Rheology of Cerebrospinal Fluid under Different Temperature Conditions

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ABSTRACT

The flow behavior of fluids can be characterized by rheology and is especially used in the fields of polymeric materials. This study focused on characterizing cerebrospinal fluid (CSF) of patients who developed a hydrocephalus after subarachnoid hemorrhage (SAH) with rheology. Samples were drawn from an external ventricular drainage (EVD) at four pre-defined time points after the initial hemorrhage. The CSF samples were analyzed using a rheometer with a double gap geometry. In addition to the characterization of viscoelastic parameters, the storage factor was calculated to determine the interactions in the fluid. The oscillatory measurements were implemented at certain temperatures which should simulate specific situations, as 5°C, at which the CSF samples were stored, 35°C for an hypothermic, 37°C for the physiologic and 40°C for an elevated body temperature.

INTRODUCTION

Rheology has received little scientific attention in the fields of medical science. Some studies have already been conducted on synovia and blood using rheology. [1-3]

The CSF as a mechanical buffer has the function to protect the brain as well as the spinal cord, but it has also a high importance for metabolic processes. Whenever the circulation of CSF is impaired, a hydrocephalus can occur. Hydrocephalus is characterized by an enlargement of the ventricles and an increased intracranial pressure. The subtypes can be distinguished by their entities, such as post-hemorrhagic, post-infectious, post-traumatic and normal pressure hydrocephalus.[4-7]

Rheological properties of the CSF samples were determined by using an oscillatory shear flow. The frequency test provides curves of the storage modulus (G`), loss modulus (G``) and the complex viscosity over a certain angular frequency range.

For additional characterization the storage factor was calculated, which was established in previous work in the field of polymer nanocomposites. In contrary to the loss factor (tan delta / damping behavior), the storage factor describes rigidity behavior of a sample, i.e. extent of interactions within the sample. The average storage factor is the ratio of the mean storage modulus and the mean loss modulus. For the evaluation of the cumulative storage factor the

storage and the loss modulus curves were integrated over the measured angular frequency range, as the Eq.1 for the calculation shows. [8,9]

$$cumulative\ storage\ factor = \int_{0,1\ rad/s}^{10\ rad/s} G` \Big/ \int_{0,1\ rad/s}^{10\ rad/s} G`` \qquad ..(1)$$

EXPERIMENTAL

CSF samples of patients after SAH were drawn from an EVD at the Department of Neurosurgery, Kepler University Hospital (KUK) at the pre-defined time points of 0, 5, 10, and 15 days with a tolerance of two days after the initial bleed. For the rheological measurements a Physica MCR 501 rheometer (Anton Paar Ltd., Graz, Austria) with a double gap geometry (DG26,7/T200/SS) was used. Frequency tests were performed with CSF samples and out of the storage and loss modulus data the cumulative storage factor was calculated.

RESULTS AND DISCUSSION

The frequency tests were operated at four different temperatures and the results show the natural trend as at the lowest temperature the sample shows the highest viscosity and at the highest temperature it shows the lowest viscosity, as it is shown in **Fig. 1**. The same tendency occurs for the storage modulus, in **Fig. 2** and for the loss modulus in **Fig. 3**. This trend is generally explained by the Brownian motion of particles in a suspension.

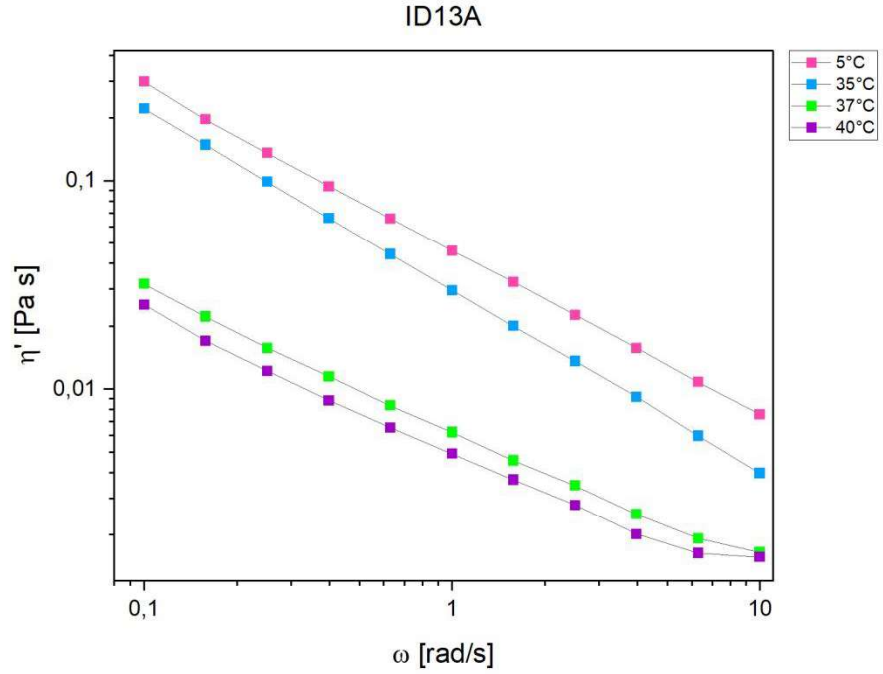

FIGURE 1: frequency test: complex viscosity of sample ID13A at 4 different temperatures

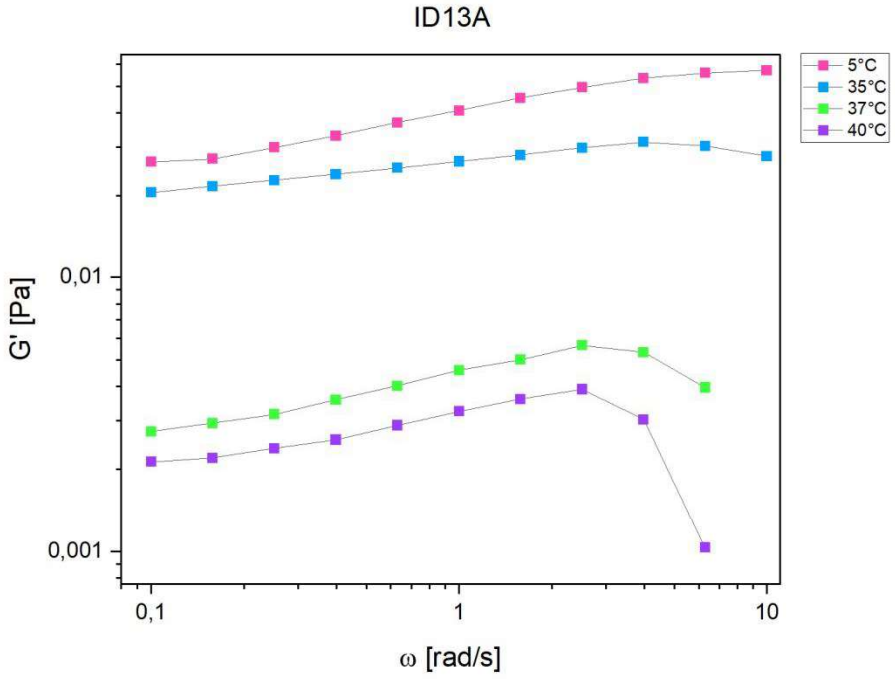

FIGURE 2: frequency test: storage modulus of sample ID13A at 4 different temperatures

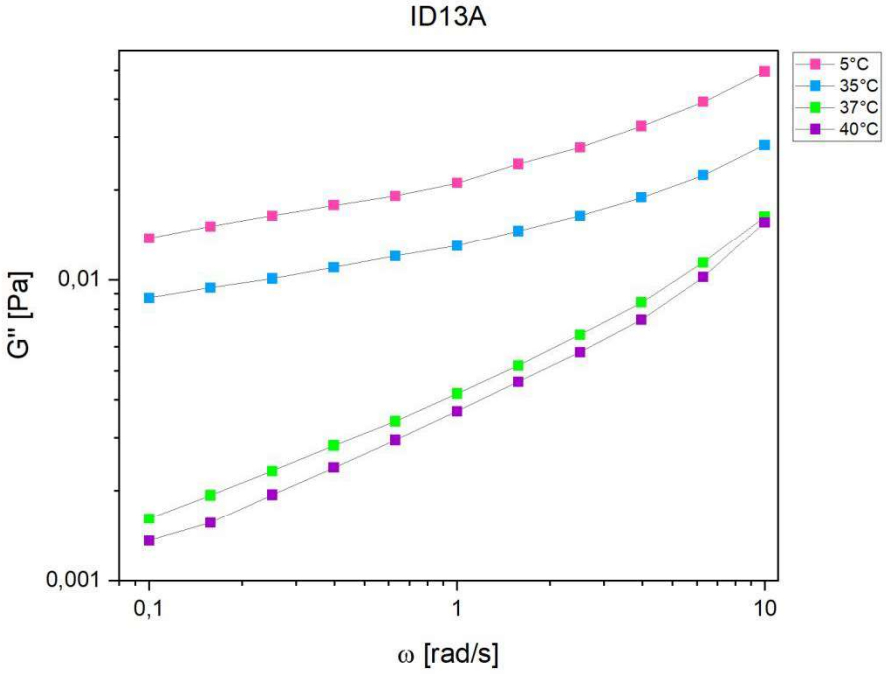

FIGURE 3: frequency test: loss modulus of sample ID13A at 4 different temperatures

The storage factor was calculated once over the integral of the storage or the loss modulus curves and again with the mean G` and G`` values. The same was also calculated for the complex viscosity. The **Fig. 4** and **Fig. 5** show the plot of either the cumulative or the average storage factor against the cumulative or average complex viscosity. The plots differ especially in the value for 5°C which changes the most relative to the other. On the other hand both plots show the highest value at 35°C, which implies at this temperature the highest physical and chemical interactions in the sample. Besides water the main constituents of CSF are erythrocytes, leukocytes, glucose, lactate and proteins which are considered to be responsible for interactions in the sample.

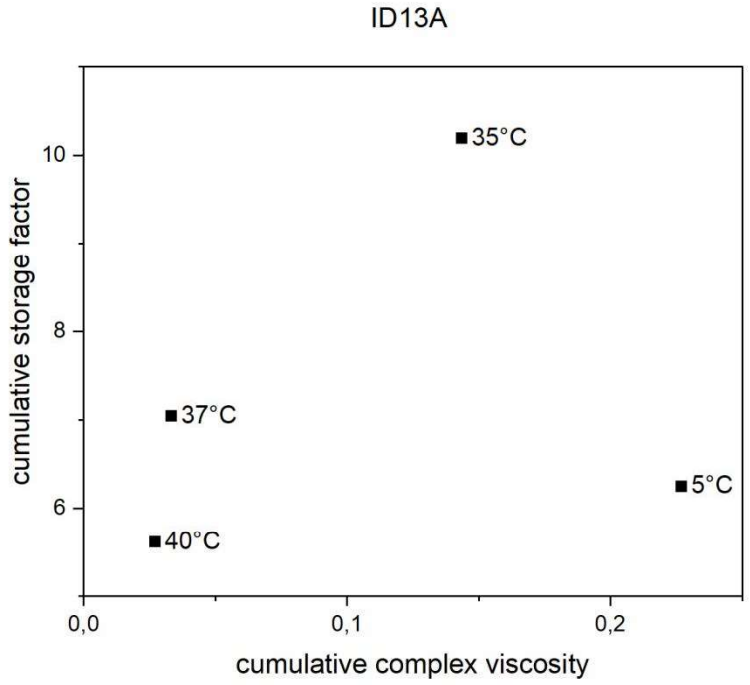

FIGURE 4: cumulative storage factor of sample ID13A

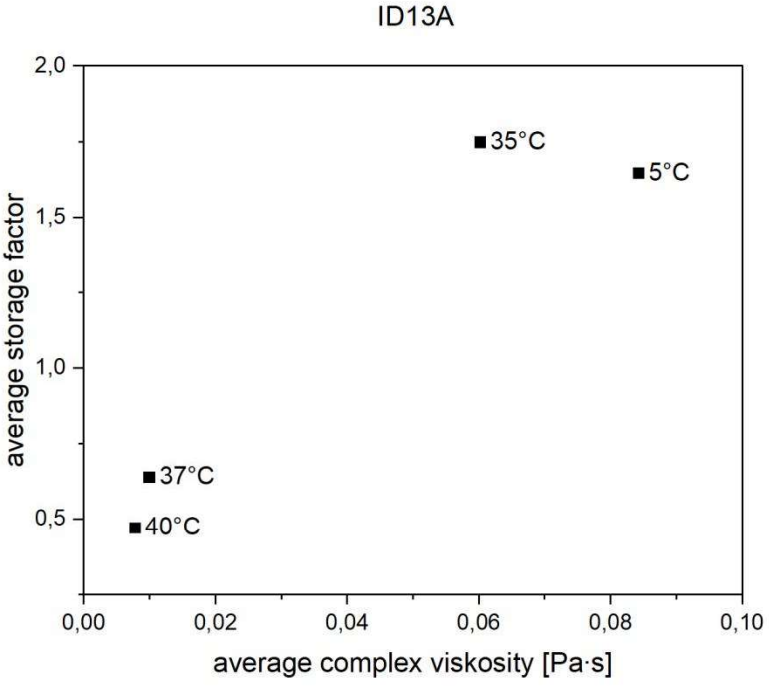

FIGURE 5: average storage factor of sample ID13A

CONCLUSION

The flow behaviour of cerebrospinal fluid samples of patients after subarachnoid hemorrhage (SAH) was measured and characterized using the conventional as well as advanced rheological evaluation by storage factor. Further investigation will focus on correlating the storage factor to laboratory parameters of the CSF samples, such as erythrocyte count, leucocyte count, glucose, lactate and total protein concentration. The aim of the ongoing observations is to determine a correlation between rheological parameters and the need for ventriculoperitoneal shunt implantation in SAH patients.

REFERENCES

1. Bradt, E.; Hild, S.; Reichel, E. K.; Voglhuber-Brunnmaier, T.; Kracalik, M. Microrheology of biofluids. In *Book of Abstracts*, *2018 Annual European Rheology Conference*. Sorrento, Paper MN10.
2. Tomaiuolo, G.; Carciati, A.; Caserta, S.; Guido, S. Blood linear viscoelasticity by small amplitude oscillatory flow. *Rheologica Acta* **2016***,* 55 (6), 485–495. DOI: 10.1007/s00397-015-0894-3.
3. Windberger, U.; Pöschl, C.; Peters, S.; Huber, J.; van den Hoven, R. Measurement of whole blood of different mammalian species in the oscillating shear field: influence of erythrocyte aggregation. *Journal of Physics:* Conference Series **2017**, 790, 12035. DOI: 10.1088/1742-6596/790/1/012035.
4. Barrand, M.; Hladky, S. Mechanisms of fluid movement into, through and out of the brain: Evaluation of the evidence. *Fluids and Barriers of the CNS* **2014**, 11, DOI: 10.1186/2045-8118-11-26.
5. Klebe, D.; McBride, D.; Krafft, P. R.; Flores, J. J.; Tang, J.; Zhang, J. H. Posthemorrhagic hydrocephalus development after germinal matrix hemorrhage: Established mechanisms and proposed pathways. *Journal of Neuroscience Research* **2020**, 98 (1), 105–120. DOI: 10.1002/jnr.24394.
6. Mumenthaler, M.; Mattle, H. *Fundamentals of Neurology: An Illustrated Guide*; Thieme. 2006.
7. Ropper, A. H.; Samuels, M. A.; Klein, J. P. *Adams & Victor`s Principles of neurology*; 10th ed.; McGraw-Hill education. 2014.
8. Kracalik, M. Recycled clay/PET nanocomposites evaluated by novel rheological analysis approach. *Applied Clay Science* **2018**, 166, 181–184. DOI: 10.1016/j.clay.2018.09.007.
9. Kracalik, M. Different approaches for calculation of cumulative storage factor as novel parameter for analysis of reinforcement in complex polymer nanocomposites. AIP Conference Proceedings; May, 2019, p 40004. DOI: 10.1063/1.5109506