Chapter 8

Conclusions and further scope of the work

The flow behavior within oesophagus has been studied in the thesis, which produced some elegant results. Swallowing is the process of transport of chewed edible substance in the digestive system including oesophagus. Although the mechanism of pumping in the oesophagus involves the same kind of wave propagation, which is a well-coordinated action of the circular and the longitudinal muscles of the oesophagus, along its wall, swallowing is nevertheless influenced by the variety of the ingested food material and also by the circumstances created by the surroundings. Herniation of oesophagus is one of them.

Liquid crystals, blood, and also some edible solutions resemble micropolar properties. We have investigated analytically axi-symmetric flow of a micropolar fluid induced by peristaltic waves with progressively dilating amplitude. By means of mathematical formulation we examined impact on swallowing of single food bolus through oesophagus. Engineering applications using polymer solutions, colloidal solutions, drilling fluids in oil industries etc. may be better understood by this investigation. It is inferred that increasing coupling number and amplitude dilation parameter enhance the pressure inside the tube, while micro-polar parameter is responsible for reducing the pressure along the axis of the tube. Local wall shear stress too increases with amplitude dilation parameter.

The study suggests that achalasia patients should avoid the consumption of micro-polar fluids. It is also concluded that reflux action weakens with dilation of wave amplitude for micro-polar flows.

Another chapter discusses the flow behaviour of suspended particles swallowing through oesophagus. Closed-form solutions for unsteady flow are obtained by regular perturbation technique up to the second order of wave number (i.e., the ratio of the tube radius to the wavelength). The focus is on fluid particle interaction.

It is observed that the fluid axial velocity exceeds the solid particle velocity almost everywhere. However, at the wall the axial velocity of the fluid is zero due to the no-slip condition imposed on it; but the suspended particulate material has non-zero positive axial velocity for the simple reason that solid particles won't adhere to solid walls. Thus, the axial velocity of the suspended particles near the tube wall overtakes the fluid velocity. It is further observed that the axial velocity is negative in the regions near maximum occlusions paving way to instantaneous backward flow. It is also concluded that rising volume fraction diminishes pumping performance and also the axial and radial velocities. The results confirm doctor's views to prescribe liquid or food items with lesser solid contents for achalasia patients and also those who suffer from oesophageal stricture and oesophageal tumours.

In the next chapters, we tried to investigate oesophageal flow in herniated states. For this we assumed linear and exponential variations of cross section of the tube to create conditions similar to sliding hiatus hernia. The fluid considered are the same that were considered for normal oesophagus.

We presented a mathematical formulation that deals with the flow of micro-polar fluid in a circular cylindrical tube of non-uniform cross-sectional area induced by peristaltic waves of increasing amplitude. This is an intended act to model swallowing of various types of foods in a herniated oesophagus. Due to sliding hiatus hernia, the cross section of the lower oesophagus does not remain uniform. Two distinct models for a peristaltically driven flow when the cross section of the tube changes linearly and exponentially respectively were attempted. The impact of bulging, which is formed by various combinations of divergence and convergence, has been examined. This may resemble the shape of the oesophagus when it suffers from sliding hiatus hernia, that is, when the abdomen protrudes through the hiatus. The effects of dilating amplitude, gradient parameter representing variation of the tube wall, the coupling number, and the micro-polar parameter, were investigated.

Bulging, caused by herniation, in tube is examined considering two different cases: (i) tube diverging entirely from the first end to the other, and (ii) tube diverging partly limited to the other end only. Effects of dilating amplitude, the coupling number and the micro-polar parameter were also investigated. Nonlinear governing equations are linearized by the theory of low Reynolds number and long wavelength approximations and computer simulation is used to estimate numerical results.

It is observed whether the tube diverges entirely or partly, pressure required for carrying the fluid is less. This makes swallowing easier, which causes sliding hiatus hernia to go unnoticed. Exponential divergence in the tube geometry makes swallowing easier than linear divergence. While pressure increases with the coupling number, it declines with the micropolar parameter. Reflux region is further found to shrink once the wave amplitude dilates.

The final analysis is meant for the transport of a Newtonian fluid with suspended solid particles in a tube which diverges exponentially under the influence of peristaltic waves whose amplitude too increases progressively. This is in continuation to model the state of hiatus hernia.

It is observed that the dragged suspended solid particles move slower than the fluid around the centre line while in a small annular region near the tube-wall on which only fluid does not slip, the particulate matter moves faster than the fluid. There is always a closed surface inside the tube on which the fluid and the solid particles both have equal velocities. This is also observed that this closed surface moves towards the wall of the tube as the wave amplitude dilation parameter increases.

In the contracted region during peristalsis, relaxed regions experience positive flow while the contracted regions have flow reversal. While swallowing, the flow is in the reverse direction in the contracted zone while it is in the forward direction in the relaxed part. However, the net flow is always positive. Wave amplitude dilation is essential for smooth swallowing in the oesophagus for the reason that the food bolus gets globular with progress and further it has to be pushed into the abdomen through the cardiac sphincter. This is all possible when pressure increases. But in case the rate of dilation crosses certain limit, flow reversal may take place. Therefore, the practitioners are advised to take care of it while artificially intervening or prescribing a suitable medicine to dilate the wave amplitude, if possible. In case restricting it within the limit is difficult, some mechanisms may be applied to slightly diverge the oesophagus at the appropriate point. This is equally advisable in engineering applications. Other researchers as well should take care of it while proponding any theory involving such circumstances.

The collective conclusion is that the introduced problems in various chapters in the thesis have feasible applications to the physiology of oesophageal swallowing.

Models introduced in the thesis can support the user to understand the spread of disease and then specify the question that is required to respond and identify necessary detailed requirements, including routine surveillance and outbreak investigations. Which can support health officials concentrate on crucial factors.

8.1 Further scope of the study

In extraordinary circumstances when nasal feeding is required, a catheter is inserted through the nose for feeding or some other clinical intervention. This is done by a trained nurse. That training must be based on experiences but there is dearth of such research work on catheterisation. Particularly when dilation of wave amplitude was not known, researches, if any, must have far from the reality. What could be the thickness of the catheter inserted, or how far it should be inserted are a few of the questions to be answered by researchers. This is because pressure is affected by an inserted catheter. Further, while a catheter is already there in the oesophagus, is feeding, even a spoon of water, through mouth risky?

In case achalasia, oesophagus does not relax properly. Catheterisation is the only solution so far. Bringing longitudinal mussels into action may be done by prosthetic oesophagus which must be based on the facts brought forward by researches including those given in this thesis. Bionics has a large role to play.

However, para-hiatus hernia which requires surgery does not seem to be tackled by an extension of the mathematical methods used to deal with sliding hiatus hernia. An alternative seems to be adequate dilation of the lower end of the oesophagus. But that too has a limitation.

****