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NUMERICAL MODELING OF BRA WEAR DURING RUNNING

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Numerical modelling of bras and their influence on breasts during sport could be a valuable tool for bra designers as it could avoid the development of prototypes and help improving the performances of bras. Such a model requires a model for the breasts and for the bra. Models of breasts are available in the literature but they are based on MRI data that are expensive and heavy to segment and mesh (see e.g. [1]). One of the main issues to develop a breast numerical model is to define a reference state for the breast without gravity, to avoid errors in the evaluation of stresses during sport. Rajagopal [2] used water to cancel the effect of gravity on a part of the breast and define the reference state; this idea is followed in the present work.

The present work is focused on modelling female breasts, simulating brawear and investigating the influence of the bra on stresses and strains in the breast. A particular objective of this work is to provide a model that can run fast enough on a regular computer, so that it is convenient to use for industrial and commercial purposes.

1. Construction of the numerical model for breasts and bra

The numerical model of breast is based on the 3D scan of the female torso with silicone implanted breasts of cup C. We chose this model as the deformation of the breasts under gravity is negligible. The obtained surface is segmented and a 3D numerical model is created with deformable skin and a single deformable solid inside the breast skin. This numerical model called M0 is considered as a reference model without gravity.

Pictures of the breasts of a second woman (cup C, natural breasts, called M1) were taken in orthostatic position: one under water to simulate a no-gravity configuration, and one in air. After morphing M0 with a Freeform method to match the morphometry of M1 under water, we obtained a model for M1 in a stress-free configuration (no gravity) and gravity was applied to M1 (in Abaqus/Explicit). The mechanical parameters of breast skin (Mooney-Rivlin model) were identified by minimizing the gap between morphometric parameters of the breast under gravity in the simulation and in the experiments. The mechanical parameters of the inside homogeneous part of the breast were identified using experimental and numerical indentation tests. We finally obtained a model of breast under gravity with stresses due to the gravity [3].

A numerical model for the bra was created using the 3D scan of a bra worn by a dressmaker's form and material parameters determined by mechanical tests. The bra is meshed with shell elements.

2. Simulation of bra wear during walking and running

As well as women use a lot of steps to put their bra on and adjust it, it requires a lot of steps for a numerical bra to be adjusted to our M1 model. Once the bra is on, we can evaluate the stresses and strains in its different areas (Fig. 1, left).

Body and nipple displacements with and without bra were measured experimentally during walking (6km/h) and running (8km/h). The measured displacements of the body (vertical and in rotation around the vertical axis) were applied to the model to simulate walking and running and evaluate the influence of the bra on the breast. First, experimental and numerical displacements of the nipple were compared to check that the bra was correctly put on. As expected, the nipple follows much more the body with bra than without bra (Fig. 1, right). Then, stresses and strains in the breast with bra could be evaluated, as well as sliding between skin and fabric. We could therefore point out the areas of the bra that needed to be optimized and compare those results to the experience of bra designers. Using Freeform morphing, the presented model can be easily adapted to different morphologies.

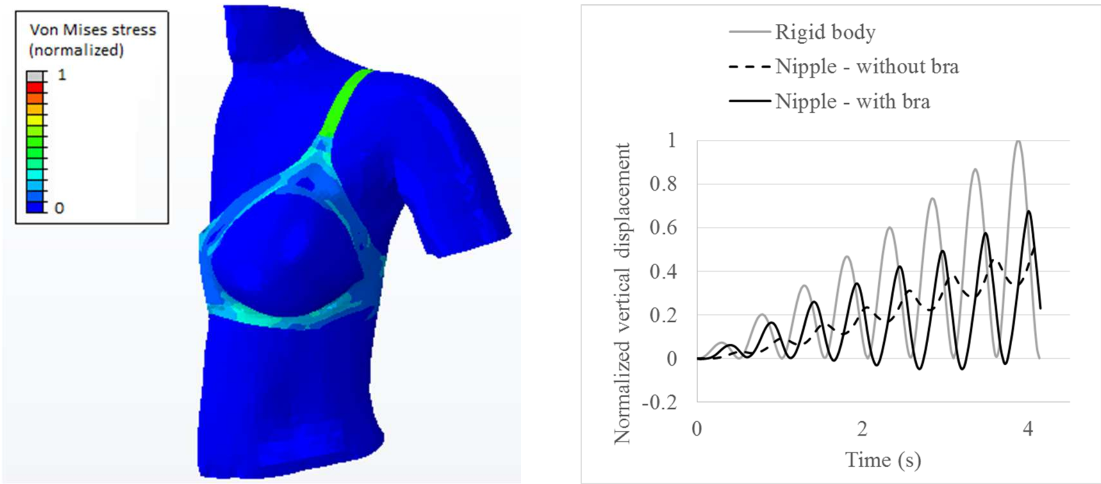

Figure 1: Left: Normalized Von Mises stress in the bra when worn by M1 model. Right: Nipple displacement (from the configuration under gravity) with and without bra during walk

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