Using Inverse Finite Element Analysis to Obtain Passive Mechanical Behavior of Abdominal Wall

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Abstract

In this work we develop a methodology to characterize in vivo the passive mechanical behavior of abdominal muscle, using for that finite element simulations combined with inverse analysis and optimization algorithms. The knowledge of the mechanical response of the muscle is needed to determine the features of the mesh in cases of hernia surgery.

Material and Methods

Experimental setup

Inflation tests were performed on New Zealand rabbits, increasing the inner pressure from 0 to 12 mmHg. Before the test, specimens were cropped from front to rear legs and the abdominal surface was spotted with black points, which allowed the cameras to track the surface while the gas was going into the cavity.

Experimental tests were recorded using a stereo imaging system, composed of two high resolution synchronized cameras. Two frames of each level of pressure were extracted and postprocessed to obtain 3D measurements of the abdominal surface along the experiment [1].

Numerical analysis

The 3D measurements allowed us to reconstruct the whole cavity for different pressures, which was lately used for a finite element simulation. To simulate the passive response of the abdominal muscle, a quasi-incompressible isotropic hyperelastic material model was proposed [2], with an exponential stress–strain response based on the Veronda–Westmann model [3].

$$W = \frac{\mu}{2\gamma}\left(e^{\gamma\left(J^{-2/3}I_1\right)} - 1\right)$$

This strain density function is two parameters dependent: μ, the shear modulus at zero strain and γ, which determines the nonlinearity of the material response. The conjuction of these parameters will define the mechanical response of the material.

Their values were obtained by inverse analysis. Starting from a seed, these parameters were allowed to change through the geometry in order to try to reproduce the experimental results. Specifically, the algorithim poses the inverse problem as a minimization problem and considering an initial finite element simulation it seeks the distribution of material parameters that yields the displacement fields that best match the experimental measures [4].

Results

Fig. 1 shows the distribution of the material parameters along the surface. Results reveal that μ takes higher values in the central zone of the surface, which means a stiffer response of the material. This area mostly coincides with the situation of the *rectus abdominis,* one of the main four muscles which lie in the abdomen. Similar distribution is found for γ.

Maximum displacement values obtained in the last simulation were similar to experimental results (see Fig. 2), so the algorithim is able to find the suitable material parameters that reproduce the deformation suffered by the abdominal cavity.

Conclusions

Considering the rabbit anatomy, *rectus* muscle seems to be more rigid than the sides of the abdomen, mostly formed by a composite of three muscles.

The methodology here used worked properly to determine the material parameters of the tissue, and it could be used in a future to determine mechanical properties of a specific abdominal wall in a surgical room.

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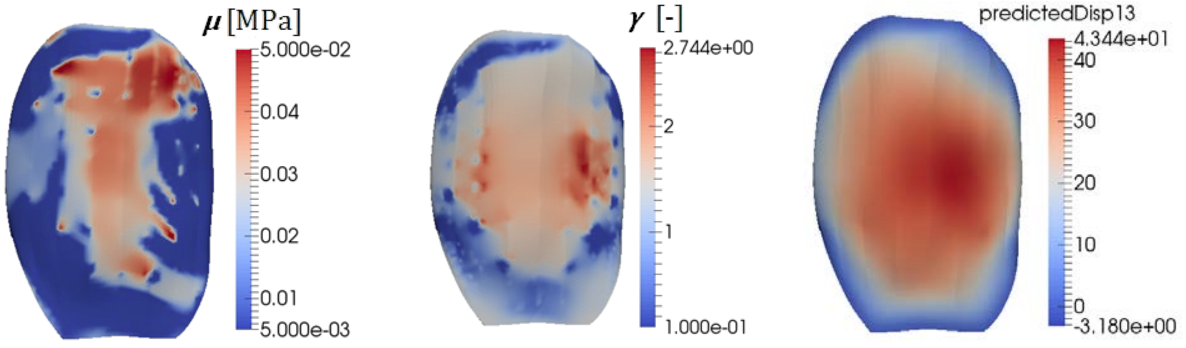
FIGURAS / LEYENDAS



(a) (b) (c)

Figure 1: *Results:* Distribution of the material parameters along the abdominal surface, μ (a) and γ (b), and predicted displacement of the geometry (c).

(a) (b) (c)

Figure 2: *Evaluation of the results:* (a) Experimental deformed shape at P = 12mmHg. (b) Numerical deformed shape of the geometry (c) Comparison, contour surface of the error between experimental and numerical displacement data.