Propagation of H1N1 virus through saliva movement in oesophagus: a mathematical model

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Abstract  H1N1 (Swine flu) is caused by the influenza A virus which belongs to the Orthomyxoviridae family. Influenza A is very harmful to the elderly, and people with chronic respiratory disease and cardiovascular disease. Therefore, it is essential to analyse the behaviour of virus transmission through the saliva movement in oesophagus. A mathematical paradigm is developed to study the saliva movement under the applications of transverse magnetic field. Jeffrey fluid model is considered for saliva to show the viscoelastic nature. The flow nature is considered creeping and assumptions of long wavelength and low Reynolds number are adopted for analytical solutions. The Basset–Boussinesq–Oseen equation is employed to understand the propagation of H1N1 virus through saliva under the effect of applicable forces such as gravity, virtual mass, basset force, and drag forces. The suitable data for saliva, oesophagus and H1N1 virus are taken from the existing literature for simulation of the results using MATLAB software. From the graphical results, it is observed that the susceptibility to viral infections is less because the magnetic field reduces the motion of the virus particle. Further, the chances of infections in males are more as compared to females and children due to variation in viscosity of saliva. Such findings provide an understanding of the mechanics of the virus floating through the saliva (viscoelastic fluids) in the oesophagus.

1 Introduction

Infectious diseases spread by contagious viruses, and different types of viruses are outbreak from time to time which is a major concern in today’s world. Influenza virus is the most common infectious disease, especially in the season, which is usually found in humans, animals, and sea mammals. There are various strains of the Influenza virus (such as A, B, C, D, Swine flu) that have been found within the last 10 years. Various studies have reported the dynamics of virus outbreaks such as SARS-CoV-2, Ebola virus, Zika virus [1–3]. Typically, these are airborne infectious viruses. However, some literature reported that it may be an airborne or waterborne infection [4]. Amira et al. [5] studied on the outbreak of the Ebola virus in West Africa and addressed how vaccination will recover the infected person over time. Further, numerous studies have discussed about the optimal control strategies in preventing the H1N1 virus spreading further, researchers have developed some models that studied how to control the transmission of the virus spreading [6–8].

In 2009, swine and avian influenza viruses were declared as pandemic when these viruses were transmitted to mammals. Swine Influenza is very infectious and originates in pigs, but it is passed mostly from person to person. Analysts continuously monitor how the virus evolves and changes its behaviour. In this way, it is reported that Swine influenza is spherical with diameters of approximately 117 nm (0.117 microns) [9]. Bahl et al. [10] classified the shape and size of the virus particles and addressed the behaviour of virus particles in the form of droplets or aerosols. In this regard, Boussinesq [11] and Basset [12] derived the equation of the particle motion to demonstrate the behaviour of the spherical particle propagating through the fluid flow. Based on their contribution to the particle study, the particle equation of motion is also known as the Basset–Boussinesq equation. Continuing in this way, Oseen [13] took into account how higher Reynolds numbers affected the Basset–Boussinesq equations and contributed in a Basset–Boussinesq–Oseen (BBO) equation with a constant forcing (the gravity term). However, no literature described how H1N1 virus particles are transported in the human body through the physiological transport of fluids like saliva movement, blood flow, urine flow, chyme movement, etc. Finlay et al. [14] mentioned the aerosol particle trajectory through the viscous fluid medium in the physiological system. Under the assumptions: (a) the particle form is presumed to be spherical, and (b) the virus particle density is presumed to be much greater than the viscous fluid density, the study of the motion of the particle in a viscous fluid flow was carried out. Kim et al. [15] reported that simulation of particle trajectory may be complex if the fluid density is more than the particle density. Because of various fluid forces such as Basset force, buoyancy, and pressure force virtual mass may intervene the analysis to be complicated.

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Typically, the virus transmits from one person to another via sneezing and talking. There are two paths of virus particles entering the human body, i.e. either nose (aerosol particle) or mouth (transmission from one person to another) [16]. This study is crucial to understanding the virus particle motion in the transmission process through the physiological system. Cao et al. [17] studied the transmission route of virus aerosol particles exhaled by patients and addressed that the horizontal diffusion distance of exhaled pollutants is about 0.75m to 1.1m, which can transmit the virus to a certain extent. The methods, technologies, and practices used to prevent respiratory infections are also based on fluid dynamics [18–21].

In some situations, the virus can be transported in the specimen itself including blood, urine, tract, cerebral spinal fluid, urine, washings of the respiratory, and stool [22]. In the human physiological system, peristaltic motion is a fluid transport mechanism in which a progressive wave of area contraction or expansion propagates along the length of a fluid-filled distensible tube or channel’s wall [23]. In the current model, saliva is taken as viscoelastic fluid medium for virus transport, where the Jeffrey fluid model is considered as a viscoelastic fluid for saliva. The Jeffrey model is a more straightforward linear model of viscoelastic fluid in which spring (elastic behaviour) [24] and dashpot (viscous behaviour) are combined in parallel, and one dashpot is also in series with this arrangement [25]. Davis [26] studied the rheological properties of saliva fluid and examined the viscoelastic behaviour of saliva fluid. Pandey et al. [27] investigated the peristaltic flow of viscoelastic fluids through oesophagus. Ishtiaq et al. [28] examined the behaviour of physiological fluids passing through non-uniform channels by considering the Jeffrey fluid model under the influence of magnetic field. Numerous models have been reported on the peristaltic flow of viscoelastic fluids to understand the significance of the magnetic field [29–33] and viscoelastic properties of the fluids [34] in physiological transport phenomena.

Paul et al. [35] examined the role of saliva in spreading viruses thus the fluid medium is an essential carrier for transferring active viruses to the laboratory for isolation, especially while collecting specimens. In many physiological transport and transmission of viruses, a question arises that why the magnetic field is important in such type transport phenomena? To clarify such a question, existing literature and data are always supported. There is a result that the weakness of the magnetic field caused the spread of the Zika virus [36]. From the literature, it is studied that the human physiological system such as living organisms (cells, viruses) are affected by the magnetic field [37]. Tripathi et al. [38] addressed the significance of magneto-hydro-dynamical study on digestive transport phenomena. The magnetic field is also considered for reliable time-efficient diagnostic testing which seems to be useful in decreasing infection in the community [39]. Various magnetic micro/nano sensor-based platforms for virus and pathogen detections are reported in literature [40–42]. Fukushima et al. [43] investigated the role of the magnetic field during viral respiratory infection and observed that magnetic fields affect the virus’ propagation.

Based on the rigorous literature review, it is observed that no study has been done on H1N1 virus particle motion through saliva. Therefore, this article is designed in such a way that a mathematical model provides the parametric results based on the estimated data available in the literature for saliva and Swine flu. Further, it is reported that the importance of the magnetic field to control the motion of virus in the physiological system. The formulated differential equations are solved using an analytical approach and graphical results are illustrated using the MATLAB software. The model is constructed in the following sequences: Section 2 presents the mathematical framework of the model where the constitutive equations of incompressible viscoelastic fluid with magnetic field are derived. Further, BBO equation is considered for H1N1 virus particle motion through saliva. Section 3 presents the results and discussion of virus velocity profile, streamlines of H1N1 virus and particle relaxation time under the effects of virus diameter and density, and saliva viscosity. Based on the simulated results, the recommendations of parametric analysis are summarized in the last section, i.e. the conclusions.

2 Model formulation

2.1 Movement of saliva under the application of external magnetic field

For saliva, a two-dimensional incompressible viscoelastic fluid is considered. The flow is governed by the peristaltic pumping which occurs in digestive system. The rhythmic contraction-relaxation waves are assumed to move with constant wave velocity (c) along the length of the oesophagus wall (L) in the axial direction which is systematically drawn in Fig. 1 that can be mathematically defined by the following expression (See Ref. [24]):

\[ H(x, t) = R_w - a_0 \cos^2 \left[ \frac{x}{\lambda} (x - ct) \right] \]  

(1)

where \( a_0 \) is the wave amplitude, \( \lambda \) is the wavelength, \( R_w = b + a_0 \) is the half width of the channel. The governing equations for incompressible, viscoelastic fluid with static magnetic field \( \mathbf{B} = (0, B_0, 0) \) in the transverse direction can be expressed as:

\[ \nabla \cdot \mathbf{v}_f = 0 \]  

(2)

\[ \rho \left( \frac{\partial \mathbf{v}_f}{\partial t} + (\mathbf{v}_f \cdot \nabla) \mathbf{v}_f \right) = -\nabla p + \nabla \cdot \mathbf{S} + \sigma (\mathbf{v}_f \times \mathbf{B}) \times \mathbf{B} \]  

(3)
v_f = (u, v, 0) corresponding to the x-y plane, p is the pressure, \( \rho \) is the density of the saliva, \( t \) is the time, \( \sigma \) is the electric conductivity and \( S = \frac{\mu}{(1 + \lambda_2 \frac{\mu}{\sigma})} \) \( \dot{\gamma} \) is the extra tensor corresponding to the viscoelastic (Jeffrey) fluid. Here \( \dot{\gamma} \) represent the rate of strain, \( \mu \) is the viscosity of the saliva and \( \lambda_1 \) is the ratio of relaxation to retardation times, \( \lambda_2 \) is the retardation time. The governing equation can be written in the Cartesian form as (See Ref. [24]):

\[
\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0
\quad (4)
\]

\[
\rho \left( \frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} \right) = -\frac{\partial p}{\partial x} + \left( \frac{\partial S_{xx}}{\partial x} + \frac{\partial S_{xy}}{\partial y} \right) - \sigma \dot{\gamma}^2 u
\quad (5)
\]

\[
\rho \left( \frac{\partial v}{\partial t} + u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} \right) = -\frac{\partial p}{\partial y} + \left( \frac{\partial S_{xx}}{\partial x} + \frac{\partial S_{yx}}{\partial y} \right)
\quad (6)
\]

where \( S_{xx}, S_{xy}, S_{yx} \) and \( S_{yy} \) are stress components of the Jeffrey fluid model. Implementing the following dimensionless variables to the above equations

\[
x^* = \frac{x R}{\lambda}, \quad y^* = \frac{y}{R_w}, \quad H^* = \frac{H}{R_w}, \quad a^* = \frac{a_0}{R_w},
\]

\[
t^* = \frac{\epsilon t}{\lambda}, \quad u^* = \frac{u}{c}, \quad v^* = \frac{v}{\delta}, \quad S_{xx}^* = \frac{R_w S_{xx}}{\mu c}, \quad S_{xy}^* = \frac{R_w S_{xy}}{\mu c} \quad \text{and} \quad p^* = \frac{p R_w^2}{\mu c}
\]

where \( \delta = \frac{\pi R}{\lambda} \) is the wave number, \( R_e = \frac{\rho c R_w}{\mu} \ll 1 \) is the Reynolds number, \( H_a = B_0 R_w \sqrt{\frac{\mu}{\sigma}} \) is the Hartman number (magnetic field parameter). According to the assumptions of \( \delta \ll 1 \) and \( \text{Re} \to 0 \), the governing Eqs.(4-6) are converted into dimensionless parameter and drop (*) for our convenience.

\[
\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0, \quad -\frac{\partial p}{\partial x} + \frac{1}{\Lambda^2} \frac{\partial^2 u}{\partial y^2} - H_a^2 u = 0, \quad \frac{\partial p}{\partial y} = 0.
\quad (7)
\]

where \( \Lambda = \sqrt{(1 + \lambda_1)} \) is considered as a constant parameter. \( p = p(x, t) \) is the function of axial direction and temporal respectively. The following boundary conditions have been assumed to calculate the axial and transverse velocities as (See Ref. [46]):

1. At the wall edge, i.e. \( y = H, \ u = 0, \ v = \frac{\partial H}{\partial t} \)
2. At the centre line, i.e. \( y = 0 \), we have \( \frac{\partial u}{\partial y} = 0 \) and \( v = 0 \).

Hence the expressions for axial and transverse velocities can be computed as :

\[
u = -\frac{1}{H_a^2} \left( \frac{\partial p}{\partial x} \frac{\sinh(H_a y)}{\cosh(H_a y)} - \frac{\partial^2 p}{\partial x^2} \left( \frac{\sinh(H_a y)}{L_{H_a} \cosh(H_a y)} - y \right) \right)
\quad (9)
\]

The rate of change of wall can be calculated by using boundary condition \( v|_{y=H} = \frac{\partial H}{\partial t} \)

\[
\frac{\partial H}{\partial t} = -\frac{1}{H_a^2} \left( \frac{\partial p}{\partial x} \frac{\partial H_a}{\partial x} \tanh^2(H_a y) + \frac{\partial^2 p}{\partial x^2} \left( \frac{\tanh(H_a y)}{L_{H_a}} - H \right) \right)
\quad (10)
\]
Fig. 2 An illustration of transmission of the H1N1 virus through saliva in the oesophagus

The axial pressure gradient is derived by integrating Eq.(10):

$$\frac{\partial p}{\partial x} = \frac{\Lambda H_a^{\Delta} \left( \frac{p(L,t) - p(0,t)}{\Lambda H_a^{\Delta}} \right)}{\Lambda H_a^{\Delta} - \tanh(\Lambda H_a^{\Delta})} L \frac{dx}{\Lambda H_a^{\Delta} - \tanh(\Lambda H_a^{\Delta})} + \frac{\frac{2}{3} \cos(2(x-t))}{\Lambda H_a^{\Delta} - \tanh(\Lambda H_a^{\Delta})} L \frac{dx}{\Lambda H_a^{\Delta} - \tanh(\Lambda H_a^{\Delta})} + \frac{\frac{1}{4} \cos(2(x-t))}{\Lambda H_a^{\Delta} - \tanh(\Lambda H_a^{\Delta})} L \frac{dx}{\Lambda H_a^{\Delta} - \tanh(\Lambda H_a^{\Delta})}$$

(11)

2.2 H1N1 virus propagation through saliva movement

The Basset–Boussinesq–Oseen equation is essential to demonstrate the motion of the nano-size virus particle in the oesophagus [47]. Figure 2 demonstrates the propagation of H1N1 virus (diameter in the range from 80 to 120 nm and density is 1100 kg/m$^3$) in the oesophagus. Oesophagus is categorized in three parts such as cervical, thoracic, and abdominal. In this model, it is considered that the H1N1 virus particle is moved through the cervical part of the oesophagus. Further the Basset equation Eq. (12) equates the mass multiplied by the acceleration of a virus particle to the total sum of stokes drag, virtual, masses, Basset, and gravity, respectively

$$m_p \frac{d v_p}{d t} = (m_p - m_f)g + m_f \frac{D v_f}{d t} - \frac{m_f}{2} \left( v_p - v_f - \frac{r^2}{10} \nabla^2 v_f \right) - 6\pi r \mu \left( v_p - v_f - \frac{r^2}{6} \nabla^2 v_f + 6\pi r^2 \mu \int_{-\infty}^{t} \frac{d}{d \tau} (v_p - v_f) \sqrt{\frac{1}{\sqrt{\pi} \nu(t-\tau)}} d \tau \right)$$

(12)

where $v_p = (u_p, v_p)$ is virus particle velocity, $m_f$ is the mass of the saliva, $g = (0, g, 0)$ is the gravity vector, $m_p$ is the mass of Swine Influenza, $r = \frac{d_p}{2}$ is virus particle radius, $d_p$ is the virus particle diameter and $\nu$ is kinematic viscosity. The suffix $p$ and $f$ designate virus particle and fluid, respectively. The non-dimensional quantities defined for the $u_p^* = \frac{u_p}{u_f}$, $v_p^* = \frac{v_p}{v_f}$, $t^* = \frac{t}{\tau_c}$, $g^* = \frac{g}{\tau_c}$. The small virus particle Reynolds number ($Re_p = \frac{|v_f | - v_p |(\rho R_w) / \mu}{\rho}$) << 1) and small flow Reynolds number $Re = (\rho R_w c / \mu)$ are considered to verify the virus particle momentum equation [48]. The convective acceleration (Stokes flow) approximating the substantial derivative (\frac{D}{d t}) as (\frac{d}{d t}) is exact to the approximation order due to uniform background flows. Dropping the (*) symbol, the non-dimensional Basset Eq. (12) can be written as:

$$\frac{d v_p}{d t} = \frac{1}{S_N} \left( \frac{2S}{2S + 1} (v_f - v_p) + \frac{3}{2S + 1} \frac{d v_f}{d t} + \frac{\alpha^2}{24S_N} \left( \frac{2S}{2S + 1} \right) \frac{(\nabla^2 v_f)}{\sqrt{\frac{1}{\sqrt{\pi} \nu(t-\tau)}}} \right)$$

$$+ \frac{\alpha}{24S_N} \left( \frac{2S}{2S + 1} \right) \frac{(\nabla^2 v_f)}{\sqrt{\frac{1}{\sqrt{\pi} \nu(t-\tau)}}} + \frac{1}{S_N} \left( \frac{2S}{2S + 1} \right) \frac{(\nabla^2 v_f)}{\sqrt{\frac{1}{\sqrt{\pi} \nu(t-\tau)}}} + \frac{1}{S_N} \left( \frac{2S}{2S + 1} \right) \frac{(\nabla^2 v_f)}{\sqrt{\frac{1}{\sqrt{\pi} \nu(t-\tau)}}}$$

(13)

where $S = \frac{\rho_f}{\rho_p}$ (density ratio), $S_N = \frac{\nu_c}{\nu}$ (stokes number), $\alpha = \frac{d_p}{\bar{r}_e}$ (size ratio). $v_{f0}$ and $v_{p0}$ are the initial velocity vectors of fluid and H1N1 virus, respectively. The fluid characteristics time is defined as $\tau_p = \frac{(\rho_f d_p^2)}{18\nu}$. In the oesophagus, the velocity of the peristaltic flow (c) is reported to be 2-4 cm/s so that the average velocity of saliva movement can be considered 3 cm/s (i.e. 30 mm/s) for the simulation of the results. The drag and Stokes drag force are identical for the spherical shape. However, drag force is defined as: $F_d = 3\pi d_p \mu \xi (v_f - v_p)$, here $\xi$ is the dynamic shape correction factor, which is unity for sphere, 1.12 for two chained and 1.27 for three chained clusters of the spheres. For non-spherical virus particles the Stokes drag force can be modified as:

$$F_d = \frac{\xi}{S_N} \left( \frac{2S}{2S + 1} (v_f - v_p) \right)$$
The axial and transverse components of the H1N1 virus velocity are expressed as:

\[
\frac{du_p}{dt} = \beta_1(u - u_p) + \beta_2 \frac{d}{dt} \frac{u - u_p}{\sqrt{t - t^*}} + \beta_3 \left( \int_0^t \frac{d}{dt} \frac{u - u_p}{\sqrt{t - t^*}} dt + \frac{(u_o - u_{po})}{\sqrt{t - t^*}} \right)
\]

\[
\frac{dv_p}{dt} = \beta_1(v - v_p) + \beta_2 \frac{d}{dt} \frac{v - v_p}{\sqrt{t - t^*}} + \beta_3 \left( \int_0^t \frac{d}{dt} \frac{v - v_p}{\sqrt{t - t^*}} dt + \frac{(v_o - v_{po})}{\sqrt{t - t^*}} \right) - \beta_4
\]

where \(\beta_1 = \frac{g}{S} \frac{2S}{2S+1}\), \(\beta_2 = \frac{3}{2S+1}\), \(\beta_3 = \sqrt{\frac{g}{S} \frac{2S}{2S+1}}\), \(\beta_4 = \frac{2(S-1)}{2S+1} \frac{g}{S} \frac{2S}{2S+1} \frac{1}{c}\).

The system of differential equation (14 and 15) is integrated numerically to obtain the virus particle velocities subjected to zero initial conditions, i.e. \(v_f(x, t = 0) = 0\).

3 Results and discussion

In this section, the computational results on axial and transverse H1N1 virus velocities along with their contour plots for swine influenza (H1N1) virus floating through the viscoelastic fluids (saliva) in the channel (i.e. oesophagus) governed by the peristaltic flow are discussed based on the computational results. Figure 3(a–d) is illustrated to see the flow characteristics of viscoelastic fluids in the channel and understand the physical interpretation of the spread of viruses. Figures 4 and 6 are plotted to discuss the motion of the H1N1 virus along with the saliva in the oesophagus and try to manipulate it via the magnetic field. The trapping phenomena of the H1N1 virus in the oesophagus are shown in Figs. 5 and 7. Further, the impact of fluid properties (saliva viscosity), H1N1 virus properties (density), virus relaxation time on the virus velocity are discussed through Figs. 8, 9, 10, 11, 12. The effects of the physical parameters including particle diameter \((dp)\), saliva viscosity \((\mu)\), contraction amplitude \((a)\) on the velocity profiles are presented in details. This model has been considered to analyse the flow of virus particles by using parametric values tabulated in the Tables 1, 2 at the fixed values of \(a = 0.4\) and \(t = 0.1\) and see the variation on the virus particle velocity for different values of Hartmann number \((Ha)\) and rheological parameter \((\lambda_1)\) of viscoelastic fluid.

### 3.1 Analysis of streamline patterns for viscoelastic fluids flowing through oesophagus

Figure 3(a–d) depicts the streamlines of axial and transverse velocity components velocity in the oesophagus at the fixed value of \(a = 0.4, \lambda_1 = 1\), and \(t = 0.1\). From Fig. 3(a & b), it is observed that the nature of axial and transverse velocity is uniform throughout the channel. As the magnetic field \((Ha = 3)\) is applied, the axial velocity is rapidly reduced. However, there is no variation in the transverse velocity as shown in Fig. 3(c & d). It means that the flow of physiological fluids can be efficiently controlled by the magnetic field which is validated by the Tripathi et al. [38] model. Further, the relaxation region of the wall reduces the velocity, while it is increased in the contraction region since the pressure is more due to the contraction of the muscles/walls but pressure is...
Table 2 Estimated values of coefficients of Stokes number, density ratio, and gravity of the viruses for particle characteristic time (τc) = 1.27

| Est. parametric value | Formulation | Value          |
|-----------------------|-------------|----------------|
| Stokes number         | SN = τp/τc  | 5.126 × 10−10  |
| Density ratio         | S = ρp/ρf  | 1.0981         |
| Stokes drag           | β1         | 13.40 × 10^8   |
| Virtual mass-I        | β2         | 0.9386         |
| Basset force          | β3         | 34655          |
| Gravity               | β4         | 26.45          |

Fig. 4 Effect of Hartmann number (Ha) on a axial H1N1 velocity, b transverse H1N1 virus velocity

minimum at relaxed position. This result has been corroborated in the literature for different non-Newtonian fluids [21]. Further, this mechanism is important to induce the fluid flow throughout the channel.

3.2 Analysis of Swine influenza (H1N1) virus propagation

Figure 4 depicts the effect of magnetic field (Ha) on normalized axial and transverse H1N1 virus velocity profiles at fixed λ1 = 1.41. Axial and transverse virus velocities are normalized in the range of axial length [−1, 1]. From Fig. 4a, it is observed that the axial velocity of H1N1 is performed in the increasing and decreasing patterns corresponding to the relaxation and contraction regions, respectively, while the transverse particle velocity behaves inversely. The global minimum value of the axial velocity is attained at Ha = 3, i.e. the motion of the H1N1 virus velocity is reduced by the magnetic field. Hartman number (Ha) is the ratio of electromagnetic force to viscous force. The Lorentz force is created for Ha >> 1 which opposes the motion of the H1N1 virus through saliva. Due to the reduction in the H1N1 virus velocity, the infection rate will also be reduced in the oesophagus which is novelty of the present analysis. This result also illustrates that the localize higher of the earth’s magnetic field intensity may decrease the risk of virus outbreak [36].

The contour plots of the axial velocity (u_p) for the different values of Hartmann number are shown in Fig. 5 at the fixed values of λ1 = 1, a = 0.4, and t = 0.1. From Fig. 5, it is observed that the magnitude of the H1N1 virus velocity is 10^7 for Hartmann number Ha = 1 while this magnitude becomes 10^6 for Ha = 5. It means that the magnetic field controls the dispersion of the H1N1 virus in the physiological system and reduces the virus speed. Fukushima et al. [43] reported remnant field strength decreases with time, due to particle rotation (relaxation).

Figure 6 depicts the influence of Jeffrey fluid parameter (λ_1) of viscoelastic fluid for normalized axial and transverse H1N1 virus velocity distribution for the fixed values of Ha = 1, x = 0.3. The axial and transverse velocities of the virus are decreased with the increment of Jeffrey fluid parameter (λ_1) because λ_1 is defined as the time interval taken by fluid to return from the deformation position. When the time intervals increase, the movement of the H1N1 virus is decreased in oesophagus.

Figure 7 depicts the effect of Jeffrey fluid parameter (λ_1) on H1N1 virus streamlines of u_p at fixed values of Hartmann number (Ha), a = 0.4, t = 0.1. It is observed that the velocity of H1N1 virus is high for Newtonian fluid (λ_1 = 0) as compare to the viscoelastic fluid (λ_1 = 5). It means that the physiological fluid that have large elasticity inhibit the movement of the virus in the physiological systems.
Fig. 5 Streamlines of the axial velocity of H1N1 virus for a $H_a = 1$, b $H_a = 5$

Fig. 6 Effect of the rheological parameter ($\lambda_1$) on a axial H1N1 virus velocity b H1N1 transverse velocity

Fig. 7 Streamlines of axial velocity of H1N1 virus for a $\lambda_1 = 0$, b $\lambda_1 = 5$

Figure 8 depicts the effect of H1N1 virus diameter on axial and transverse velocity components for the fixed values of $\lambda_1 = 1$ and $a = 0.4$. From the literature, it is observed that the size of the swine influenza virus particle is from 80 to 120 nm. From Fig. 8(a & b), it is observed that both the axial and transverse virus particle velocities are performing the increasing and decreasing patterns in the oesophagus. However, overall virus velocity is high for the low diameter of the virus. Thus, the small size virus particles are flowing rapidly in the oesophagus as compared to larger diameter.

Figure 9 shows the viscosity effect of saliva on the flow of H1N1 virus particles at the fixed value of $a = 0.4$. From the literature, it is found that the viscosity of saliva varies in the range of [0.000829, 0.00129] (Ns/m²). Usually, saliva behaves as water when the viscosity of saliva is 0.000829 (Ns/m²) while the saliva viscosity in the male is 0.00105 (Ns/m²) and in the female is 0.00129 (Ns/m²) reported in Ref. [50]. From Fig. 9a, it is observed that the axial velocity of the H1N1 virus for high viscous fluid is less as
Fig. 8 Effects of H1N1 diameter on the a axial H1N1 virus velocity b transverse H1N1 virus velocity

Fig. 9 Effect of saliva viscosity $\mu$ (Ns/m$^2$) on the a axial H1N1 virus velocity b transverse H1N1 virus velocity

compared to less viscous fluid. This happens because of the fluid with a high viscosity has high resistance, and moves more slowly than a fluid with a low viscosity. It means that the movement of the virus particle is more in males as compared to females which further conclude that the chances of infections in males are more as compared to females and children [51]. This study suggests that males have to be more careful for avoiding the virus infections however the females and children should also take extra care to prevent themselves from the viruses. This is another novelty of the present analysis.

Figure 10 shows the effect of wave amplitude of the oesophagus on the axial and transverse velocities of the H1N1 virus. It is observed that a large amplitude of wave propagation is significantly increasing virus velocity in the channel. A larger amplitude of wave propagation enhances virus velocity whereas low amplitude opposes momentum development. This result illustrates that the person who has less rhythmic contraction in the oesophagus, the H1N1 virus particles are flowing slower since the pressure gradient generated due to the rhythmic contraction and relaxation process will be lesser.

Figure 11a represents the variation of the H1N1 virus relaxation time ($\tau_p$) with virus diameter. This result shows that small-sized virus particles ($d_p = 80\,\text{nm}$) enter through saliva more quickly than large-sized virus particles ($d_p = 120\,\text{nm}$). Further, it is found that a person with lesser saliva viscosity takes the virus longer to settle. Figure 11b depicts the variation in H1N1 virus relaxation time for different virus particle densities ($1000 - 1200\,\text{kg/m}^3$). It is observed that virus relaxation time increases for high density ($\rho_p = 1200\,\text{kg/m}^3$) of viruses which takes more time to settle inside the saliva. Stokes number describes the behaviour of virus particles floating in a fluid medium. When H1N1 particles are spherical or non-spherical in shape, their drags are not the same as the Stokes drag. This can be explained with the help of the shape correction factor. Figure 12 represents the effect of the shape of H1N1 virus particles on the Stokes drag. It is observed that non-spherical H1N1 virus particles travel faster than spherical H1N1 virus particles in axial direction as well as in transverse direction. This result validates the standard result of the physics that non-spherical particles experience a larger drag force as compared to the spherical particles.
4 Conclusions

The present study is focused on H1N1 virus transmission through the oesophagus because it is more reactive than aerosol as it enters the human body and infected the tissues. Further, the impact of the magnetic field on Swine Influenza virus particles floating in the viscoelastic fluid medium is examined. Some notable outcomes of the present model are abridged below:

- The viscoelastic nature of the saliva reduces the propagation of the H1N1 virus in the oesophagus.
- The susceptibility towards H1N1 viral infection is reduced as the magnetic field slows down the motion of the virus particle.
- The virus travels at a low speed through the oesophagus of female as compared to the male due to the saliva’s viscosity.
- Small sized H1N1 virus particles are more harmful rather than larger virus particle diameters.
Large amplitude of wave propagation is significantly increasing H1N1 virus velocity in the channel.

Non-spherical H1N1 viruses travel faster than spherical H1N1 viruses through the saliva movement.

The H1N1 virus moves faster with higher amplitude of peristaltic wave propulsion in a single cycle and similar trends are noticed in successive cycles.

A person with lesser saliva viscosity (μ = 8.29 × 10^{-4} Ns/m²) takes the H1N1 virus longer to settle down.

This analysis provides an understanding of the mechanics of the H1N1 virus floating through the saliva (viscoelastic fluid) in the oesophagus governed by the peristaltic motion. Recommendations of present analysis help to design and manufacture the devices for the magnetic therapy process which can reduces the infections due to the similar type of viruses Influenza (A, B, C, D).

Data availability
No data associated in the manuscript.

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