TISSUE-SCALE MODELING OF KELOIDS TO PREVENT THEIR GROWTH

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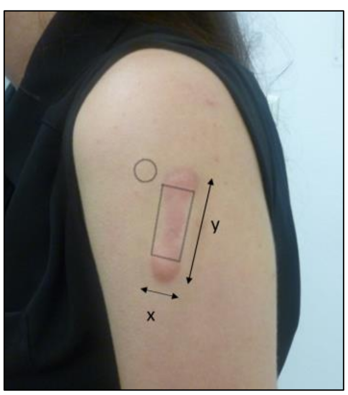
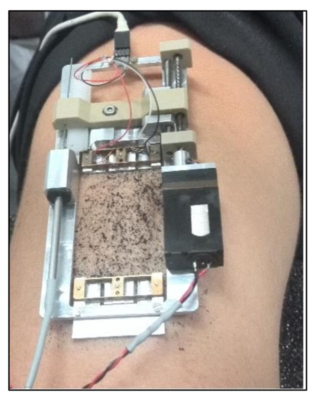
BACKGROUND: The keloids grow on specific anatomical sites subjected to natural mechanical load, such as the sternum, abdomen, arm, *etc*... They propagate due to repeated human postures, peripheral stress of the of the tissue, or anatomical singularities [1]. Besides the genetic and biological factors, the mechanical factor plays an important role in the occurrence and propagation of keloids. A multi-disciplinary collaboration between dermatology, mechanics, and computational science researchers has been established to analyze the mechanical effects of these cutaneous alterations.

METHODS: Starting from a multimodal investigation of a patient (Figure 1a), a numerical pipeline consisting of several open-source frameworks has been developed, leading to stress field analysis in a domain composed of a keloid and surrounding healthy skin [3]. Using the experimental data issued for a uni-axial tensile test performed on the domain (Figure 1b), the material parameters of the keloid are identified based on a hyperelastic model mimicking the mechanical behavior of the cutaneous layer. The identification process focuses on finding the best set of parameters that minimizes the discrepancy between the experimental and model data. Afterward, the stress field is quantified for the found parameter set, showing the fragile zones and the directions along which the keloid tends to propagate.



(a)



(b)

Figure 1. Experimental investigation into the mechanical response of keloid scar (from Chambert et al. 2019 [2]). (a) Butterfly-shaped keloid (x=15mm, y=47mm). (b) A uni-axial was test carried out on a butterfly-shaped keloid with an extensometer.

RESULTS: The presented numerical method was validated by means of synthetical data and applied to a set of real data from the study of Sutula *et al.* [4], consisting of displacement fields (captured by the Digital Image Correlation technique) and reaction force (measured by a force sensor). As results, the material parameters of a keloid scar and surrounding healthy skin (on a 22-year-old Caucasian woman's arm) formulated in Gent's model are:
$\widehat{\boldsymbol{m}} = \{\mu_{keloid} = 9.13\ kPa; J_{m_{keloid}} = 0.0155; \mu_{healthy-skin} = 7.03\ kPa;\ J_{m_{healthy-skin}} = 0.169\}$,
with relative errors of $\varepsilon_{force} = 1.09\%$ and $\varepsilon_{displacement} = 5.34\%$ (Figure 2).

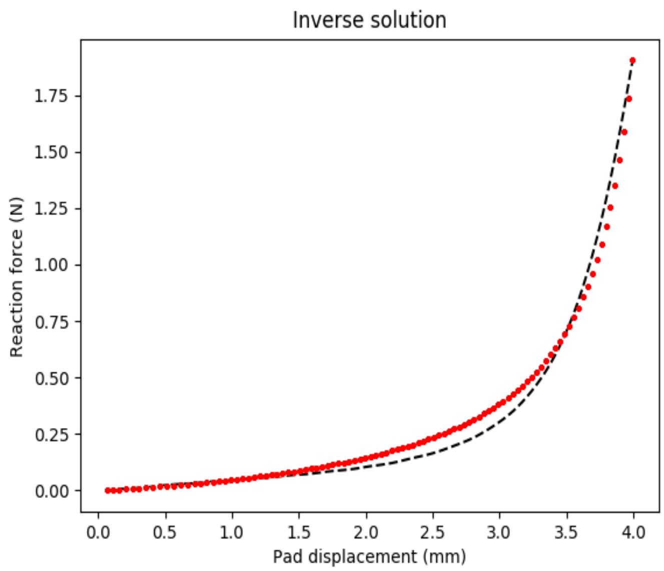
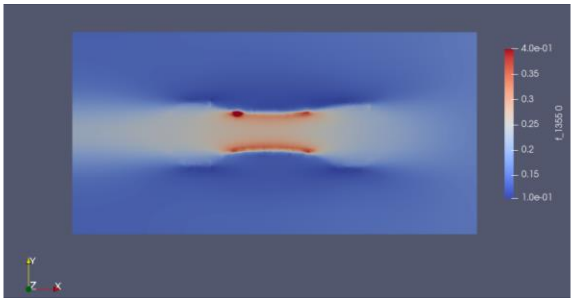


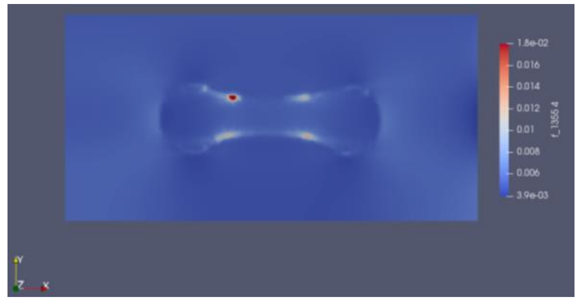
Figure 2. Model fitting for the identified optimal parameter set $\widehat{\boldsymbol{m}}$

With a direct simulation of natural pre-stretch using $\widehat{\boldsymbol{m}}$, the distribution of Cauchy stress was computed for each component: normal stress σ_{xx} and σ_{yy} and shear stress σ_{yy} (Figure 3). A qualitative analysis of those fields will indicate to the clinician which direction the propagation will presumably come across. In our case, the stress along directions XX, YY, and XY is more pronounced on the interface keloid/healthy-skin on the interior side. The clinical solution should be conceived to counter the stress in those areas.

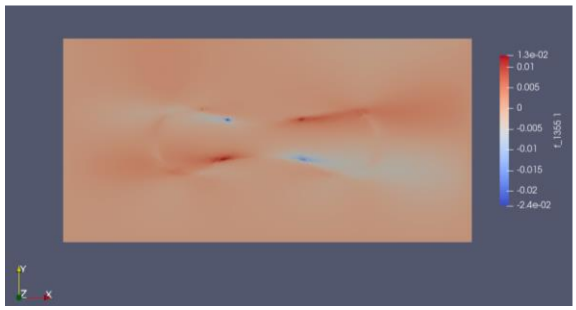
CONCLUSION: We proposed a numerical method to estimate the material parameters of a keloid scar and the surrounding healthy-skin. The main objective of this methodology is to conceive specifications of a customized medical device to confine keloid growth or prevent its growth. The application to a patient-specific dataset revealed that our approach is promising and can contribute to shedding light on the unpredictable behavior of keloids. We recommend though, to apply it in a clinical trial with different subjects and sites to explore its limits and enhance its performance.



σ_{xx}



σ_{yy}



σ_{xy}

Figure 3. Stress fields of keloid/healthy-skin materials under natural bi-axial stretch. The values in the color bar were computed in MPa.

References

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[2] Chambert et al, J Mech Behav Biomed Mater, 99:206-215, 2019.
[3] Elouneg et al, Comput Struct, 255(2):106620, 2021.
[4] Sutula et al, J Mech Behav Biomed Mater, 112:103999, 2020.