Plenary Lecture

FINITE ELEMENT CONTINUUM DAMAGE MODELING OF SKIN OVER AURICULAR IMPLANTS

Scott J. Hollister
Patsy and Alan Dorris Chair in Pediatric Technology
Center for 3D Medical Fabrication and Department of Biomedical Engineering
Georgia Institute of Technology, Atlanta, GA USA
scott.hollister@bme.gatech.edu

Summary: We hypothesize the increased strain on skin over an auricular scaffold constricts blood flow leading to adverse remodeling of skin extracellular matrix. In addition, increased skin strain may also cause direct structural damage. We further hypothesize that location of both the vascular remodeling and direct structural damage may be predicted using isotropic Continuum Damage modeling, where damage is characterized by a scalar parameter D that varies from O (no damage) to 1 (complete failure). We utilized the Simo Reactive Damage Mechanics model $D\left(\sigma_f, time\right) = 1 - \frac{a}{\sigma_f}\left(1 - e^{-\frac{\sigma_f}{a}}\right)$ in FEBio to predict damage distribution in an idealized skin stretched over an ear implant, where a is a constitutive parameter chosen as 15 MPa to match the failure stress of rat skin reported by Haut[1]. The reactive damage constitutive model reduces the material elastic properties as damage accumulates: $W = \left(1 - D\right) W_0$. Two types of PCL ear scaffolds were modeled, a solid implant and a 59% porous implant with spherical pores. The ear scaffold was pushed into the skin to model surgical implantation to a depth of 26mm, assuming frictional sliding elastic contact occurred between skin and scaffold.

We further modeled scaffold modifications used to potentially mitigate skin damage. These scaffold modifications included 1) reducing the overall scaffold stiffness from PCL to that of auricular cartilage[2], 2) placing tissue cylindrical tissue biopsies in between the skin and scaffold, and 3) creating a form fitting helix cushion between the scaffold and skin.

Results for both the solid and 59% porous PCL scaffolds showed the highest damage results (up to 0.2) over the superior and lateral areas of the helix. These damage locations correlate with skin dehiscence locations over implanted ear scaffolds in a rat model[3]. Of the various mitigation strategies, significantly reducing the scaffold stiffness to match that of auricular cartilage was most effective in reducing damage. However, reducing the scaffold stiffness to that of auricular cartilage[2] leads to significant scaffold deformation and loss of shape, which defeats the purpose of creating a scaffold to reconstruct facial aesthetics. One compromise is the use of a thinner soft material in between the stiffer aesthetic stiffer scaffold and the skin. This stiffness gradient would reduce stress and therefore damage in the skin. Results showed this approach could reduce accumulated skin damage between 5% and 20%. In conclusion, continuum damage modeling can be used to determine of possible dehiscence locations of skin over facial plastic scaffolds, and inform design of interventions that may mitigate skin dehiscence.

References

[1] Haut RC. The effects of orientation and location on the strength of dorsal rat skin in high and low speed tensile failure experiments. J Biomech Eng. 1989;111(2):136-40. Epub 1989/05/01. doi: 10.1115/1.3168354. PubMed PMID: 2733408.

[2] Zopf DA, Flanagan CL, Nasser HB, Mitsak AG, Huq FS, Rajendran V, Green GE, Hollister SJ. Biomechanical evaluation of human and porcine auricular cartilage. Laryngoscope. 2015;125(8):E262-8. Epub 2015/04/22. doi: 10.1002/lary.25040. PubMed PMID: 25891012; PMCID: PMC4512857.

[3] Chang B, Cornett A, Nourmohammadi Z, Law J, Weld B, Crotts SJ, Hollister SJ, Lombaert IMA, Zopf DA. Hybrid Three-Dimensional-Printed Ear Tissue Scaffold With Autologous Cartilage Mitigates Soft Tissue Complications. Laryngoscope. 2021;131(5):1008-15. Epub 2020/10/07. doi: 10.1002/lary.29114. PubMed PMID: 33022112; PMCID: PMC8021596.