Computational simulation of pressure changes during embryo transfer

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ABSTRACT

Purpose: The embryo transfer into the uterus by a transcervical catheter is the final stage of in-vitro fertilization procedure. This study was designed to analyze the influence of injection speed on pressure fluctuation inside the transferred fluid.
Methods: Computational fluid dynamics was applied to calculate pressure changes in the transferred load for the following injection speeds: 0.01, 0.1, 1, 6, 12 and 20 m/s. A 3D geometrical model of the flow domain was created in ANSYS Modeler. The computations were carried out using the CFD code Parallel ANSYS Fluent 12.1 with the segregated solver SIMPLE (Semi-Implicit Method for Pressure-Linked Equations). The model was solved in double precision on a control volume unstructured 3D mesh made in ANSYS Mesher.
Results: The results of the present study indicate that the total, static and dynamic pressures rise with increase of the injection speed of the transferred load.
Conclusions: Taking these results into consideration, it is advised to transfer the embryos with minimal injection speed because the magnitude of the pressure changes rises with the injection speed of the transferred load.
Key words: Catheter, embryo, embryo transfer, fluid velocity, pressure based catheter

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INTRODUCTION

Embryo transfer (ET) is a fundamental element of the *in-vitro* fertilization process. During ET a newly formed embryo is placed within the uterus by means of a transcervical catheter. A successful ET includes a smooth and atraumatic passage of the ET catheter through the cervix and deposition of embryos to a site in the endometrial cavity where the chance of implantation is greatest [1-4]. Apart from the embryo quality and operator experience, the ET catheter properties are the most important for a positive ET outcome. The fact that high rates of fertilization in the laboratory result in a relatively low rate of take home babies have led investigators to focus the blame on various features of the ET procedure [1-4]. So far, a little attention has been placed on the physical forces acting on embryo in the process of embryo transfer.

Therefore, in the current work, the pressure changes inside the transferred fluid during the injection phase of ET were analyzed and their possible impact on embryo viability was discussed.

MATERIALS AND METHODS

A numerical approach using computational fluid dynamics (CFD) was implemented during the present study. To complete the experimental approach presented in a previous article [5], a numerical model of the ET catheter ending and a model of the uterus were studied during the injection phase of ET. The entire period of injection lasted for 0.02s. Water, being a model of the medium of embryo culture, was injected at a time interval of 0.01s at a linear rising rate into the uterus model, which contained glycerin at rest. The water flow rate was then reduced to zero. The diameter of the inner compartment of the catheter used for the experiments and simulations was 0.4 mm. The tip narrowing was assumed to be 20% of the diameter of the inner compartment. Embryo culture medium properties were assumed to be those of liquid water, (density ρ=998.2 kg/m^3 and dynamic viscosity μ=0.001003 kg/(m·s)). In order to mimic the viscose uterine fluid, the uterus model was filled with glycerin of density ρ=1236.25 kg/m^3 and dynamic viscosity μ=0.799 kg/(m·s), which has similar density as that of the uterine fluid [6]. A 3D geometrical model of the flow domain was created in ANSYS Modeler.

Calculations were performed for the following mean velocities: 0.01, 0.1, 1, 6, 12 and 20 m/s.

The flow was assumed to be transient, incompressible, and turbulent, as described by the Reynolds-averaged Navier-Stokes equations (RANS) with the SST k-ω turbulence model. The computations were carried out using the CFD code of Parallel ANSYS Fluent 12.1 with the segregated solver SIMPLE (Semi-Implicit Method for Pressure-Linked Equations). The model was solved in double precision on a control volume, unstructured, 3D mesh of 3,961,001 control volumes made using ANSYS Meshing.

The study was approved by the local ethics committee.

RESULTS

The results of the present study indicate that the total, static and dynamic pressures rise with increase of the injection speed of the transferred load.

With an injection velocity of 0.01 m/s at the level of line A, the total pressure in point A was 1.7 mmHg and was comparable to pressure at point B 1.7 mmHg. The static pressure at point A and B was comparable, 1.7 mmHg vs 1.7 mmHg. The dynamic pressure at point A was 0.001 mmHg and was lower than in point B 0.002 mmHg.

Table 1.Relation between average fluid velocity and pressure at point A and B of embryo transfer catheter (Figure 1).

Injection speed [m/s]	**0.01**	**0.1**	**1**	**6**	**12**	**20**
Total pressure at point A [mmHg]	1.69	2.71	21.89	567.22	2027.65	5618.1
Total pressure at point B [mmHg]	1.68	2.59	20.77	551.19	1984.13	5479.1
Static pressure at point A [mmHg]	1.69	2.61	12.95	344.79	1267.9	3571
Static pressure at point B [mmHg]	1.68	2.29	5.43	110.04	354	962.7
Dynamic pressure at point A [mmHg]	0.0010	0.10	8.94	222.43	759.75	2047.1
Dynamic pressure at point B [mmHg]	0.0023	0.30	15.34	441.15	1630.13	4516.4

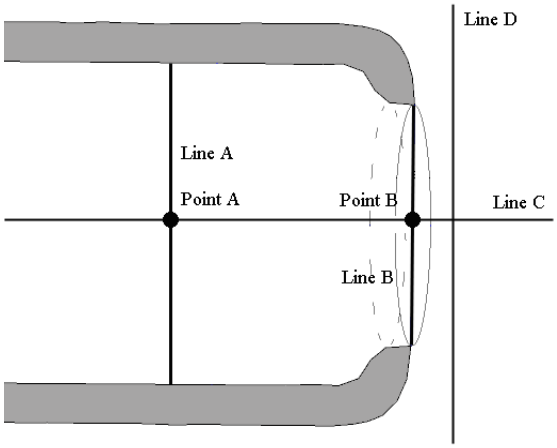

Figure 1. The cross-section of the embryo transfer catheter tip.

For the injection velocity of 0.1 m/s at the level of line A, the total pressure in point A was 2.7 mmHg and was comparable to pressure at point B 2.6 mmHg, Table 1, Figure 1. The static pressure at the point A and B was comparable, 2.6 mmHg vs. 2.3 mmHg. The dynamic pressure at point A was 0.1 mmHg and was lower than in point B 0.3 mmHg.

For the injection velocity of 1 m/s at the level of line A, the total pressure in point A was 21.9 mmHg and was comparable to pressure at point B 20.8 mmHg, (Table 1, Figure 1).

The static pressure at point A was higher than at point B, 13 mmHg vs. 5.4 mmHg. The dynamic pressure at point A was 8.9 mmHg and was lower than in point B 15.3 mmHg.

For the injection velocity of 6 m/s at the level of line A, the total pressure in point A was 567.2 mmHg and was comparable to pressure at point B 551.2 mmHg, Table 1, Figure 1. The static pressure at point A was higher than at point B, 344.8 mmHg vs. 110 mmHg. The dynamic pressure at point A was 222.4 mmHg and was lower than in point B 441.2 mmHg.

For the injection velocity of 12 m/s at the level of line A, the total pressure in point A was 2027.7 mmHg and was comparable to pressure at point B 1984.1 mmHg, (Table 1, Figure 1). The static pressure at point A was higher than at point B, 1267.9 mmHg vs. 354 mmHg. The dynamic pressure at point A was 759.75 mmHg and was lower than in point B 1630 mmHg.

For the injection velocity of 20 m/s at the level of line A, the total pressure in point A was 5618.1 mmHg and was comparable to pressure at point B 5479.1 mmHg, (Table 1, Figure 1). The static pressure at point A was higher than at point B, 3571 mmHg vs. 962.7 mmHg. The dynamic pressure at point A was 2047.1 mmHg and was lower than in point B 4516.4 mmHg.

Table 1 presents detailed data on shear stress for the particular injection velocities.

Figures 2, 3, and 4 present the total pressure at the level of catheter outlet, outside the catheter outlet, and along the central line of the catheter, respectively.

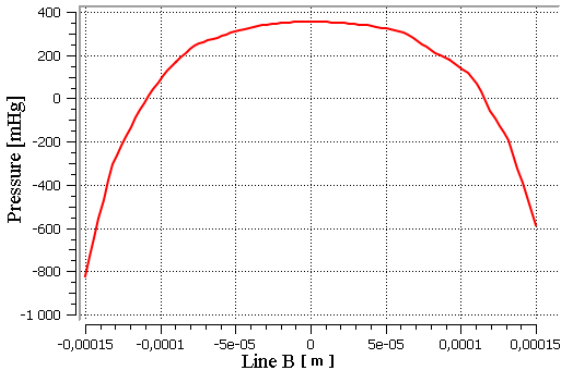

Figure 2. Pressure at the level of the catheter outlet (line B, Fig.1) for the ejection speed of 12 m/s.

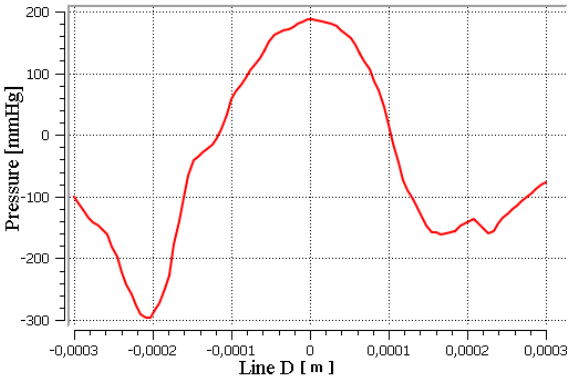

Figure 3. Pressure 0.04 mm from the catheter outlet (line D, Fig.1).

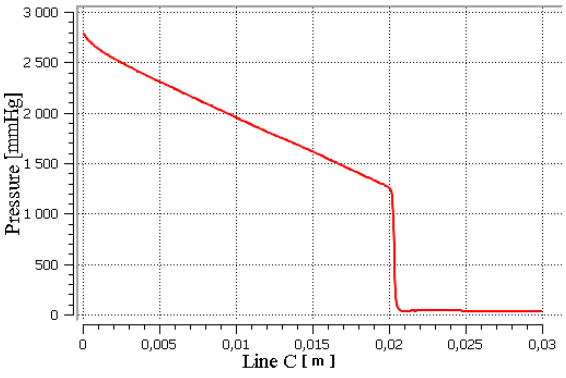

Figure 4. Pressure along the central line of the catheter (line C, Fig.1).

DISCUSSION

The purpose of this study was to examine the influence of the ejection speed of the transferred load on pressure changes. The results of the current study indicate that the total, static and dynamic

pressures rise with increase of the injection speed of the transferred load.

The general idea of delivering an embryo into the uterine cavity is relatively simply. The pressure generated in the working chamber of the insulin syringe is passed into the catheter where it causes the ejection of the transferred load. However, it is easy to note that the diameter of the plunger of the insulin syringe is up to ten times greater than that of the catheter. The immediate consequence of this data is that when the insulin syringe plunger is moved by 1 mm, it transports approximately 140 times more volume of medium than the catheter. Therefore, it is very easy to generate high pressure inside the transferred load in a very short time period.

To date, a little attention has been placed on a pressure changes during ET as a possible factor influencing the embryo viability. In the literature, there are some evidences for cell damage caused by local pressure fluctuations. Key and coworkers noticed that a pressure gradient, not exposure duration determined the extent of the epithelial cell damage in a model of pulmonary airway reopening [7]. Furthermore, Bilek et al. [1] investigated surface-tension-induced lung epithelial cell damage in a model of airway reopening, and they concluded that the steep pressure gradient near the bubble front was the most likely cause of the observed cellular damage. An abrupt pressure fluctuation in the cell environment may influence many vital aspects of the cell anatomy and physiology. For example, the cell membrane of the pulmonary epithelial cells could be disrupted by the steep pressure gradient appearing during airway reopening [1, 7]. Moreover, cytoskeletal damage *in vitro* was demonstrated after the impact of 16 MPa (120 000 mmHg) on a human renal carcinoma cell line [8]. It was also demonstrated that the high pressure could inactivate intracellular enzymes [9, 10]. It is certain that positive pressure does not actually cause damage to the cells but the steep increase in pressure (compression), followed by negative pressure (decompression), does cause damage since biological structures can only be damaged by shear or extension and not by positive pressure [11, 12].

The narrowing of the catheter tip constitutes the obstacle for the transferred load, especially for the embryo in the peripheral region of the catheter lumen. Furthermore, the narrowing of the catheter tip considerably increases injection speed of the transferred fluid and causes abrupt pressure fluctuations (Figure 4). It is known that narrowing of small blood vessels results in distortion and fragmentation of erythrocytes, such as in the microangiopathic hemolytic anemia or hemolytic-uremic syndrome [13]. Therefore, it would be appropriate to eliminate any narrowing of the catheter lumen.

CONCLUSIONS

Taking the results of the present study into consideration, it would be advised to transfer the embryos with minimal injection speed because the magnitude of the pressure changes rises with the injection speed of the transferred load.

Conflicts of interest

The authors have declared no conflicts of interest.

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