Rheological Characterisation of Sclerosing Foams in Biomimetic Settings Using Clinically Relevant Parameters

Alireza Meghdadi[1], Andrew Lewis[2], Stephen Jones[2], Venisha Patel[2], Timothy Millar[1], Dario Carugo[3]

[1] Department of Mechanical Engineering, University of Southampton, SO17 1BJ, United Kingdom;

[2] BTG International Ltd, Camberley, GU15 3YH, United Kingdom

[3] Department of Pharmaceutics, UCL School of Pharmacy, University College London, WC1E 6BT, United Kingdom

Background: Sclerotherapy is one of the most common and least invasive methods of treatment against varicose veins. While bench-top properties of sclerosing foams (e.g. bubble size distribution and foam half-life) have been characterised previously, their flow behaviour remains largely uncharacterised. Given that aqueous foams exhibit a time-dependent rheology due to ageing phenomena (i.e. liquid drainage, bubble coarsening and coalescence), the identification of appropriate rheological measurement systems is critical to the quantification of clinically meaningful foam properties.

Methods: A biomimetic pipe viscometry apparatus was used to characterise the rheology of polidocanol (1%) sclerosing foams across a clinically relevant range of shear rates (6 s^{-1} – 400 s^{-1}) within polytetrafluoroethylene pipes of different diameters (2.48 mm and 4.48 mm). Foams were formulated using varying liquid-to-gas ratios (1:3, 1:4 and 1:5) and manufactured using the Tessari and DSS (double syringe system) methods. Additionally, end-effect and wall-slip correction methods were utilised to model the nominal rheology of foams. The rheological data were fitted into the power-law model to obtain the fluid flow index (n) and the fluid consistency index (K) of sclerosing foams, followed by systematic statistical analysis of power-law indices.

Results: The observed rheological behaviour of sclerosing foams is shown to be dependent on pipe diameter and liquid-to-gas ratio, while the effect of formulation technique appears to be statistically insignificant. Although wall-slip correction ultimately failed in providing physically meaningful results; nevertheless, end-effect correction was successful. Sclerosing foams behaved as shear-thinning fluids with flow indices ranging $0.24 < n < 0.45$, while the observed consistency indices ranged $2.98 < K < 12.49$. The nominal (end-effect-corrected) rheology of foams where shown to follow similar trends with respect to liquid-to-gas ratio and formulation technique when measured in different tube diameters, although the range of the flow consistency indices were narrowed by end-effect correction ($2.21 < K < 6.30$). In addition to the power-law characterisation of sclerosing foam rheology, the rheograms demonstrated evidence of a quasi-static drainage effect that affected foam viscosity during slower injections.

Conclusions: In this study, a biomimetic set-up was successfully employed to evaluate sclerosing foam rheology. Overall, results suggest a direct correlation between foam dryness and viscosity. Different manual techniques of formulating foams (DSS *vs.* Tessari) resulted in foams with comparable rheology. Additionally, this study provides a detailed description of the power law indices of different physician compounded sclerosing foams. Findings from this study could inform the optimisation of sclerosing foam's formulation and administration techniques.