrumentation



ArtUs portable beamformer



Low-profile transducer



Air pump

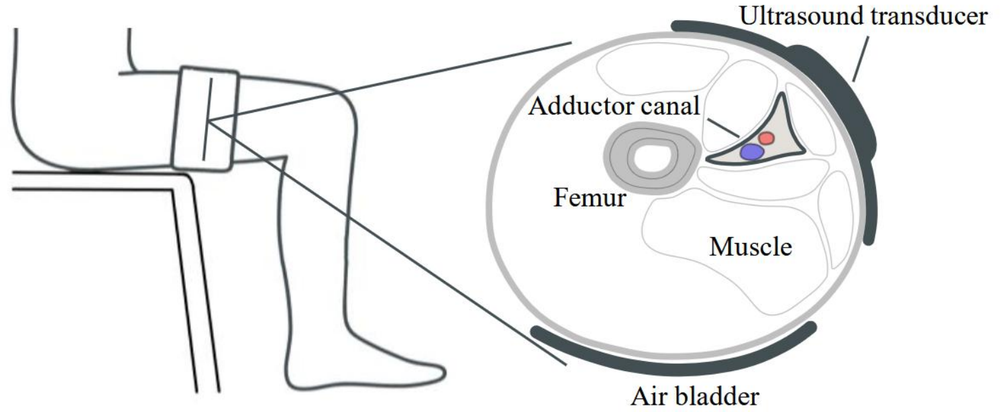


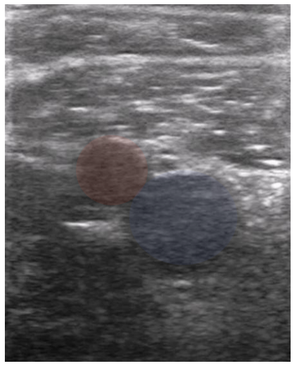
Air bladder



Compression actuator

Measurement site





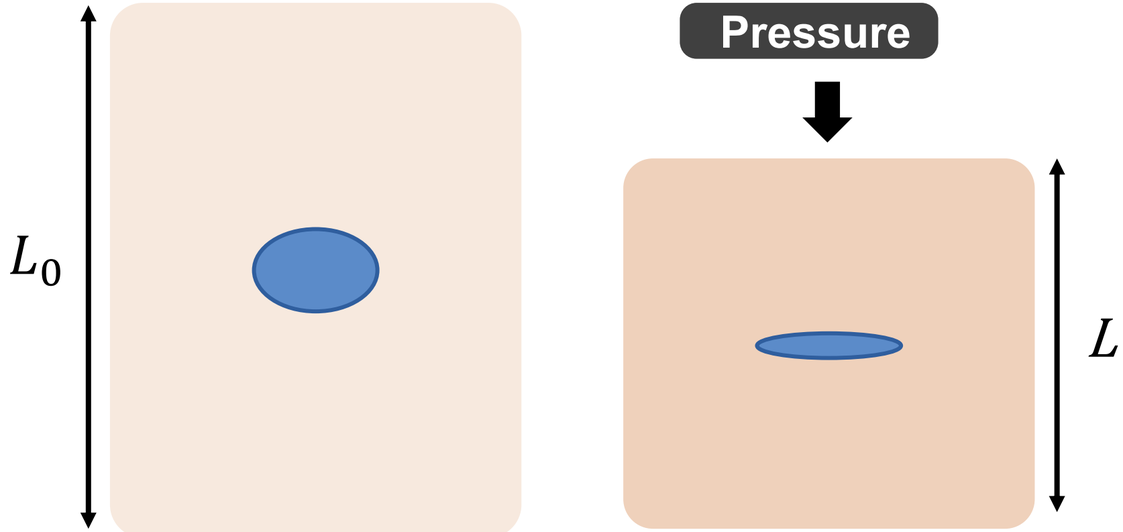
Anteromedial upper thigh

Femoral vein imaged within the adductor canal

Image size 60 × 38 mm

Methods
Strain Estimation

- **Strain** quantifies relative tissue deformation, estimated directly from ultrasound RF data, frame by frame[2].
- Expressed in **%**: the higher the strain, the more the tissue is compressed.
- For each frame, the **median strain** in the region of interest is paired with the **bladder pressure.**



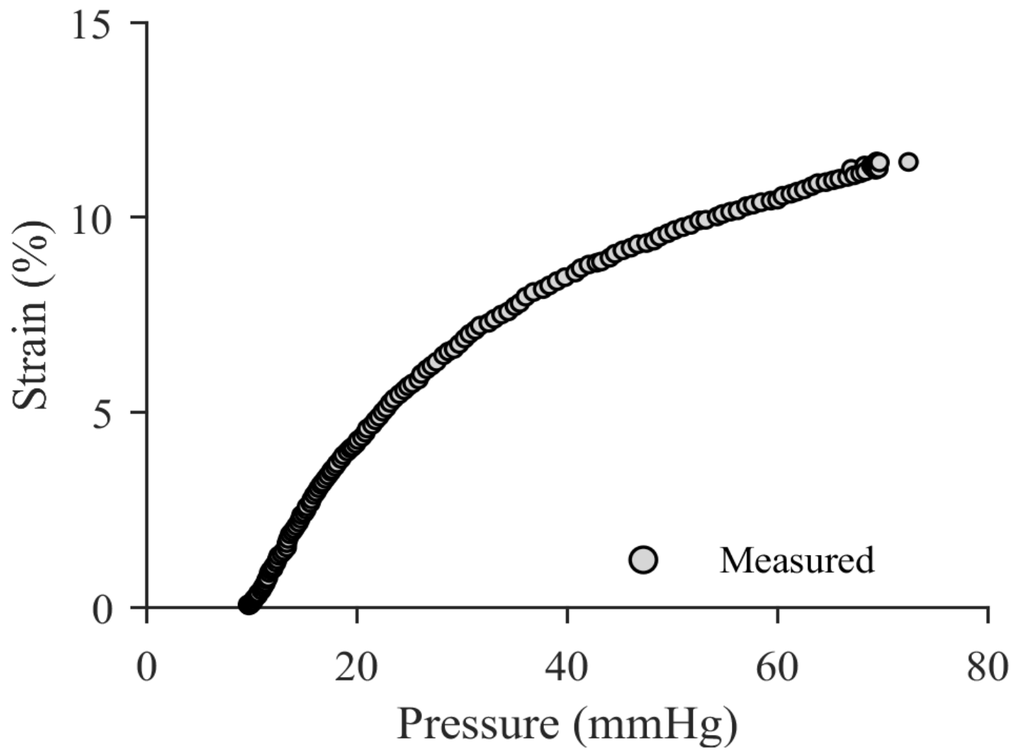
$$\varepsilon = \frac{L_0 - L}{L_0}$$

[2] R. Jurkonis, R. Eitminavičius, V. Marozas, A. Sakalauskas, Automating compression ultrasonography of human thigh tissue and vessels via strain estimation, BIOSTEC 2025

Methods

Participants and Data Acquisition

Measured **pressure–strain** curve



Participants

- 30 healthy volunteers (15 women);
- 22 curves analysed.

Protocol

- Pressure raised gradually until the femoral vein fully collapsed;
- RF data and pressure recorded simultaneously;
- Strain: median value in a 54 × 32 mm ROI per frame.

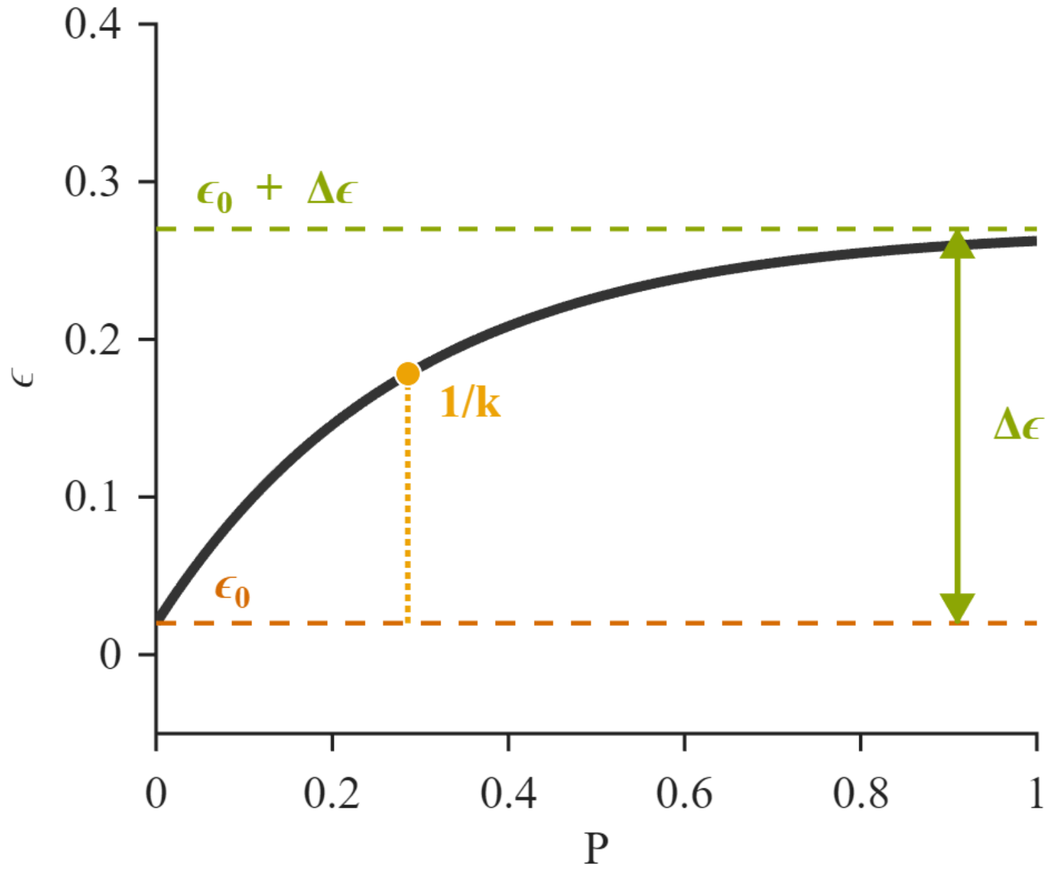
Predictors

- Demographic, anthropometric and body composition.

Ethics approval No. BE-2-67 (Kaunas Region Biomedical Research Ethics Committee); written informed consent from all participants.

Methods

Pressure–Strain Curve and Exponential Model



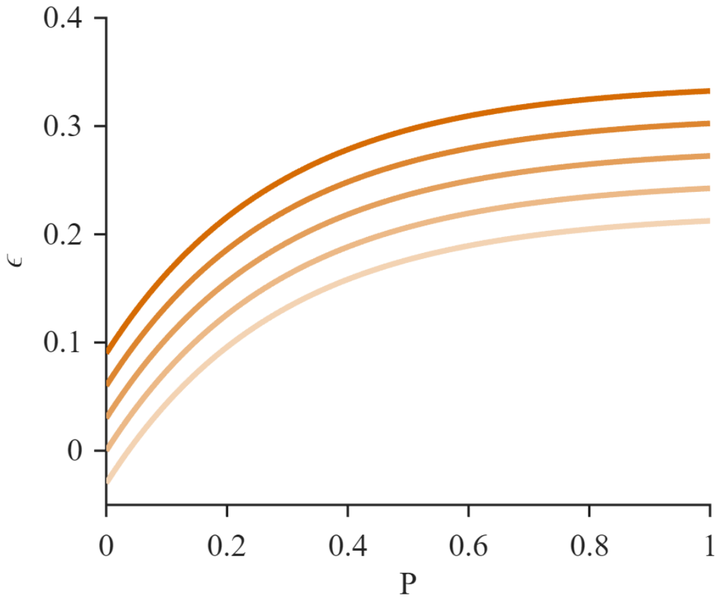
$$\varepsilon = \varepsilon_0 + \Delta\varepsilon(1 - e^{-kP})$$

ε_0 – offset $\Delta\varepsilon$ – amplitude k – curvature

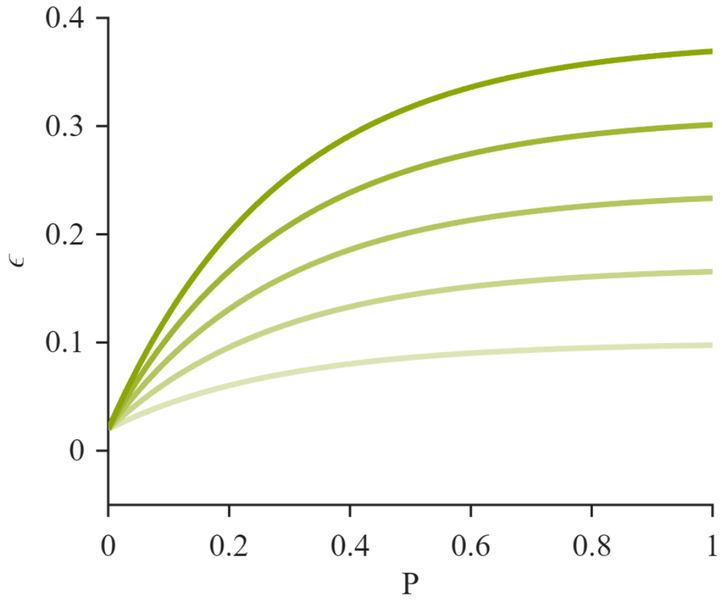
Methods

Pressure–Strain Curve and Exponential Model

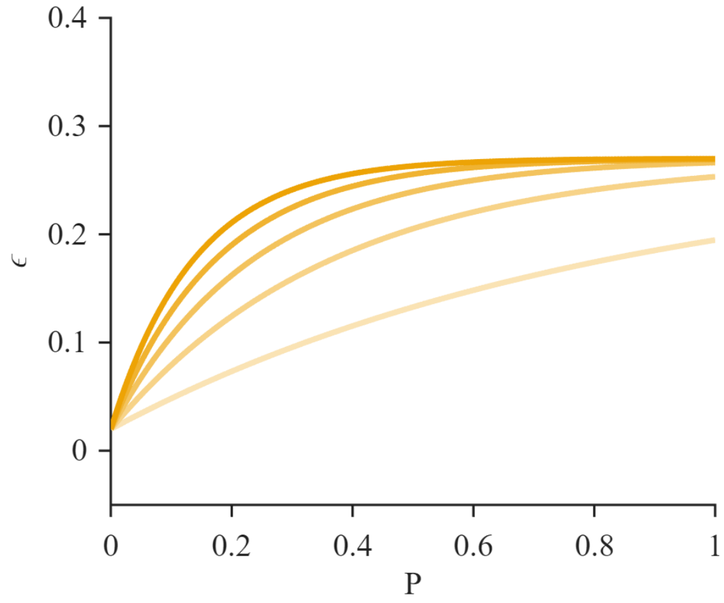
ε_0 – offset



$\Delta\varepsilon$ – amplitude



k – curvature



Methods
Predictor Sets

S — age, sex | height, weight, BMI | thigh circumference, thigh length

B — body fat mass, body muscle mass, left leg fat mass, left leg muscle mass, hydration

- Correlated variables ($r > 0.7$) were never placed in the same set.
- Variables from the same conceptual block were never placed in the same set.
- A set was dropped if it shared two variables with another set, and the remaining variable in that set was also strongly correlated ($r > 0.7$).

Standard sets



Body composition sets



Methods

Regression and Validation

Three regularized models – chosen for the small sample and correlated predictors

Ridge

Ridge regression

Shrinks coefficients to reduce overfitting

PCR

Principal component regression

Reduces predictors to fewer latent components

PLS

Partial least squares

Latent components weighted by the response

Leave-one-out cross-validation

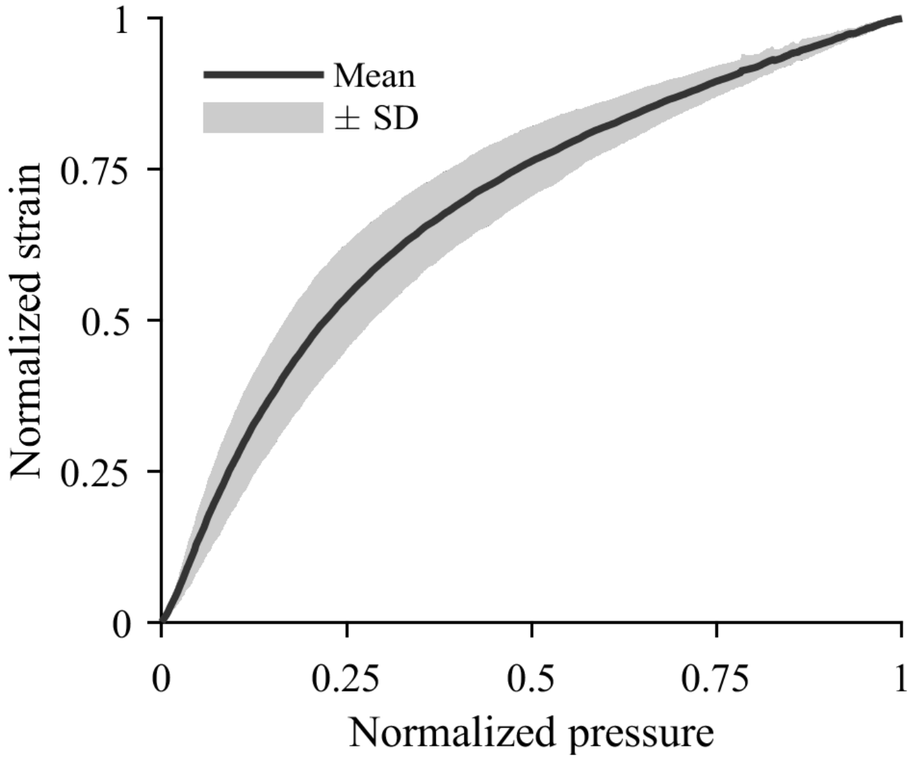


- test subject
- training subjects

- **Scaling and hyperparameters** set within each training fold only
- **Log and logit transforms** keep parameters physically valid

Results
General Tendencies

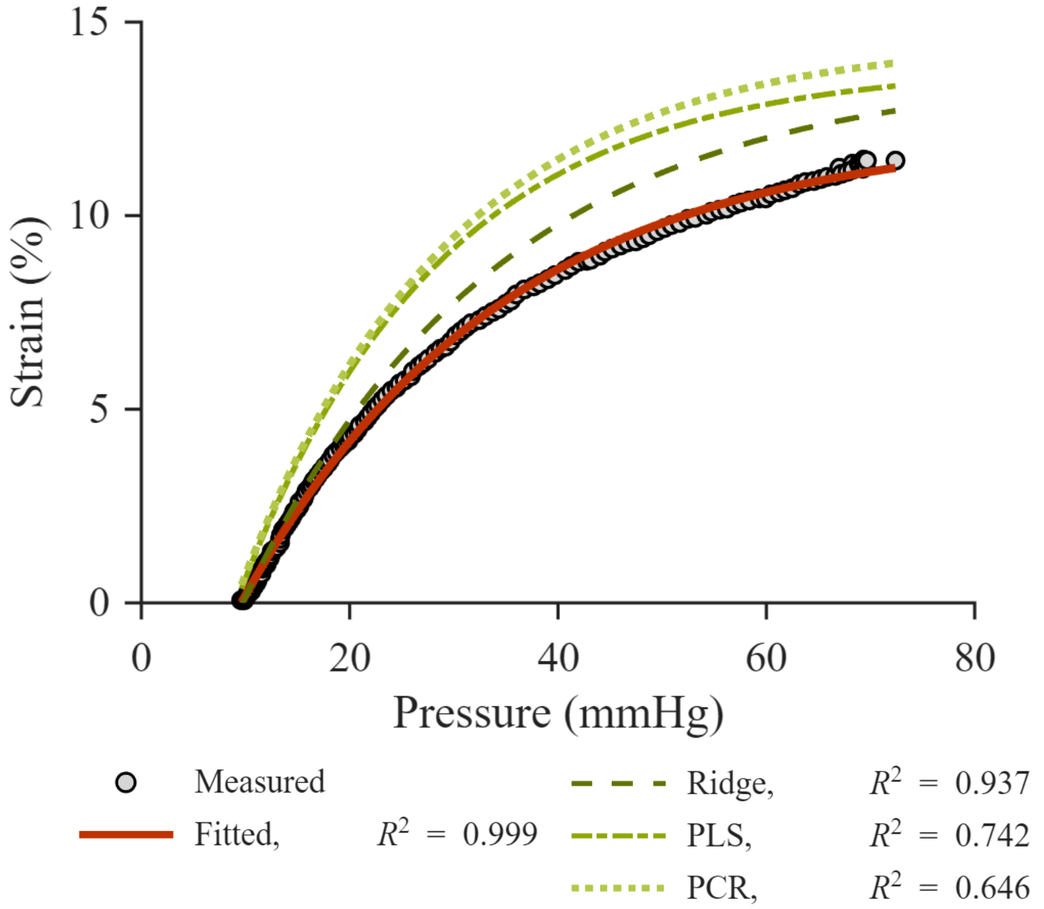
- **Consistent non-linear response** across all subjects, with a narrow SD band.
- **Strain rises steeply** at low pressures, then approaches saturation.
- **Common mechanical behaviour** suits a parametric (exponential) model.



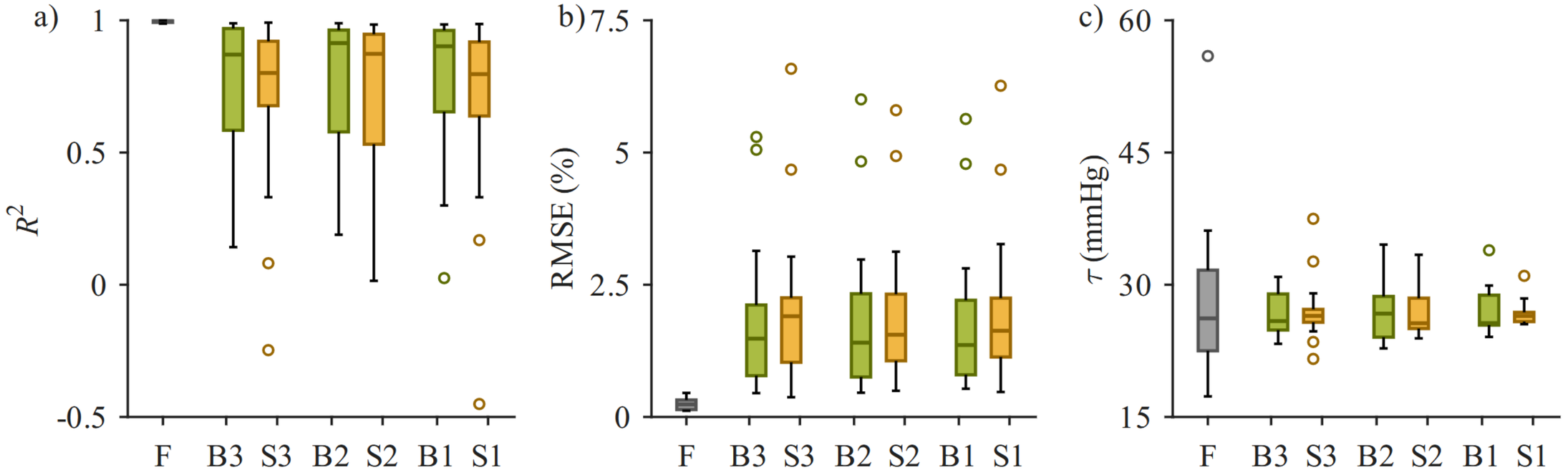
Results

Individual Example

- **Fitted curve** closely follows measured data (R^2 = 0.999).
- **All three models** reproduce the curve shape but overestimate strain at high pressures.
- **Ridge regression** came closest for this subject (R^2 = 0.937).
- **Gap between fitted and predicted curves** shows the limit of subject characteristics alone.



Results
Model Performance



F – fitted

B3 (Ridge), B2 (Ridge), B1 (PLS) – body composition sets

S3 (PCR), S2 (PLS), S1 (PLS) – standard sets

B3 height, thigh circ., left leg fat mass
B2 thigh circ., body muscle mass
B1 left leg muscle mass
S3 age, weight, thigh length
S2 sex, weight
S1 weight

Conclusions

- Pressure–strain curves are reliably described by a three-parameter exponential model (median R^2 0.997).
- Subject characteristics carry enough information to estimate the general curve shape (median R^2 0.797–0.914).
- Body composition variables add only a small, consistent improvement – standard anthropometric measurements may suffice.
- Predicted subject-specific curves could support automated quality control in compression ultrasonography.

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