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# MECHANOBIOLOGICAL WRINKLING INSTABILITIES IN SKIN. AN ISOGEOMETRIC ANALYSIS APPROACH.

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## INTRODUCTION

The skin is the human body's interface to the external environment and, as such, is involved in a wide range of biophysical interactions. The geometry and biophysics of this multi-layered structure are key elements in determining the nature and characteristics of these interactions. As humans age, their skin undergoes a series of natural biophysical alterations which occur in combination with the effects of external environmental factors. During this process, the formation and evolution of wrinkles alter the physical properties of the skin surface. Unveiling the underlying mechanical principles that condition the morphologies and patterns of wrinkles are therefore essential in predicting how an aged skin interacts with its environment. From the view point of physics, wrinkles are the result of a complex interplay between material and structural properties, boundary and loading conditions, the exact nature of which remains to be elucidated [1-2]. For thin membranes, the bending energy term, critical to wrinkling, is proportional to the second derivative of the local curvature of the mid-surface and, in a finite element context, this means that $C^1$-continuity across finite element boundaries is required. Therefore, not only the displacement field but also its first derivatives need to be continuous across element boundaries. NURBS-based isogeometric techniques [3] can fulfill these requirements and are therefore promising to investigate the biomechanics of skin.

In this contribution, a 3D multiphysics isogeometric finite element framework was developed to study the highly non-linear mechanical instabilities of human skin arising as a a result of purely mechanical and mechanobiological forces (growth).

## MATERIALS AND METHODS

The NURBS-based finite element environment is valid for arbitrary kinematics, can handle non-linear materials and multi-field problems such as those encountered in mechanobiology. The isogeometric computational procedures are based on Bézier extraction operators [4] which faciliate the numerical implementation into "traditional" finite element programme structures by providing a mapping between NURBS and Bézier basis functions (up to third order).

Volumetric [5] and surface [6] growth constitutive models were implemented using density as an additional field. A generic multi-layer isogeometric model of the epidermis (*stratum corneum* and viable epidermis) was built and subjected to various instability-inducing conditions: in plane mechanical compression, in-plane growth and volumetric shrinking. A perturbation procedure based on a preliminary eigenvalue analysis was devised to simulate wrinkling instabilities. It consisted in seeding geometric imperfections as combination of scaled buckling modes to trigger instabilities. A path-following procedure was used to handle the post-instability behaviour.

**RESULTS AND DISCUSSION**

The numerical framework was shown to be robust to simulate the non-linear mechanics of skin in the context of wrinkling instabilities. It is noteworthy that no use of explicit scheme solving techniques was made. As expected, the ratio between material and structural properties of each skin layer was key in shaping the characteristics of the induced wrinkling instabilities. The superior continuity properties of NURBS-based isogeometric finite elements allow to maintain accuracy of the results with a minimum number of elements. Continuity of the density field (and so growth) across elements is also an attractive feature of the present computational framework.

Further improvements to the present research could include the ability to account for self-contact of surfaces and adaptive mesh refinement. The use of anatomically-based geometry of the skin layers is also essential to consider in the future.

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