

# Simulating ECM Mechanical Response to Wound Healing with a Spring-Turnover Model

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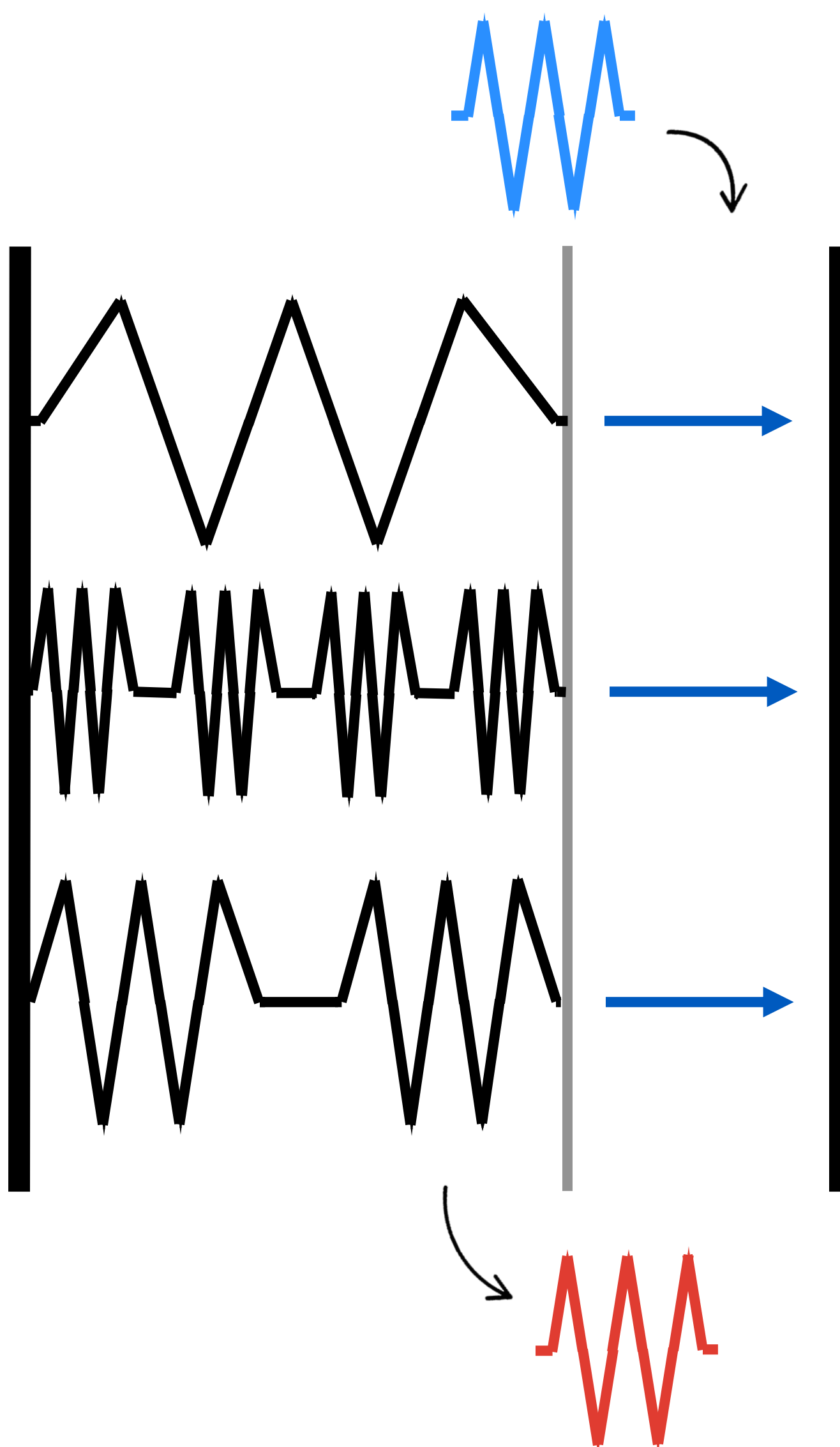
## Introduction

The extracellular matrix (ECM) is a non-cellular scaffold composed of fibrous proteins (e.g. collagen, elastin, fibronectin) and proteoglycans. It provides structural integrity and regulates cell behaviour during tissue repair.

While the biochemical role of the ECM has been widely studied, its mechanical role is harder to isolate experimentally due to continuous turnover of collagen and its interdependence with cells.

In this study, we adapted a spring–turnover model to explore how ECM mechanics influence wound healing.

## Methods



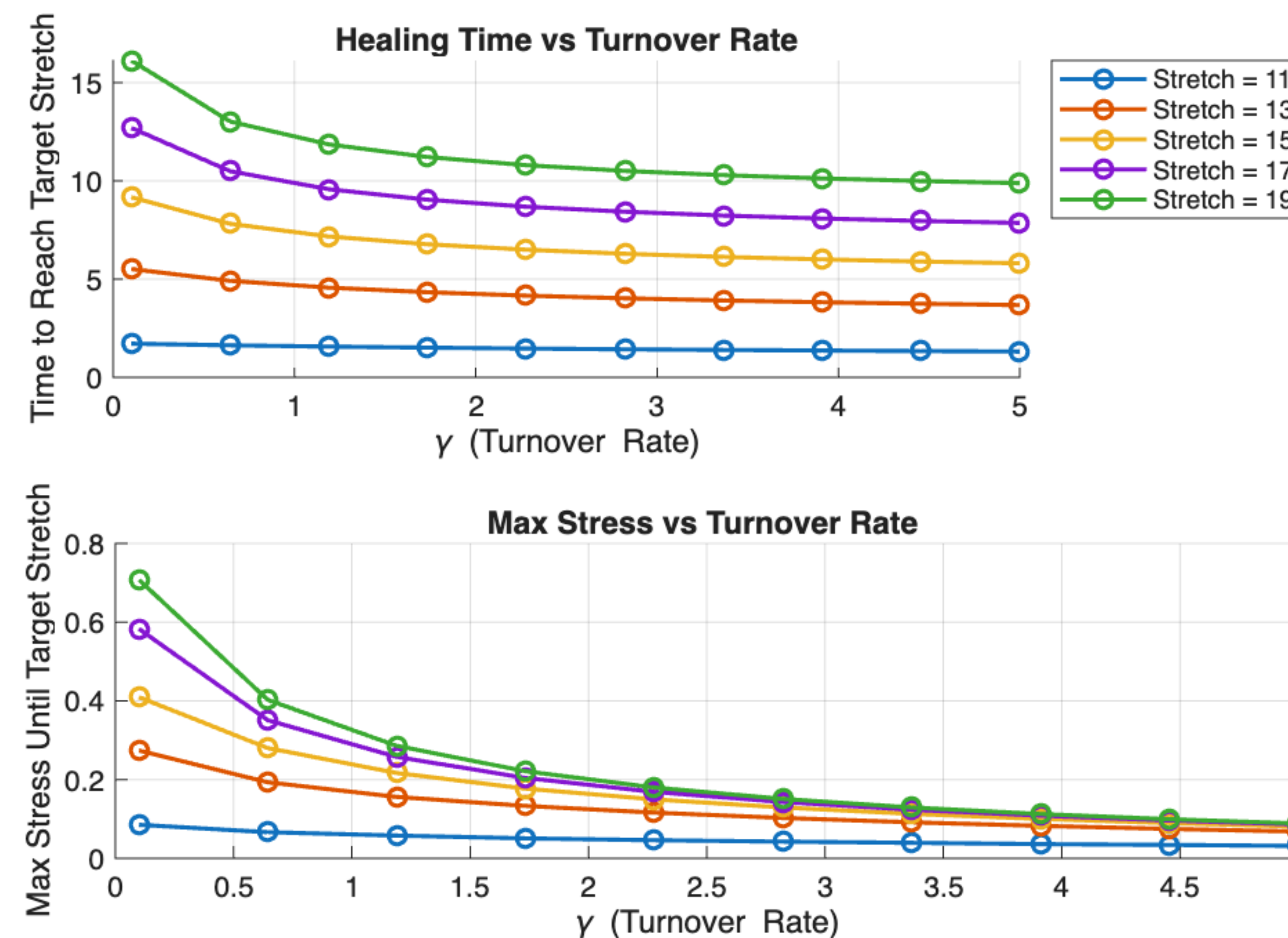
A mathematical model was used to understand the mechanics of the ECM. This model represents collagen fibres as chains of springs in series, with many fibres arranged in parallel to form an ECM network.

In living tissue, collagen is constantly deposited and degraded, so the lengths of fibres evolve over time. To capture this, the model includes turnover, where springs can be added to or removed from chains. This dynamic behaviour is expressed through a simple gain–loss equation (ODE), which updates the number of fibres of each length as time progresses.

Wound closure was simulated using a growth boundary condition, where the system expanded at a constant rate to close a gap, or the wound while undergoing turnover. Two regimes were tested: an infinite bath with unlimited collagen supply, and a finite bath where supply was limited. Healing outcomes were measured by closure speed, peak stress during repair, and residual stress.

## Results

### a) Infinite Bath



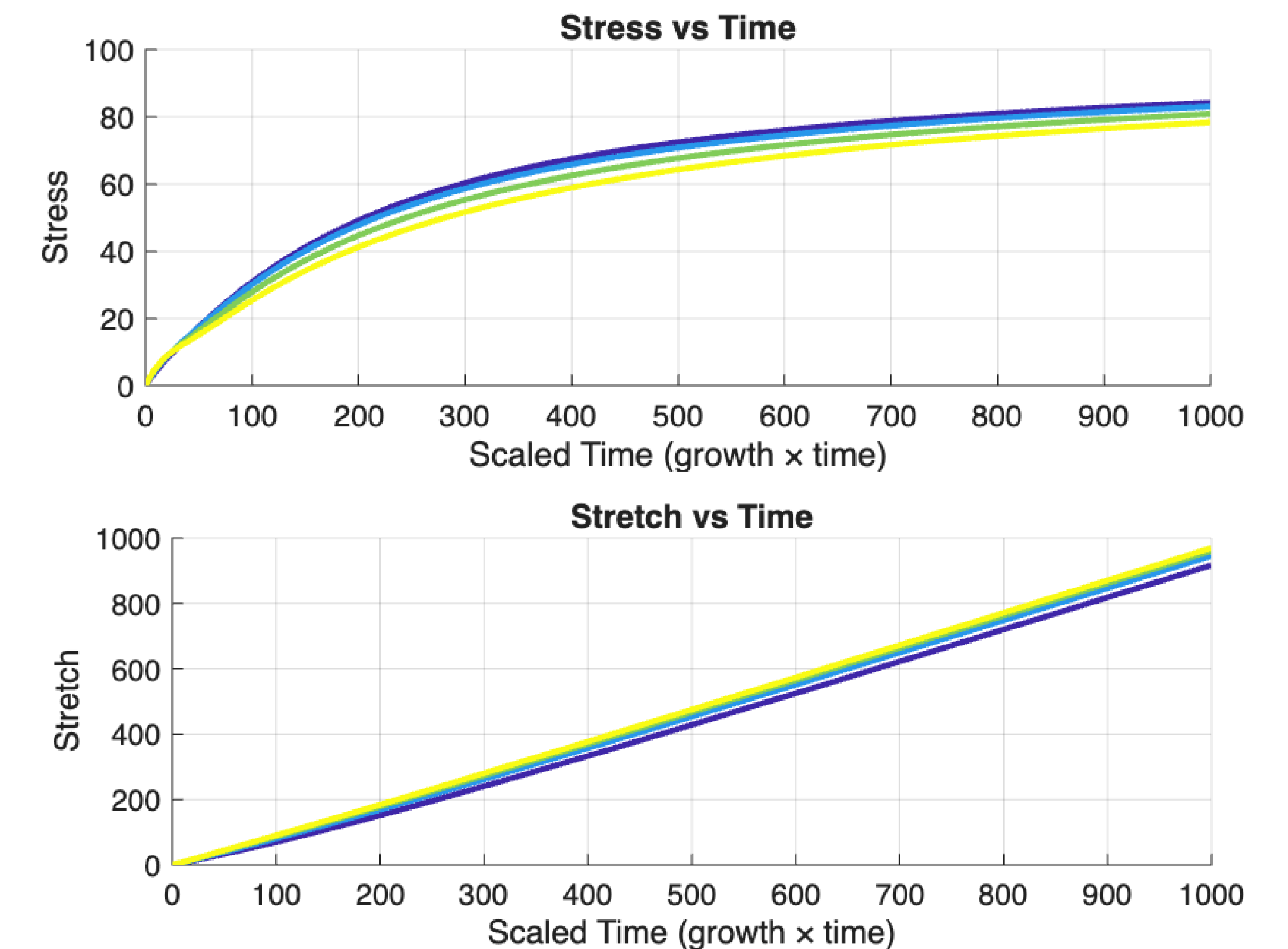
The plots here show the time it takes to close wounds of different sizes and peak stress until closure for different turnover rates between 0.1 to 5.

These indicate that when collagen supply is abundant faster turnover mainly accelerates mechanical catch-up early, shortening the time needed to reach a given degree of closure; once turnover is “fast enough,” additional increases yield little extra speed.

Plotting peak stress against  $\gamma$  reveals that faster growth (larger  $\gamma$ ) leads to lower peak stresses.

- Increasing turnover accelerates healing and reduces stress, while increasing growth demand (wound size) raises the stress the ECM must bear.

### b) Finite Bath



Here, stretch and stress in the finite bath case at a fixed growth rate ( $g=10$ ) were compared. The bath sizes are between range from 1 to 2 with yellow being the highest bath size and purple the lowest.

We see that larger baths permitted greater stretch, while smaller baths lagged slightly. In systems with small baths, stress rose rapidly and stabilised at a high level, while larger baths reduced both the rate of stress build-up and the final plateau value.

- This indicates that limited collagen supply impairs the ECM's ability to remodel under growth, leading to sustained mechanical loading. Biologically, this behaviour mirrors chronic wounds.

## Conclusion

ECM mechanics strongly influence wound healing outcomes. Healthy repair requires both adequate collagen supply and efficient turnover to relieve stress. Pathological repair arises when either factor fails: unlimited supply without turnover still leaves stress, while fast turnover cannot rescue healing if supply is exhausted. This highlights a balance between collagen availability, turnover capacity, and growth demand as the key determinant of whether wounds resolve healthily or become chronic.

Future work that might be conducted is to develop regime maps to visualise mechanical outcomes under varying conditions. It is also possible to compare stiffness changes with literature to link mechanics to fibrosis and scarring.