Simulation of Mechanical Properties of Human Ovum for ICSI Application using Alginate Hydrogel

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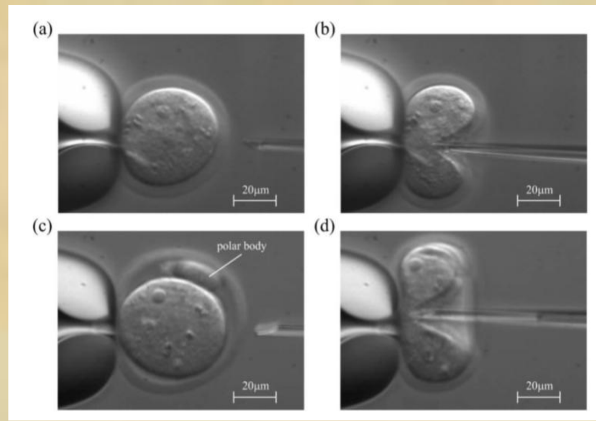
Aim

The aim of this research is to simulate compression analysis of an artificial ovum with the purpose of developing experimental and clinical samples for the Intra-Cellular Sperm Injection (ICSI) process.

ICSI

Intra Cellular Sperm Injection (ICSI) is one of the most important applications of microinjections.



A major factor affecting the success rate of the ICSI process is attributed to the method of needle insertion into the ooplasm and the harms which it causes Due to the impact during injection.

Proposed method

- ✓ Use the hydrogel as substitute artificial ovum for mechanical testing in the laboratories to gain a better understanding the ovum's mechanical behaviour at the time of injection.
- ✓ Develop a new procedure for the injection process.

The Outline of this research is as follows:

- ✓ Analytical & Mechanical modelling of artificial ovum (Alginate hydrogels
- ✓ Material selection
- ✓ CAD modelling and Finite element analysis
- ✓ Sample manufacturing
- ✓ Testing
- ✓ Comparison the results of testing and modelling

Mechanical model of Hydrogel

The assumptions used in this modelling of the artificial ovum are below:

1. The sample is assumed to be spherical with completely amorphous cross-linked gel inside.
2. The whole volume of the samples (Fabricated gel) does not change when injected.
3. The layers have a negligible flexural rigidity, so the deformation is due to layer stretching.
4. The gel sample is free of initial stress or residual stress.
5. The model starts with the planar circular area as the tip of injector which is in contact with the layers at the time of injection with zero residual stress.
6. The needle of the injector moves at a constant velocity.
7. The gel is composed of incompressible homogenous isotropic material.

$$\sum F_y = ma = m\frac{dV}{dx} \qquad F - F_p - 2\sigma_d \pi r h\frac{dw}{dx} = 0 \qquad F = P.A = P\pi a^2$$

$$P = K_1T_1 + K_2T_2 \qquad T_i = \frac{h}{\lambda_1\lambda_2}\lambda_i\frac{\partial W}{\partial \lambda_i}, (i = 1,2) \qquad W = C_1(I_1 - 3) + C_2(I_2 - 3)$$

$$I_1 = {\lambda_1}^2 + {\lambda_2}^2 + {\lambda_3}^2 \qquad I_2 = \frac{1}{{\lambda_1}^2} + \frac{1}{{\lambda_2}^2} + \frac{1}{{\lambda_3}^2} \qquad \lambda_1 = \frac{dx_1}{dx_2}, \quad \lambda_2 = \frac{dy_1}{dy_2}, \quad \lambda_3 = \frac{1}{\lambda_1\lambda_2}$$

$$\left[\frac{2hK_1}{\lambda_1\lambda_2}\left({\lambda_1}^2 - \frac{1}{{\lambda_1}^2{\lambda_2}^2}\right)(C_1 + {\lambda_2}^2C_2) + \frac{2hK_2}{\lambda_1\lambda_2}\left({\lambda_2}^2 - \frac{1}{{\lambda_1}^2{\lambda_2}^2}\right)(C_1 + {\lambda_1}^2C_2)\right].\pi a^2 - F_p - 2\sigma_d\pi r h\frac{dw}{dx} = 0$$

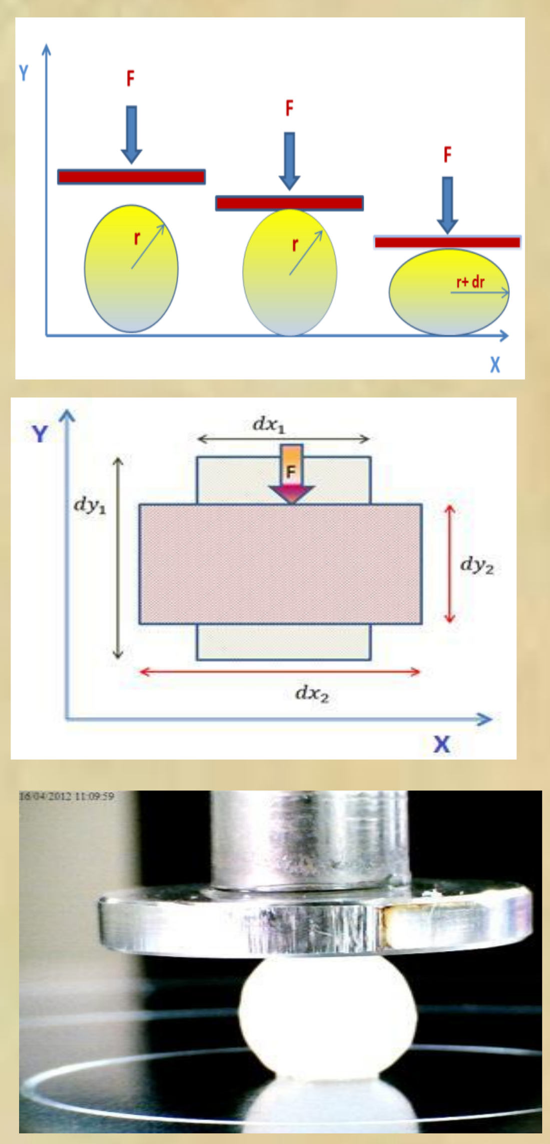


Figure :a Compression model b) Free Body Diagram c) Real Experiment Photo

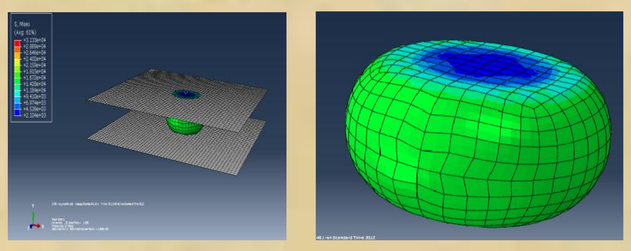
CAD Model specification

This part shows the finite element analysis which was made to simulate the compression of the gel. The software used for this section is abaqus 6.10.

$C1 = 27779\ ^{N}/_{m^2} \qquad C2 = -11017\ ^{N}/_{m^2}$

Out put:

Force (N)	Young's Modulus (KPa)	Density (kg/m3)
5	0.493±0.039	733.22±25



Experiment results

This part shows the mechanical results of the gel when tested by the compression test device (Zwick/Roell Z030). This device tested the compressive strength as a mechanical property of the gel.

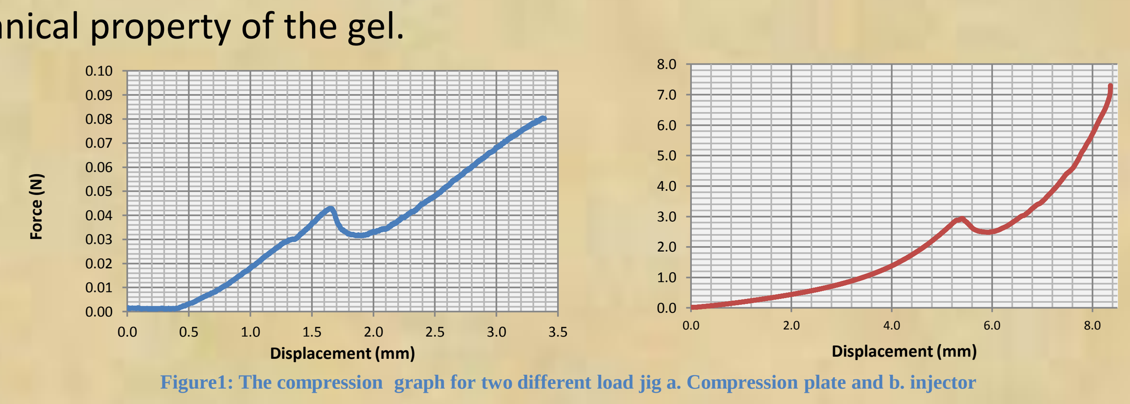


Figure1: The compression graph for two different load jig a. Compression plate and b. injector

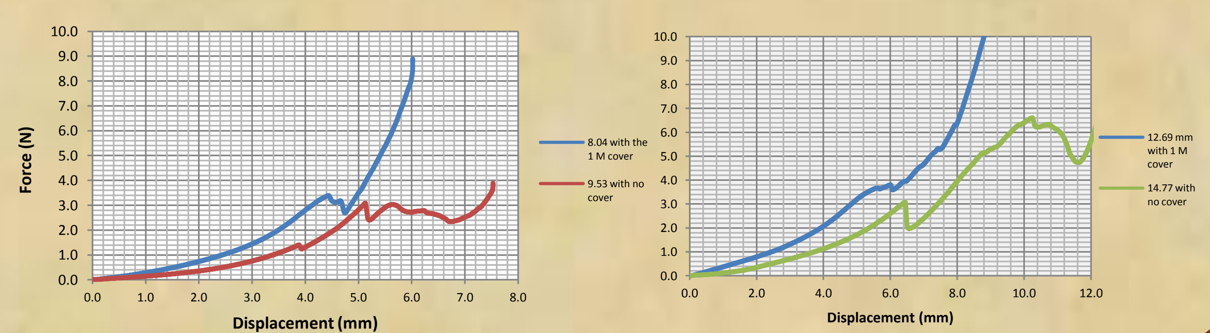


Figure 2: The comparison results between the CaCl2 cover and without cover for the diameter of more and less than 10 mm

Material selection

Different materials for the artificial ovum have been suggested, but finally a type of hydrogel is proposed, named alginate acid sodium salt. To solidify this, some calcium chloride solution was added into or on the surface. The table shows the experiments for understanding the suitable doses of the alginates acid salt and molarities of calcium chloride. Two different methods were applied here to crosslink the liquid gel. One was covering it by $CaCl_2$ and the other was injecting it instead of covering

Moles of Calcium chloride	10% alginate Salt	5% alginate Salt	2% alginate Salt
0.1 M	10% soft cross linked on the both surface with liquid gel between	15% cross linked just on the both surface but liquid between	NT
0.5 M	50% hard cross linked with liquid gel between	85% soft cross linked on the both surface	100% soft cross linked
1 M	100% hard cross linked	100% hard cross linked	NT

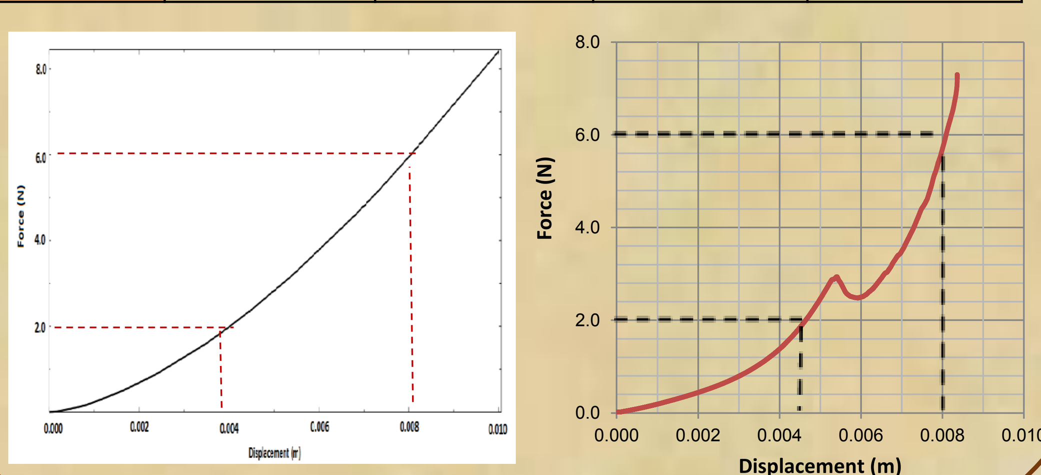
Not useful good perfect

Table 1: shows the experimental data for finding suitable gels

Results comparisons

The following Table and Figures shows the comparison between FE model and Sample experiment to illustrate the accuracy of the model.

Type	DATA	before puncturing	puncturing point	after puncturing point
FEA Model	displacement (mm)	4.2	NA	8.4
	force (N)	2	NA	6
Experimental result	displacement (mm)	4.64	5.19	8.09
	force (N)	2	2.75	6



Discussion

The experimental results satisfy the modelling results, but the fracture point is not shown by the FEA modelling because the material introduced for the abaqus program is totally elastic. This modelling can help to understand the forces applied on the gel when it is compressed; this model gives the results that help researchers to find the mechanical properties of the gel. This model can provide micro conditions like those of an ovum compression to find its mechanical properties. The FEA also shows clearly that the analytical and FE models are supported by the experimental results. This will help this model to be used to find the mechanical properties of an actual ovum when injected.

graph 1 shows, the amount of force acting on the hydrogel from the injector needle is much smaller than that from the plate one. This causes higher stress on the place of compression, so less force is needed to puncture the surface, but both have the same force profile. This shows that the profile of the force is independent of the type of compressor.

Figure 2 indicates that the sample which was covered by 1 M CaCl2 can tolerate greater force and also be more stable than the samples which have a 0.5 M injection. The puncturing force for the samples with the 1 M cover is higher than for the samples with no cover. The reason for this is the higher molarity of the $CaCl_2$ causing the higher crosslinking, which can tolerate more force and is more stable at the time of injection.

Conclusion

This study presents an artificial ovum made of hydrogel for experimentation on a larger scale to predicate these properties in micro size, which is one of the applications of multi-scale experiments. These samples were tested by compression test device using two different load jigs with two different contacting areas. These graphs can illustrate the mechanical properties of the designed artificial ovum.

This models and samples can be used in laboratory experiments.

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