Peristaltic Flow Characterization of a Shear Thinning Fluid through an Elastic Tube by UVP

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Abstract :
In-vitro small intestinal flow characteristics of a shear thinning fluid are investigated by transient '2-wave'-squeezing of an elastic tube under different speeds of peristalsis. Such peristaltic flow is the essential physiological transport mechanism in the gastro-intestinal tract. The peristalsis involves both expansion and contraction type of flow (crest and trough of a wavelength). We met the challenge of implementing the UVP technique for monitoring the velocity fields during appropriate peristaltic propulsion of a shear thinning fluid through an elastic tube (in vitro modeled small intestine). The higher wave speed of peristalsis results in higher magnitude of back flow velocity (negative) both in the wave crest and trough regions with positive value being adjacent to the tube wall. In addition, the approximated wall shear rates at the wave trough are also found to be higher than those in the wave crest. The higher value of back flow is expected to be responsible for the improved mixing and convection leading to higher mass transport through the intestinal wall. The measured pressure difference between crest and trough of a peristaltic wave increased, as the wave speed got faster. However, the crest region showed a higher pressure compared to the trough region since the magnitude of back flow velocity in the wave trough is found to be much higher compared to that in the wave crest.

Zusammenfassung :
In-vitro Dünndarmströmungscharakteristiken einer scherverdünnenden Flüssigkeit werden mit Hilfe einer transienten „Doppelwellen"-Quetschströmung in einer elastischen Röhre bei unterschiedlichen Peristaltik-Geschwindigkeiten gemessen. Diese Peristaltikströmungen sind für den physiologischen Transportmechanismus im Magen-Darm-Trakt verantwortlich. Die Peristaltik betrifft sowohl den Ausdehnungs- als auch den Kontraktionstyp der Strömung (Wellenberg und -tal). Die Herausforderung bestand in der Implementation der UVP-Technik zur Überwachung des Geschwindigkeitsfeldes während geeigneter peristaltischer Strömungen eines scherverdünnenden Fluids durch eine elastische Röhre (in vitro-Modellierung des Dünndarms). Die höhere Wellengeschwindigkeit der Peristaltik führt zu einer größeren Rückströmungsgeschwindigkeit (negativ) sowohl im Bereich des Wellenbergs als auch des Wellentals mit positiven Werten in der Nähe der Kanalwand. Darüber hinaus waren die approximierten Wandschergeschwindigkeiten im Wellental größer als im Wellenberg. Eine größere Rückströmungsgeschwindigkeit ist für eine verbesserte Durchmischung und Konvektion verantwortlich, die zu einem größeren Massentransport durch die Darmwand führt. Die gemessene Druckdifferenz zwischen Wellenberg und -tal der peristaltischen Welle nahm mit größerer Wellengeschwindigkeit zu. Jedoch gab es in der Region des Wellenbergs einen höheren Druck als in der Talregion, da die Rückströmungsgeschwindigkeit im Wellental größer war als im Wellenberg.

Résumé :
Les caractéristiques d'écoulement in-vitro dans le petit intestin d'un fluide rhéo-amincissant sont étudiées au moyen d'écrasement «á 2 vagues» d'un tube élastique sous différentes vitesses péristaltiques. Cet écoulement péristaltique est le mécanisme de transport physiologique principal dans le conduit gastro-intestinal. La péristasis implique des écoulements d'expansion et contraction (la crête et le ventre d'une longueur d'onde). Nous avons relevé le défi d'utiliser la technique de UVP afin d'évaluer les champs de vitesse durant la propulsion péristaltique appropriée d'un fluide rhéo-amincissant dans un tube élastique (le modèle in-vitro du petit intestin). La vitesse d'onde plus élevée de la péristasis entraîne une plus grande magnitude de la vitesse en contre-courant (négative) dans la crête de l'onde ainsi que dans les régions d'amplitude positive qui sont adjacentes aux murs du tube. De plua, les vitesses de cisaillement approximées calculées dans le ventre de l'onde sont plus grandes que dans les crêtes. La plus grande valeur de contre-courant peut-être à l'origine d'un mélange et d'une convection améliorés, ce qui conduit à un plus grand transport de masse au travers de la paroi de l'intestin. La différence de pression mesurée entre la crête et le ventre d'une onde péristaltique augmente lorsque la vitesse de l'onde augmente. Cependant, la région de la crête présente une pression supérieure par rapport à la région du ventre puisque l'amplitude de la vitesse de contre-courant dans le ventre de l'onde se révèle bien plus grande comparée à celle dans la crête.

Key words: elastic tube, in vitro, shear thinning fluids, peristaltic flow, pulsed ultrasound Doppler velocimetry

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ed measuring lines in the wave troughs (trough-1 & trough-2), indicating more contraction of the squeezed tube at that region (so the target and actual measuring lines are seen to be different by UVP). The velocity magnitude measured in the second trough is observed to be more negative than that of the first trough, as trough-2 is forwarded by the trough-1 along the wave direction. The wall shear rates in the wave trough varied from 3 to 4 s^{-1} and the approximated maximum elongation rate from crest to the trough is 0.44 s^{-1} under the peristaltic motion of 10 mm/s.

3.4 PRESSURE DIFFERENCE UNDER PERISTALSIS

The local pressure in a wavelength is measured by placing pressure sensors (P1 and P2) in direct contact with the fluid as shown in Figure 1. The speeds of peristalsis are varied as 2, 4, 6, 8 and 10 mm/s. The two pressure sensors are also connected with moving part of the peristalsis (the sensors are always seen to be at the same position as the peristaltic wave travels). The distance between two sensors are about 25 mm. The pressure difference between tube crest and its corresponding two troughs is measured. The crest region shows a higher pressure compared to the trough region, since the magnitude of back flow velocity in the wave trough is much higher (negative) compared to that in the wave crest. Therefore, a higher velocity head corresponds to a lower pressure head as in the wave trough according to Bernoulli's law. The pressure difference between crest and trough of a peristaltic wave is found to be increased with increasing the wave speed as expected (Figure 10). However, the pressure difference between center of crest and trough is found to be low about 0.2 to 0.7 mbar due to low mean fluid velocity and relatively large gap in the trough (required to locate the pressure sensors). The velocity profiles and pressure gradients of a shear thinning fluid in an elastic tube are investigated experimentally under different speeds of peristalsis. It is found that UVP can be applied successfully for peristaltic flow characterization

4 CONCLUSIONS

The study of *in vitro* small intestinal flow (peristaltic squeezing of an elastic tube) of non-Newtonian fluids is important to biofluid mechanics encountered in the human body. The velocity profiles and pressure differences are investigated experimentally under peristaltic flow of a non-Newtonian shear thinning CMC aqueous solution in an elastic tube. The higher wave speed of peristalsis results in higher magnitude of back flow velocity (negative) both in the wave crest and trough regions with positive value being near the tube wall. The higher value of back flow is expected to be responsible for the improved mixing and convection leading to higher mass transport through the intestinal wall. In addition, the approximated wall shear rates also found to be increased with increasing the peristaltic motion, which correspondingly is expected to enhance the mass transfer by reducing the viscosity of a shear thinning fluid. The pressure in the tube crest is found to be higher than that in the trough. The pressure difference between center of crest and trough is low since the mean fluid velocity is low and gap in the trough is relatively large. The detailed knowledge gained about non-Newtonian peristaltic flow is aimed to use in future for mass transport investigations across the elastic membrane tube wall.

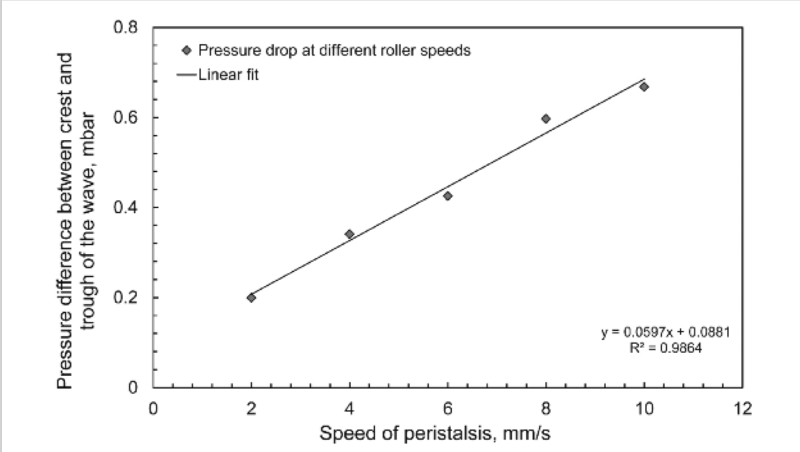

Figure 10: Variation in the pressure difference with different speeds of peristalsis.

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