Fluid velocity during embryo transfer

Mrugacz G.[1], Grygoruk C.[1*], Kolodziejczyk M.[2], Gagan J.[2], Ratomski K.[2], Grusza M.[1]

[1]Center for Reproductive Medicine BOCIAN, Akademicka 26, 15-267 Bialystok, Poland
[2] Faculty of Mechanical Engineering, Bialystok Technical University, Bialystok, Poland

ABSTRACT

Purpose: The embryo transfer into the uterus by a transcervical catheter is the final stage of in-vitro fertilization procedure. So far, a little attention has been placed on the impact of embryo transfer procedure on embryo viability. This study was designed to analyze fluid velocity changes in the transferred load during the injection phase of embryo transfer.

Materials and methods: Computational fluid dynamics was applied to calculate fluid velocity 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 transferred fluid velocity was highest in the center of the catheter lumen and lowest at the proximity of the catheter's wall. The narrowing of catheter lumen diameter by 20% amplified the transferred fluid velocity by 78%. The abrupt increase in fluid velocity, caused by narrowing of the catheter tip was followed by the abrupt drop of fluid velocity outside the catheter.

Conclusions: Taking these results into consideration, it is advised to eliminate any narrowing of the catheter lumen in order to assure more favorable conditions for the transferred embryos.

Key words: Catheter, embryo, embryo transfer, fluid velocity, pressure based catheter

***Corresponding author:**
Center for Reproductive Medicine „Bocian"
Akademicka 26, 15-267 Bialystok, Poland
Tel/Fax.: +48 85 7447700;
e-mail: cezary.grygoruk@gmail.com

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INTRODUCTION

The procedure of embryo transfer (ET) is the final manual intervention in-vitro fertilization procedure (IVF). During ET, a newly formed embryo is placed within the uterus by a transcervical catheter. The catheter loaded with embryos is inserted into the uterine cavity through the cervical canal of the uterus. Then, the load is injected and the catheter is removed from the cavity. 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]. Several factors, having an impact on the ET success, have been described as for example the number, quality and stage of development of the embryos, the receptivity of the uterus, the risk of expulsion of the embryos from the uterine cavity, the instrumentations used as well as the ability and specific experience of the operators. It has been also suggested that mechanical factors, such as catheter type, method of loading the catheter, placement of the catheter tip may be the cause for the relatively low pregnancy rates. 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 transferred fluid velocity 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 using ANSYS DesignModeler.

The average fluid velocity was computed at the line A, B, C and D (Fig. 1). 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 narrowing of catheter lumen diameter by 20% increased the transferred fluid velocity by 78% (Table 1). With an injection velocity of 0.01 m/s at the level of line A, the fluid velocity at the cross-section at the level of line B reached 0.018 m/s. With an injection velocity of 0.1 m/s at the level of line A, the fluid velocity at the cross-section at the level of line B reached 0.178 m/s. With an injection velocity of 1 m/s at the level of line A, the fluid velocity at the cross-section at the level of line B reached 1.77 m/s. With an injection velocity of 6 m/s at the level of line A, the fluid velocity at the cross-section at the level of line B reached 10.7 m/s. With an injection velocity of 12 m/s at the level of line A, the fluid velocity at the cross-section at the level of line B reached 21.4 m/s. With an injection velocity of 20 m/s at the level of line A, the fluid velocity at the cross-section at the level of line B reached 35.7 m/s.

Table 1 presents detailed data for the particular injection velocities.

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

Table 1. Relation between average fluid velocity of the transferred load at the level of the line A (Figure 1) to average fluid velocity at the catheter outlet (line B).

Average velocity of fluid at the level of line A [m/s]	0.01	0.1	1	6	12	20
Average velocity of fluid at the level of line B [m/s]	0.018	0.178	1.77	10.7	21.4	35.7

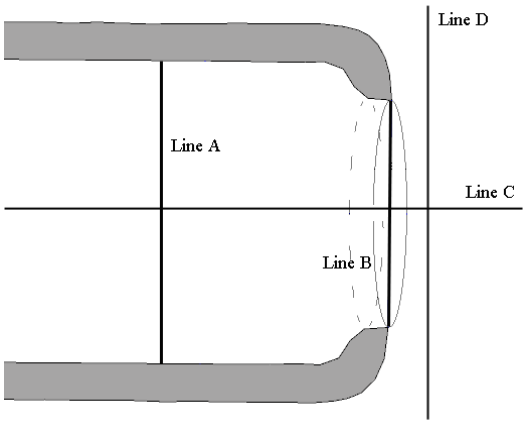

Figure 1. The cross-section of the embryo transfer catheter tip.

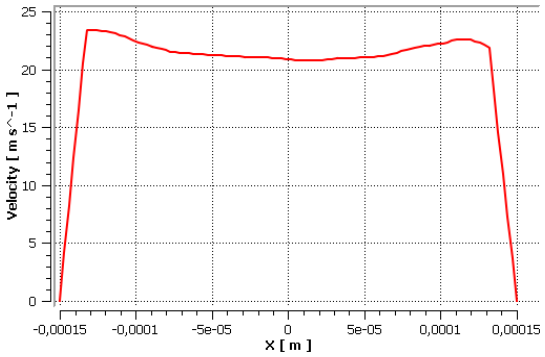

Figure 2. Fluid velocity at the level of the catheter outlet (line B, Fig.1) for the ejection speed of 12 m/s.

The transferred fluid velocity was the lowest in proximity to the catheter's wall. The fluid speed was highest at center of the catheter lumen (Fig. 3). The narrowing of the catheter tip caused the abrupt increase of fluid velocity.

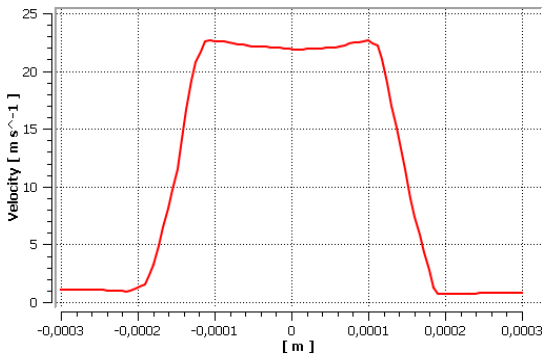

Figure 3. Fluid velocity 0.04 mm from the catheter outlet (line D, Fig.1) for the ejection speed of 12 m/s.

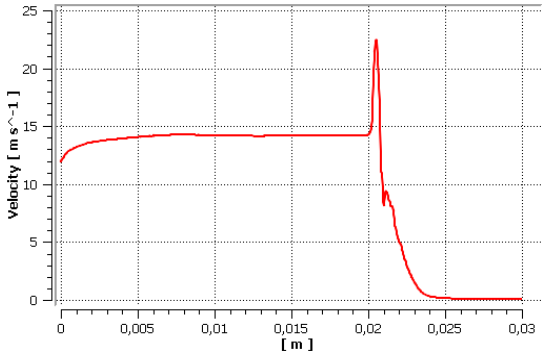

Figure 4. Fluid velocity along the central line of the catheter (line C, Fig.1) for the ejection speed of 12 m/s.

DISCUSSION

The aim of this study was to investigate the fluid velocity of the transferred load during the injection phase of ET. The results of the present study indicate that the narrowing of the catheter tip considerably amplifies 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. The following consequence of the such abrupt pressure rise is the fast ejection speed of the transferred load. According to our previous study, it can reach a mean speeds of 12 m/sec. So fast transferred fluid flow inside catheter can generate unfavorable physical conditions for the transferred embryos. According to the concept of the fluid flow inside a tube with a circular cross-section, the fluid in the central region moves faster than in the peripheral region of the catheter lumen (Fig.2). The fluid flow velocity gradient exerts shear stress on any object placed inside the fluid. Taking under consideration the diameter of the embryo, which are approximately 120-180 um, the embryo which flow closer to the wall of the catheter will be exposed to the tremendous speed gradient, which evoke the significant shearing forces, which can be detrimental to the cell structure and overall viability of the embryo.

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. 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 [7]. Therefore, it would be appropriate to eliminate any narrowing of the catheter lumen. Furthermore, it would be optimal to maintain embryos in the center of the catheter lumen during ET, far from the catheter's wall.

CONCLUSIONS

Taking the results of the present study into consideration, it would be advised to eliminate any narrowing of the catheter lumen in order to assure more favorable conditions for the transferred embryos.

Conflicts of interest

The authors have declared no conflicts of interest.

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