Parametric study of mechanical behavior of auxetic geometries for skin tissue engineering

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SKIN TISSUE ENGINEERING

Skin tissue engineering research aims to develop **functional skin substitutes** that closely **mimic** the structure, function, and appearance of **natural skin**. This involves creating **scaffolds** using biomaterials that replicate the **extracellular matrix** of the skin, providing a framework for **cell growth** and organization similar to natural tissue [1].

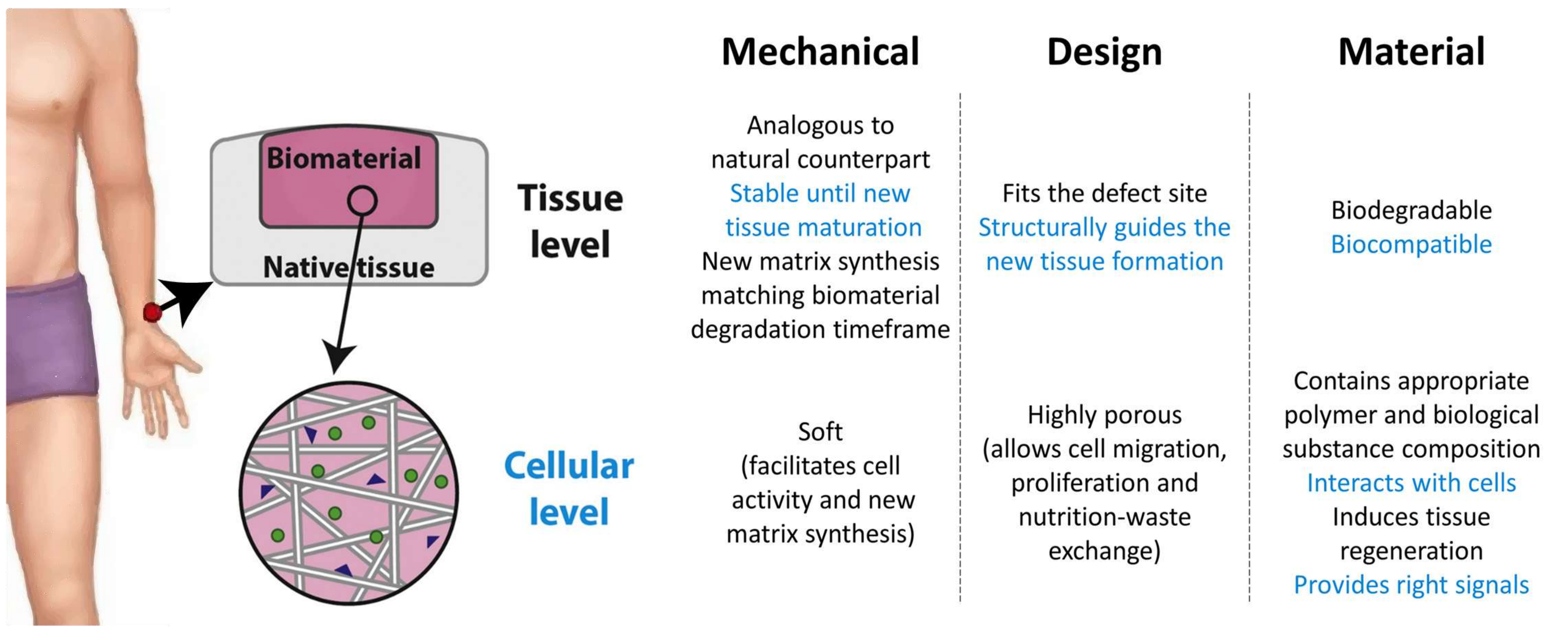


Figure 1: Properties of an ideal construct for soft tissue engineering applications, at both cellular and tissue levels, encompass considerations from mechanical, design, and material perspectives.. Adapted from reference [2].

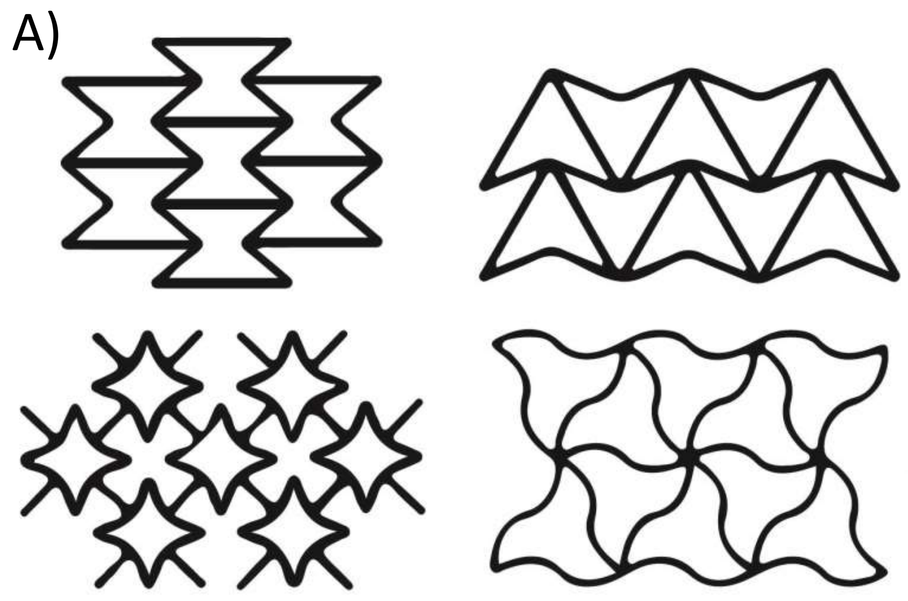
AIM

The **aim** of this work is to **study** different structures for tissue engineering **scaffolds** that incorporate micro-scale **auxetic designs** and observe the variation in the overall mechanical behavior **influenced** by changing their **geometrical parameters**.

AUXETIC GEOMETRIES FOR SCAFFOLDS

- **Auxetic structures**: exceptional **shape adaptability** [3]
- **Tailorable** mechanical properties

A)



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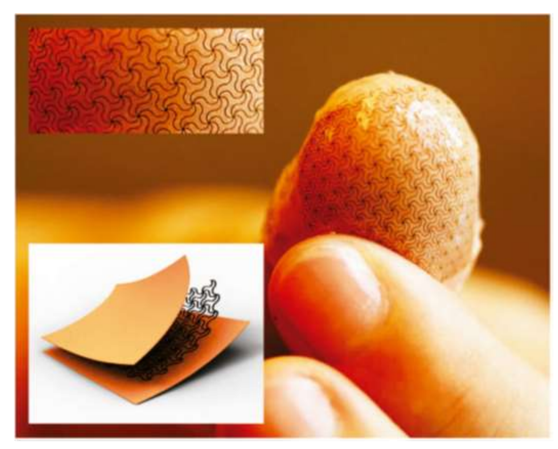

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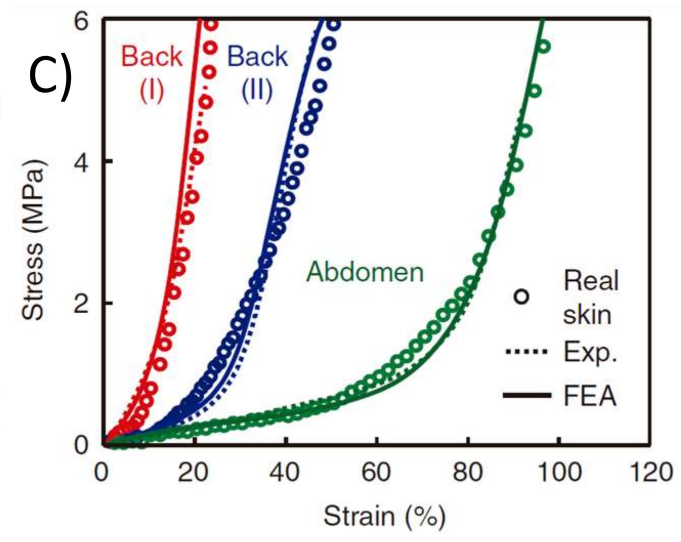


Figure 2: A) Examples of some auxetic geometry designs. **B)** Soft network mesh with an auxetic pattern developed for use in biomedical applications. Adapted from [4]. **C)** Stress-strain responses of human skin compared both numerically and experimentally with different soft auxetic networks, showing their ability to tune their mechanical properties. Adapted from [4].

PARAMETRIC STUDY

- The object of the study are **fibrous scaffolds** with **2D auxetic** designs created by depositing 10 layers of poly ε-caprolactone (**PCL**) fibers.
- **Numerical simulations** are conducted using the finite element method (FEM) and the software **Abaqus** to simulate **uniaxial tensile tests** of the scaffolds.
- To **streamline** the simulation process, a **Python-based** software tool has been developed to **automate** the generation, calculation, and post-processing of the **simulations**.
- The **parametric study** focuses on key geometric parameters, such as **fiber length** (A, B) and **angle** between fibers (α). Different values are **combined** for each parameter, taking into account the necessary **conditions** to ensure the **viability** of the design.

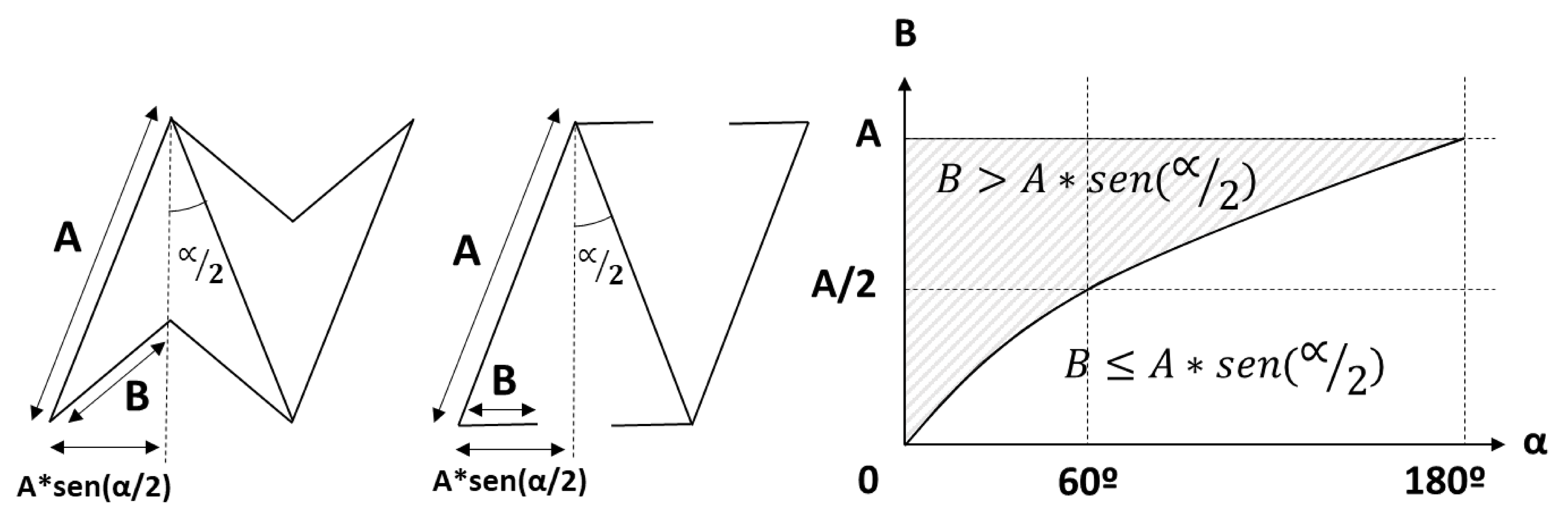


Figure 3: Example of parametric study of auxetic design. Once the geometrical parameters are set, the design conditions for the structure are defined. Different combinations of these parameters are selected and introduced in the software tool to conform the models for running numerical simulations. The values for the parameters are selected from the grey area.

ON-GOING RESULTS

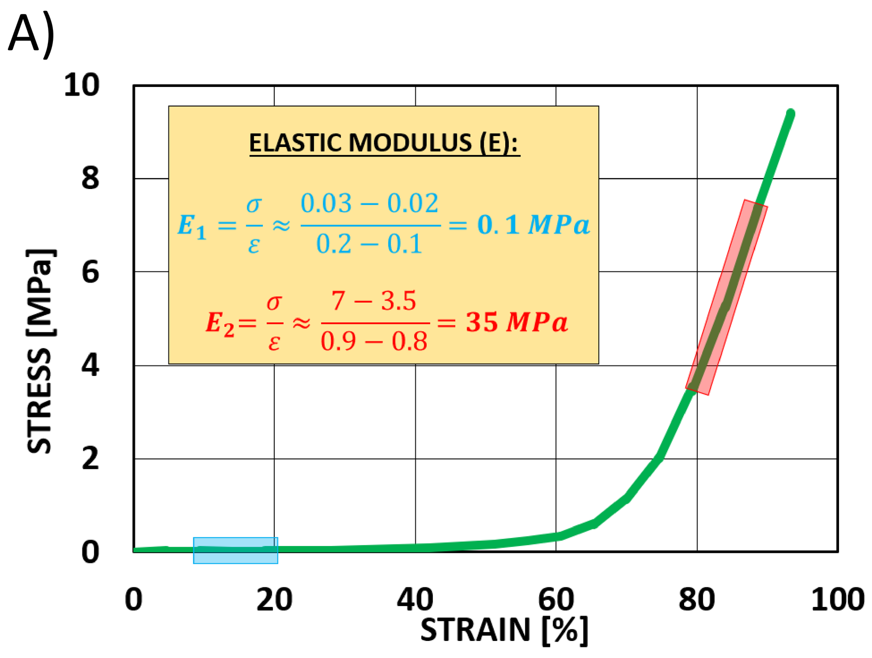
- **Mechanical properties** of the scaffolds are **determined** from the **forces** and **displacements** of the numerical simulations.
- These data are used to **calculate** important parameters such as the **elastic modulus**, **stress-strain** curves, and **Poisson's ratio**.
- These values are then **compared** with appropriate skin scaffold mechanical properties obtained from **literature**[5,6].

	Elastic Mod. [MPa]	Min. Poisson's Ratio [-]
Natural skin [5,6]	4.5 – 25 MPa	– 1.7
Aux. scaffolds	5 – 60 MPa	– 2.4

Table 1: Comparison of natural skin mechanical properties obtained from literature [5,6] and mechanical properties of auxetic scaffolds obtained from numerical simulations.

- **Auxetic scaffolds** have demonstrated the ability to **exhibit "J-shaped"** stress-strain **curves**, which are typical of **soft tissues**, like skin.

A)



B)

Figure 4: A) Stress-strain curve exhibiting the characteristic "J-shape" pattern, consisting of a low mechanical stiffness behavior at the beginning, associated to the initial "unfolding" of the structures, followed by a progressive stiffening caused by the alignment of the fibers within the stretching direction that finally ends producing plastic deformation at high strain rates in some fibers. **B)** Image of an example of auxetic scaffold model from the numerical simulations.

CONCLUSIONS

- The **mechanical behavior** of scaffolds is **dependent** on the specific **auxetic micro-design** selected.
- Alterations in the **geometrical parameters** of the design enable the **customization** and adjustment of the **mechanical properties** of the scaffold.
- **Auxetic scaffolds** have demonstrated the capacity to **replicate** the mechanical behavior of **natural skin**, thereby offering effective mechanical support for skin tissue engineering applications.

References

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