

AND TISSUE MECHANICAL VARIABILITY

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1. Introduction

Mechanical stability of skin and underlying tissues under load is critical for understanding the development of pressure injuries. Wearable medical devices can create localized loading that produces internal tissue deformation even when surface pressures appear moderate, particularly in the sacral region. Using finite element (FE) modeling, we evaluate how differences between individuals (e.g. skin thickness & stiffness) and device geometry (sensor vs. cable) influence internal stress and strain distributions across skin and deep tissue layers [1,2].

2. Methods

Models: Include: Epidermis, dermis, adipose, muscle, and bone. Two FE geometries were used: a simplified back-region model (Fig 1A) representing average male/female anatomy (models 1/2) and a realistic sacral model (Fig 1B) based on MRI-informed sacral geometry for localized wearable-device loading [3,4].

Pressure levels: Externally applied 2-10 kPa pressures via a circular 10-mm diameter sensor or an elongated cable (Fig. 1)

Tissue mechanical variability: Soft-tissue stiffness baseline represents literature-based average tissue stiffness and was varied $\pm 20\%$ to model e.g., aging or disease effects.

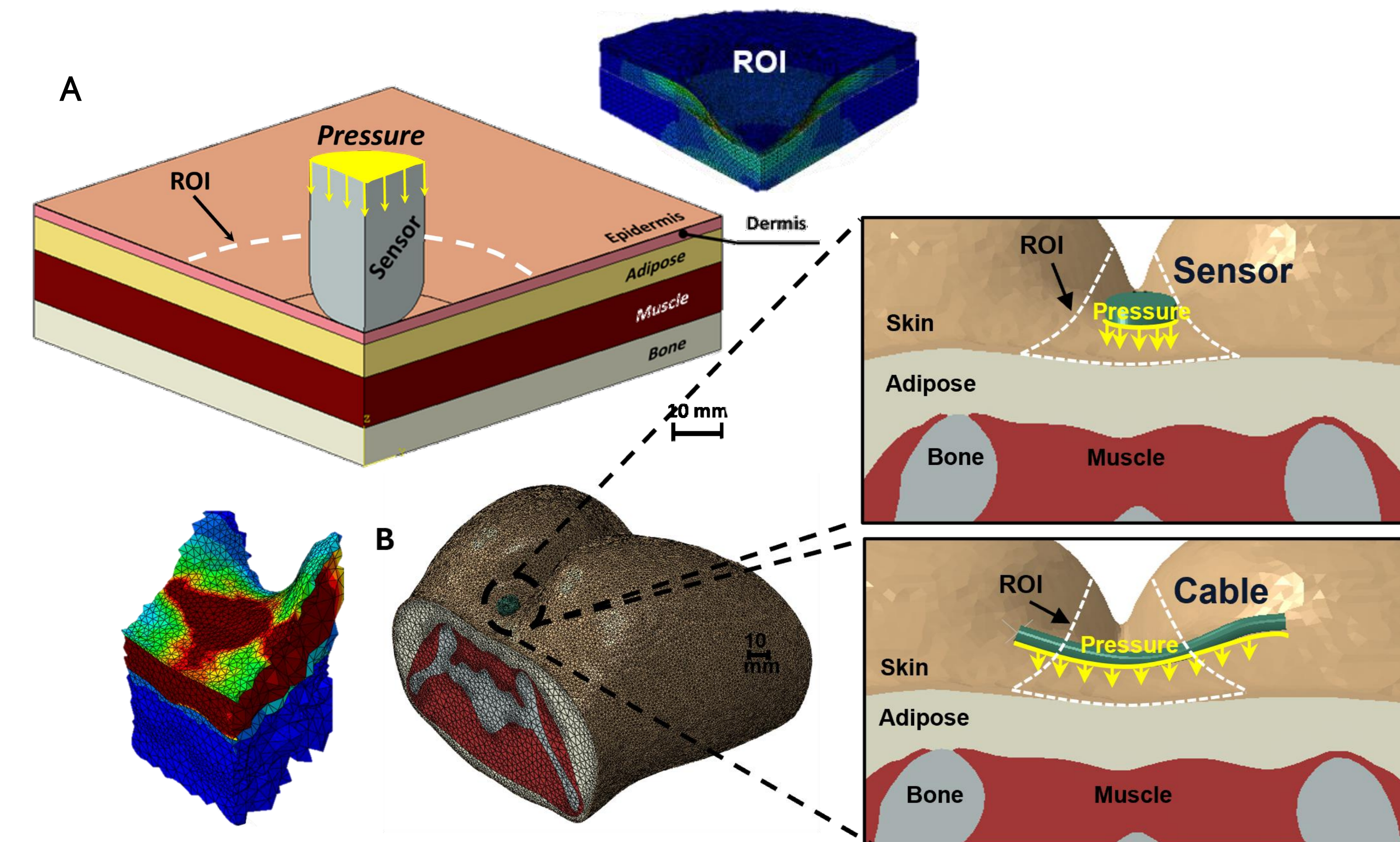


Fig. 1 Geometry of skin model with an applied pressure
All computational models were created using Abaqus/CAE 2024

Outcome measures

Effective stress and strain within a 30-mm region of interest (ROI) using the following two metrics:

Inter-person tissue mechanical variability

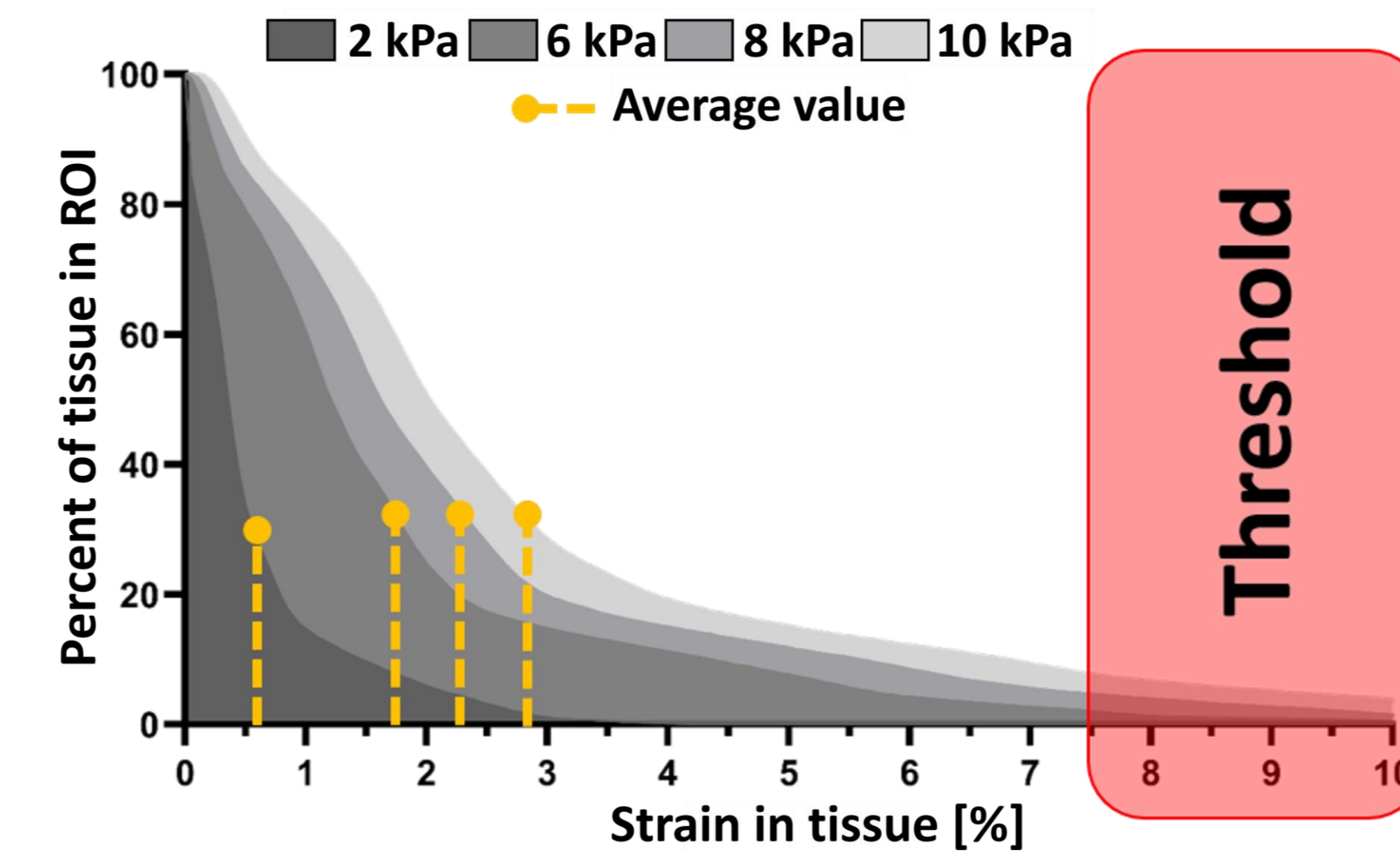


Fig. 2 Strain damage threshold was defined as the 75th percentile at 10 kPa from Model 1.

$$\text{Tissue Exposure} = \frac{\text{AUC}_{\text{threshold}}}{\text{AUC}_{\text{total}}} \times 100$$

Threshold was chosen as $>9\%$ strain induces cell damage [5], while 3-6% [6,7] strain promotes tissue repair.

Contacting wearable-device geometry effect

Normalized risk index (RI) was defined from the area under curve (AUC) of cumulative stress/strain distributions within the ROI \rightarrow magnitude and spatial extent of tissue loading.

$$\text{Risk Index} = \frac{\text{AUC}_{\text{stress or strain}}}{\max(\text{AUC}_{\text{stress or strain}})} \times 100$$

3. Results

Inter-person tissue mechanical variability

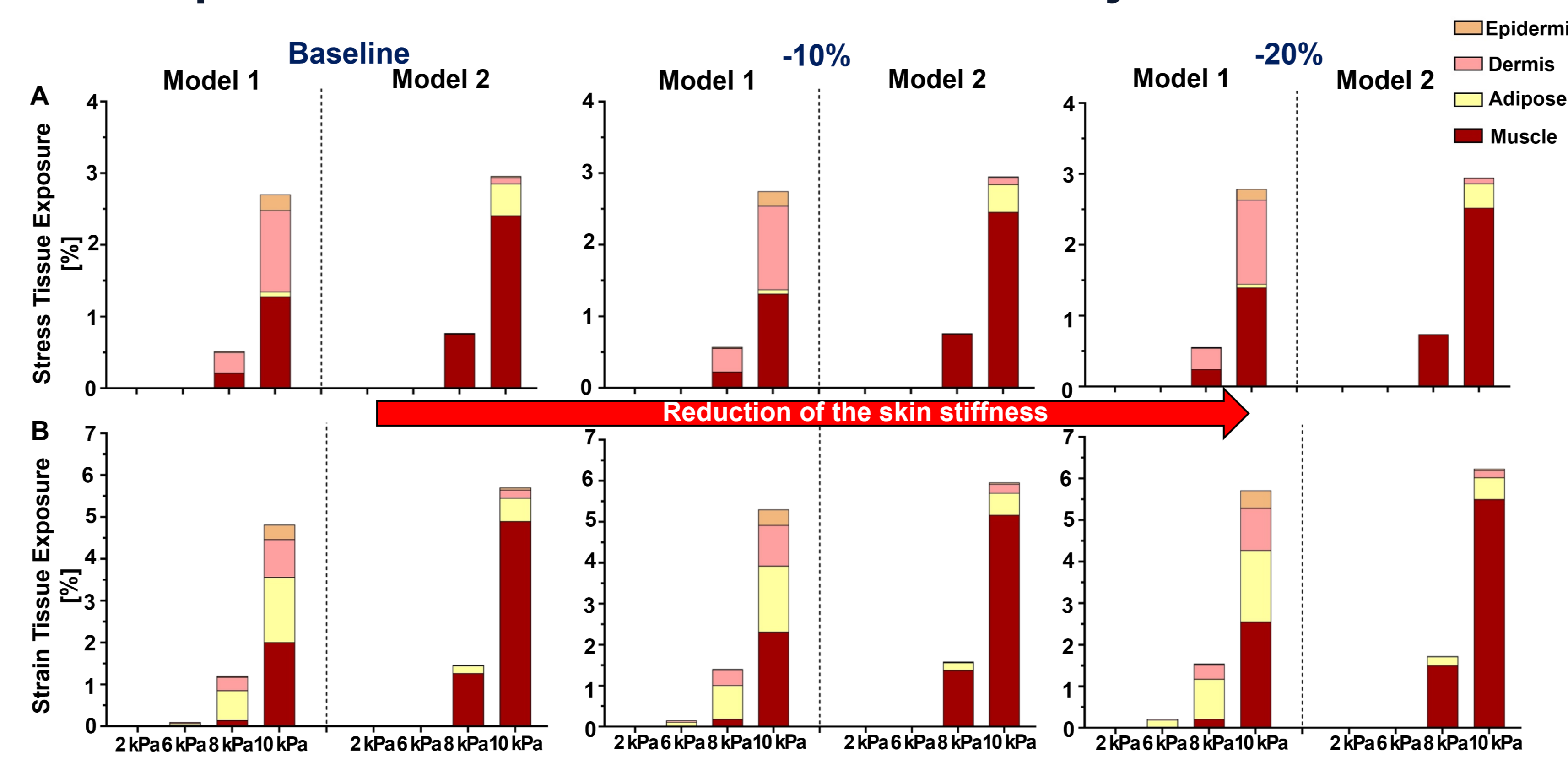


Fig.3 Percent tissue exposed to high stress (A) or strain (B) increases with higher loads and reduced stiffness. Muscle is the most affected layer, with dermis and adipose layers exhibiting increased exposure in Model 1 under softening.

Contacting wearable-device geometry effect

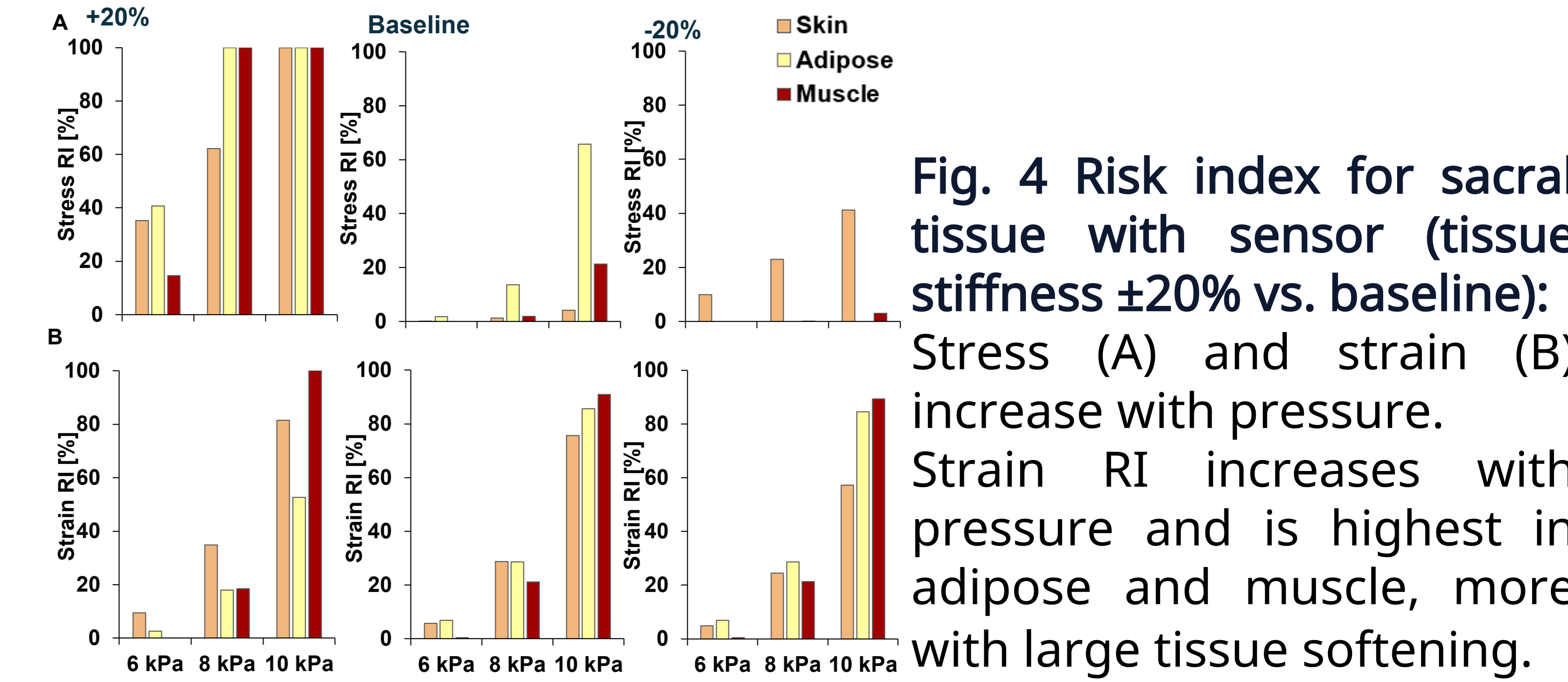


Fig. 4 Risk index for sacral tissue with sensor (tissue stiffness $\pm 20\%$ vs. baseline): Stress (A) and strain (B) increase with pressure. Strain RI increases with pressure and is highest in adipose and muscle, more with large tissue softening.

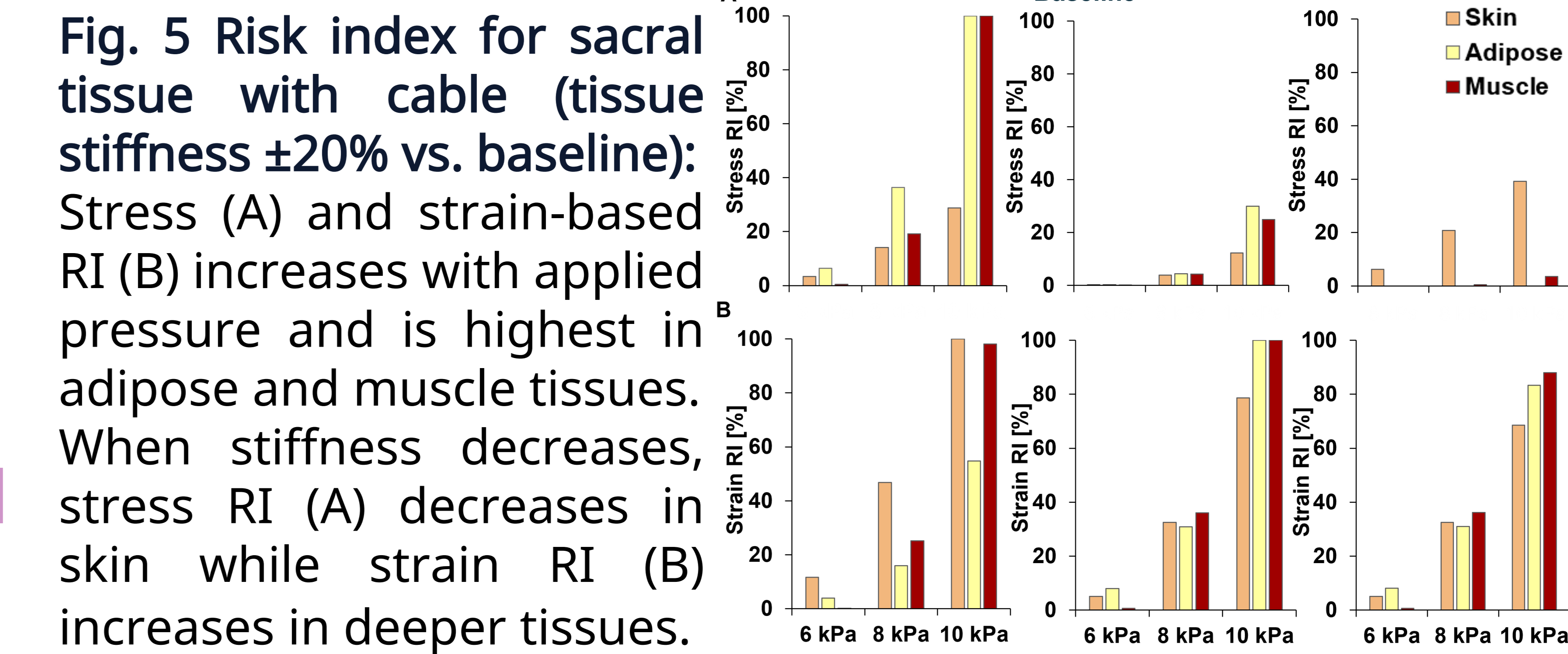


Fig. 5 Risk index for sacral tissue with cable (tissue stiffness $\pm 20\%$ vs. baseline): Stress (A) and strain-based RI (B) increases with applied pressure and is highest in adipose and muscle tissues. When stiffness decreases, stress RI (A) decreases in skin while strain RI (B) increases in deeper tissues.

4. Discussion & Conclusion

- Increasing pressure and reduced stiffness increase tissue exposure to high stress and strain, with higher exposure in models with less adipose tissue.
 - Cable loading \rightarrow higher strain exposure in deeper tissues.
 - With increasing pressure, strain increase across all tissue layers, mainly in adipose tissue and muscle.
- Even moderate surface pressures may lead to substantial internal deformation in pressure-vulnerable regions.

5. References

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 [2] Simonova, Weih's et al. under review [6] Toume, Weih's et al. *Int Wound J* 14(4):698-703 (2017)
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 [4] Shoham & Gefen *J Tissue Viability* 21(2):39-46 (2012)

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