Investigating the mechanical behavior of the human oocyte: A computational study conducted in a clinical setting

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Abstract

The oocyte (the female cell involved in reproduction) is the largest cell in the human body (about 100 μm in diameter). From an engineering view point, the oocyte can be described as a thin spherical membrane full of fluid (cytoplasm core) surrounded by a thick (about 20 μm) highly elastic layer called the Zona Pellucida (ZP) (Figure 1).

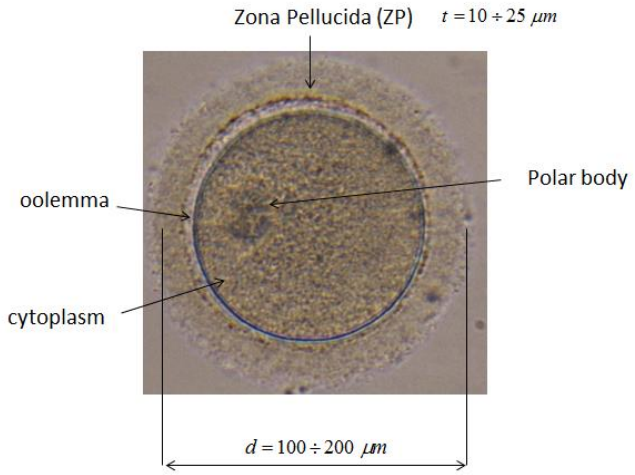

Figure 1: Structure of the human oocyte.

Intra-Cytoplasmic Sperm Injection (ICSI) is a medical technique in which fertilization of the oocyte is performed In-Vitro. Several oocytes are first aspirated from the ovaries of the patient. Then, under a microscope, each oocyte is held in place using suction and carefully injected with the male genetic material (sperm). Following successful fertilization the embryologists select embryos to transfer into the patient's uterus. Five to six days following fertilization, a sudden increase in embryo inner volume mechanically stretches the ZP leading to initial thinning followed by rapture of the ZP termed "hatching". If "hatching" of the embryo out of the ZP does not occur, pregnancy cannot take place. Despite the apparent importance of ZP mechanics, in the hatching process, ZP mechanics does not play a role in the selection of embryos for transfer.

In the current study, clinical data from ICSI processes was obtained and analyzed using image analysis software. The clinical data was utilized to develop oocyte specific finite element models and study the ZP mechanical response. The computational methodology for the study of oocyte mechanics is shown figure 2.

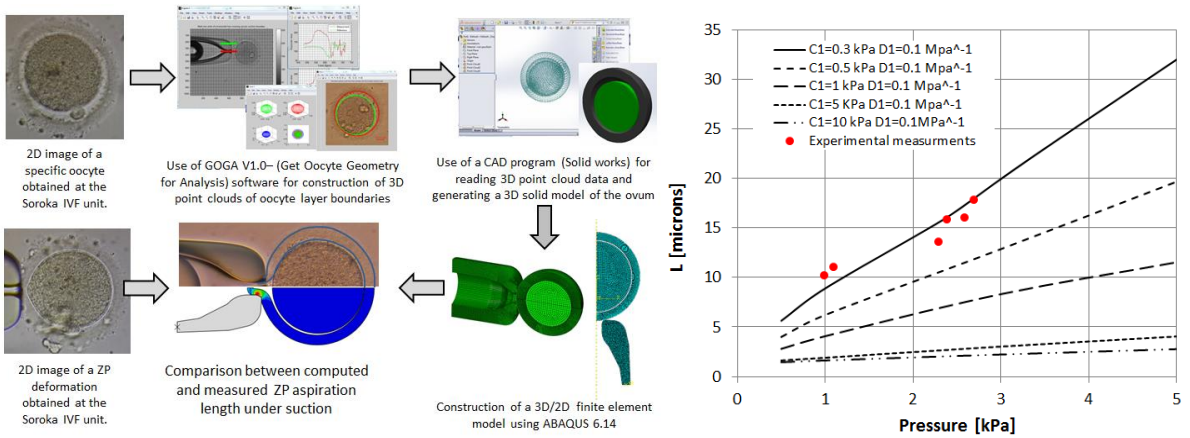

Figure 2: Methodology for the study of ZP mechanical response (left), ZP deformation as a function of suction pressure (right).

A total of 20 patients and over 100 oocytes were used in the study. It is demonstrated that linear elastic constitutive models commonly used in literature to describe ZP mechanics [1,2,3] are limited and that the mechanical behavior of the ZP can be better described by using an isotropic compressible hyper-elastic strain energy density function. This study also shows that oocyte aspirated from the same patient may have different stiffness values and as a consequence it is hypothesized that the rate of successful embryo implantation may be significantly increased by taking into consideration specific oocyte and embryo mechanics.

Keywords: Oocyte mechanics, hyper-elasticity, Zona-Pellucida

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