

Physics Models of Pronuclear Movements in Eggs

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Abstract: Based on published experimental data, Newton's laws, and Coulomb's law, we investigate natural and normal pronuclear movements in wild types of eggs and develop physics models to fit the experimental data quantitatively. The difference between our modeling calculated results and the experimental data is less than 20%. Our models explain why and how pronuclei move in even or in variant velocities. We hypothesize: During the migration, positively charged asters (or self assembled microtubules) drive two negatively charged sperm and egg pronuclei to move towards each other. The driving force comes from a spontaneous and strong Electromagnetic Field (EMF). Hamilton's principle determines the path of these movements. A natural and normal EMF inside or around the pronuclei can be alternated environmentally. An abnormal EMF could induce aberrant embryos that cause life disease. We believe our models are helpful to further understand the mechanism of fertilization and have potential clinical value to prevent aberrant embryos that induce human life disease.

Key Words: Fertilization, Electromagnetic, Electric, Field, Hamilton, Newtonian, Coulomb

INTRODUCTION

Fertilization (Sexual reproduction) involves the recombination of genetic information from parents to produce offspring. Prior to the recombination, an important procedure is the pronuclear movement (i.e. the migration of inherited information).

In experiments, pronuclear movements have been observed in constant migration velocities [1-2], or in variant migration velocities. An aster (or asters) and a sperm pronucleus form a super complex because they always move or rest as a whole [1, 3-4], otherwise an aster (or asters) and an egg pronucleus form a super complex because they always move or rest as a whole [2]. However, we have not found any reported physics theory (model or hypothesis) to explain why and how these phenomenons happen.

In 1988, Meggs proposed a hypothesis of Electric Fields (EF) determination of the spatial organization of Microtubules (MT) [5]. In our recent papers, we proposed physics models to investigate the mechanisms of the mitosis [6], amitosis [7] and cytokinesis. We believe that Electromagnetic Field (EMF) plays an important role in the biological events.

To reveal the mechanism of procedure of pronuclear movement in fertilization, based on the published experimental data, Newton's laws and Coulomb's law, with the concept of EF and/or EMF, we develop our physics models of pronuclear migration in eggs in this paper.

MATERIALS AND METHODS

Experimentally, two kinds of super complexes have been observed: an aster (or asters) and a sperm

pronucleus form a super complex because they always move or rest as a whole [1, 3-4], otherwise an aster (or asters) and an egg pronucleus form a super complex because they always move or rest as a whole [2]. In each case, asters or microtubules are essential for pronuclear migration [8-9].

In our previous study, we consider the protoplasm as electrolyte with an uneven charge distribution as well as a runtime environment driven by biochemical or biophysical events. We assumed: nuclei have net negative charges and asters (or self assembled microtubules) including proteins (e.g. actins) have net positive charges, the activated microtubules are electrically, positively polarized at positive growing ends and negatively polarized at negative growing ends. The EF through pores of nuclear envelopes and centrosomes are stronger than that through other locations, the stronger the EF, the more the microtubules grow [6].

To explain the mechanism of the pronuclear movements observed, we further assume: Before an egg is fertilized, the EF is weak and an egg pronucleus moves randomly in the egg. After an egg is fertilized, biochemical events provoke a spontaneous and strong EF in protoplasm and cortex. Positively charged asters drive two negatively charged sperm and egg pronuclei to move towards each other. Hamilton's principle determines the path of these movements.

We consider the simplest case that has only one aster, one sperm pronucleus and one egg pronucleus. The aster and the sperm pronucleus form a super complex. In a cylindrical coordinates and laboratory reference system, we assume a couple of sperm and egg pronuclei migrate along the z-axis to obtain analytic solutions mathematically (Fig. 1).

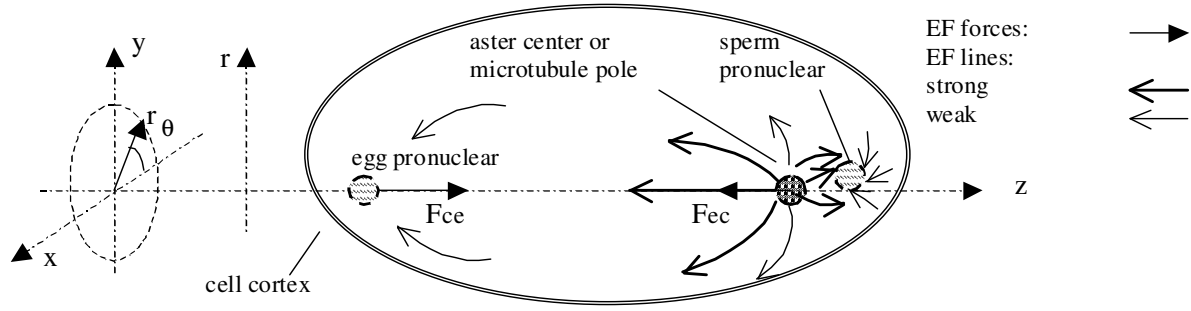


Fig. 1. Pronuclear migration in an egg: Microtubules grow along stronger EF lines.

Assuming the pronuclei and the aster center have roughly sphere shapes, we use an extended Coulomb's law to estimate the EF force on an egg pronucleus,

$$F_{ce} = -F_{ec} = \frac{Q_e Q_s}{4\pi\epsilon d_{es}^2} d_{es0} + \frac{Q_e Q_a}{4\pi\epsilon d_{ea}^2} d_{ea0} + \sum_i \int \frac{Q_e dq_i}{4\pi\epsilon d_{ei}^2} d_{ei0} \quad (1)$$

$\epsilon = \text{permittivity}$

Where F_{ce} and F_{ec} are vectors of EF forces. Q_e , Q_s , Q_a and Q_i are equivalent charges of an egg pronucleus, a sperm pronucleus, an aster center and a microtubule respectively. dq_i is an integral unit of charge on a microtubule (except the pole). d_{es} , d_{ea} , and d_{ei} are respectively distances of charge centers between Q_e and Q_s , between Q_e and Q_a , and between Q_e and dq_i . All these distances should be greater than a sum of pronuclear sizes of an egg and a sperm. d_{es0} , d_{ea0} and d_{ei0} are unit vectors of the distances. We can obtain corresponding equations (F_{cs} and F_{sc}) for an approach of a sperm pronucleus and a super complex of an egg pronucleus and an aster by exchanging subscript e and s in equation (1). The motions are estimated with Newtonian equations (2), (3), (4) and (5), where m_e , m_s and m_c , v_e , v_s and v_c , F_{er} , F_{sr} and F_{cr} are respectively effect masses, velocities and resistances of the egg, the sperm, and the super complex.

$$m_e \frac{dv_e}{dt} = F_{ce} + F_{er} \quad (2)$$

$$m_c \frac{dv_c}{dt} = F_{ec} + F_{cr} \quad (3)$$

$$m_s \frac{dv_s}{dt} = F_{cs} + F_{sr} \quad (4)$$

$$m_c \frac{dv_c}{dt} = F_{sc} + F_{cr} \quad (5)$$

In equations (2) to (5), the resistances are always against the direction of migrations. The stronger the resistance, the slower the movements; the stronger the EF or the less the masses, the faster the migration. From

the above analysis, our methods demonstrate the source and the kind of the driving force for the pronuclear motion is EMF and the dominant force comes from EF. Therefore, our models provide an explanation of mechanisms of pronuclear migration in a physics perspective.

RESULTS AND DISCUSSION

A. Constant Migration Velocities: For experiments of constant migration velocities [1] or [2], we neglect equation (3) or (5), because the super complexes do not move, must be: $|F_{ec}| < \text{maximum } |F_{cr}|$, or $|F_{sc}| < \text{maximum } |F_{cr}|$. We consider equation (2) or (4) only. If the resistance is just overcome by the EF force: $|F_{ce}| = \text{maximum } |F_{er}| + 0_+$ or $|F_{cs}| = \text{maximum } |F_{sr}| + 0_+$, v_e or v_s must be a constant (> 0), mathematically. Therefore, our equations explain why and how the migration velocities for the eggs or sperms are constants.

B. Variant Migration Velocities: For experiments of variant migration velocities [3], we use equations (2) and (3) only, because a sperm and an aster form a super compound. The published experimental data show relative migration velocities are faster from the distant to the near. To get analytical solutions, we simplify equation (1) as:

$$F_{ce} = -F_{ec} = \frac{Q_c Q_e}{4\pi\epsilon(z_e - z_c)^2} z_0 \quad (6)$$

Q_c is an equivalent charge of the super complex. z_c and z_e are central positions of Q_c and Q_e . z_0 is a unit vector of z . From equations (2), (3) and (6), we obtain,

$$m_r \frac{dv_r}{dt} = \frac{Q_c Q_e}{2\pi\epsilon z_r^2} z_0 + \frac{m_e}{m_e + m_c} F_{er} - \frac{m_c}{m_e + m_c} F_{cr} \quad (7)$$

Where a relative velocity $v_r = v_c - v_e$, a relative distance $z_r = z_c - z_e$ and a reduced mass $m_r = m_c m_e / (m_c + m_e)$. When the EF force is much greater than the resistances, integrating equation (7), we get,

$$v_r^2 = \frac{-1}{m_r} \frac{Q_c Q_e}{\pi \epsilon} \left(\frac{1}{z_r} - \frac{1}{z_{r0}} \right) \geq 0 \quad (8)$$

z_{r0} is an initial relative distance. The relative distances and relative velocities are more efficient and meaningful in evaluation of the migration. From equation (8), we know that the square of the velocity is approximately inversely proportional to the relative velocities when the resistance can be neglected. We will never obtain this derivative mathematical result without our analysis and simplification in physics. Therefore, equation (8), in mathematics and physics, explains the experimental data of why and how the less the relative distance, the faster the relative velocity is. To further support our equations, we calculate the normalized relative velocity ($1/z_r - 1/z_{r0}$), and compare the change rate of the normalized relative velocity with that of the experimental data of the relative velocity (3, 1984). The difference is less than 20%.

DISCUSSION

Our models quantitatively explain why and how the migration velocities for the eggs or sperms are sometimes constants and sometimes variant and fit experimental data. We can directly calculate EF and the corresponding forces as long as we know the related data, such as charge distribution, permittivity and resistance.

For experiments of constant migration velocities [1] or [2], the migration velocities for the eggs or sperms are approximately independent of time because the resistance is just overcome by the EF force according to our physics models. For experiments of variant migration velocities [3-4], the relative migration velocities for the eggs or sperms are faster when the relative distances are less, because EF force is much greater than the resistance according to our physics models. We calculate the normalized relative velocity ($1/z_r - 1/z_{r0}$), and compare the change rate of the normalized relative velocity with that of the experimental data of the relative velocity [3]. Our models fit 80% of the experiment data. Therefore, our physics models explain why and how the migration velocities for the eggs or sperms are sometimes constants and sometimes variant.

Oscillations during pronuclear migration [1, 4] could be caused by periodic arrays of cellular skeletons. The choosing mate option [1] could be processed by a discharge, a reverse charge, and a recharge of pronuclei. Other forces in an egg are neglected because they could be randomly or uniformly distributed. Pronuclei perform Brownian movements when all forces are random [1]. The further research in future could be in the direction of pronuclear fusion and choosing mate option experimentally and theoretically. Biochemical or biophysical events could be involved in

pronuclear activation. A natural and normal EMF or EF inside or around the pronuclei can be alternated environmentally. An abnormal EMF or EF could induce aberrant pronuclei and embryos that cause life disease. In recent years, many investigations of pronuclear migration have been reported. E.g. *tac-1* is essential for pronuclear migration [10]; loss of function of the gamma-tubulin gene by RNAi does not affect pronuclear migration [11]; pronuclei treated with antibodies will not move at all [12-13]; some special biochemical treatments may [14] or may not [15-17] affect to the motion; mutant defected pronuclei migrate abnormally [18-21] or normally [22]. We think all of the above results are caused by normal or abnormal EMF (EF) distribution. Though, we develop our physics models for a natural and normal pronuclear migration using a simple case of one sperm pronucleus, one egg pronucleus and one aster, we believe our physics models are also applied to investigations of multiple sperm pronuclei (or multiple egg pronuclei), in both normal and abnormal biological environments, in principle.

The drawbacks of the methods could be errors of neglecting magnetic field (MF) effect, and using equivalent charge to replace the integration of the charge distribution in equations (6) and (7); it is difficult to obtain the charge distribution and equation (8) is not valid when two pronuclei move closely because the resistance can not be neglected in this situation. Theoretically, we can estimate any term if we know other three terms from experimental measurements. But, problem is that we can only measure the velocity and acceleration in most experiments today.

CONCLUSIONS

We originally introduce Coulomb's EMF into investigations of pronuclear movements, and provide physics models to fit the experimental data (fit > 80%). Pronuclear migration is dependent of cellular EMF or EF. The migration is normal when the EMF or EF is normal, otherwise it is not.

ACKNOWLEDGMENT

We thank Dr. Cheng, Yaoting for financial support and Miss Vivien Cheng for helpful suggestions and comments, for this publication.

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