Evaluation of rheology-based properties of cerebrospinal fluid using cumulative factors

Thessa-Carina Bauer[1], Elke Bradt[1], Sabine Hild[1], Andreas Gruber[2,3], Tobias Rossmann[2,3], Francisco Ruiz-Navarro[2,3], Johannes Oberndorfer[2,3], Harald Stefanits[2,3], Milan Kracalik[1]

[1] Institute of Polymer Science, Johannes Kepler University, Altenberger Str. 69, 4040 Linz, Austria
[2] Department of Neurosurgery, Kepler University Hospital, Wagner Jauregg Weg 15, 4020 Linz, Austria
[3] Clinical Research Institute for Neurosciences, Faculty of Medicine, Johannes Kepler University, Krankenhausstr. 5, 4020 Linz, Austria

INTRODUCTION

Rheology can describe the flow behavior of a material. Typically rheological measurements are applied in fields of polymer science. With a closer look to biological fluids some similarities can be found. Although macromolecular components are only present in low concentrations they cause a specific flow behavior of biological fluids. The viscoelastic properties are important to characterize especially samples that do not confirm the ideal viscous or ideal elastic behavior. Cerebrospinal fluid (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.

EXPERIMENTAL

CSF of patients with hydrocephalus requiring external drainage were analysed using a rheometer setup, like it is schematically shown in Fig1. MCR702 rheometer (Anton Paar GmbH, Graz) was used equipped with a double gap measurement geometry (DG26,7/T200/SS). The rheological measurements were operated in two modes the rotational, for the stationary shear behavior and the oscillatory mode for the viscoelastic based parameters. The operation modes are illustrated in Fig.1 with the double gap geometry. The oscillatory tests were operated at four different temperatures (5°C, 35°C, 37°C, 40°C) to simulate storage and specific conditions in the human body, as hypothermic, physiological and elevated body temperature.

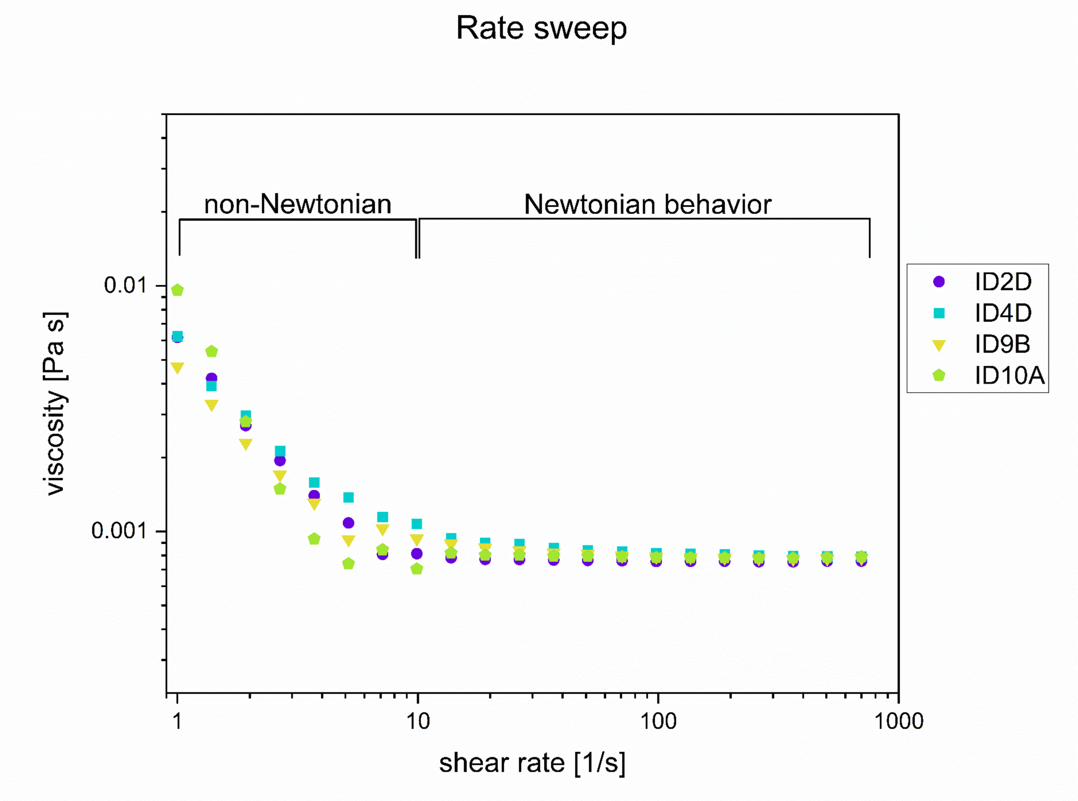

Figure 2: Rotational test: Different samples measured at 37°C. The samples were anonymised with ID numbers and the letters correspond to the time point of drainage.

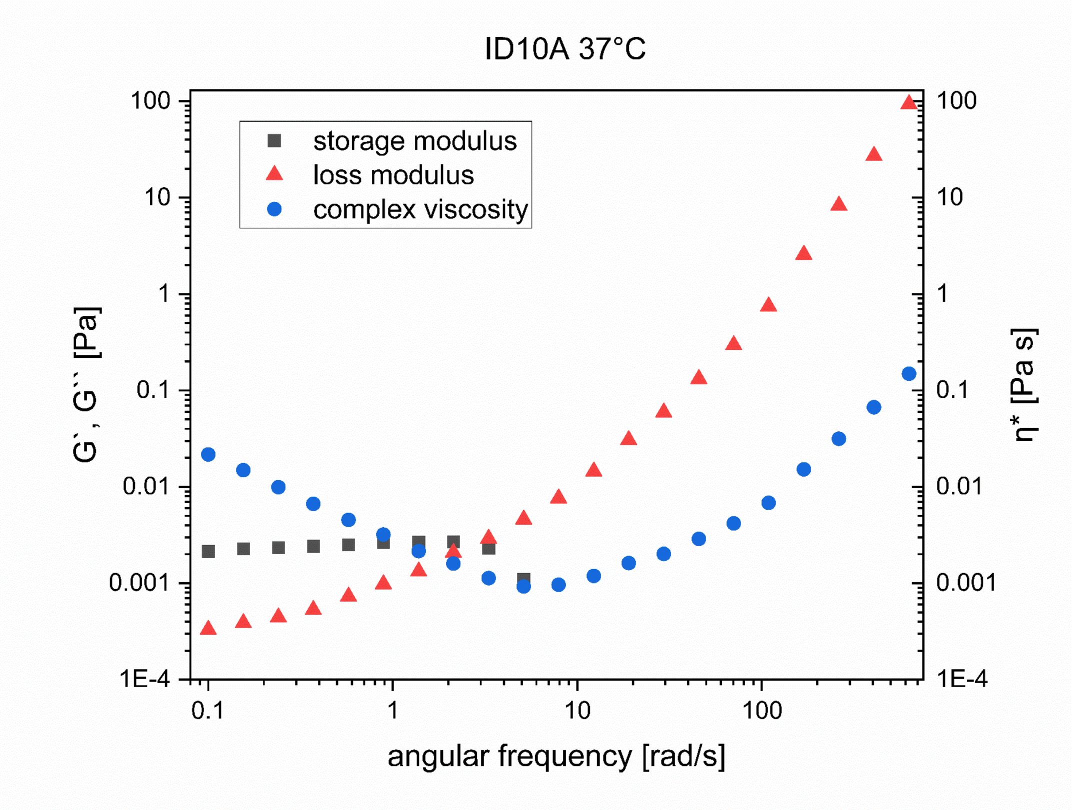

Figure 3: Frequency test: ID10A at 37°C.

laboratory parameters

- Erythrocyte count
- Leukocyte count
- Glucose concentration
- Lactate concentration
- Total protein concentration

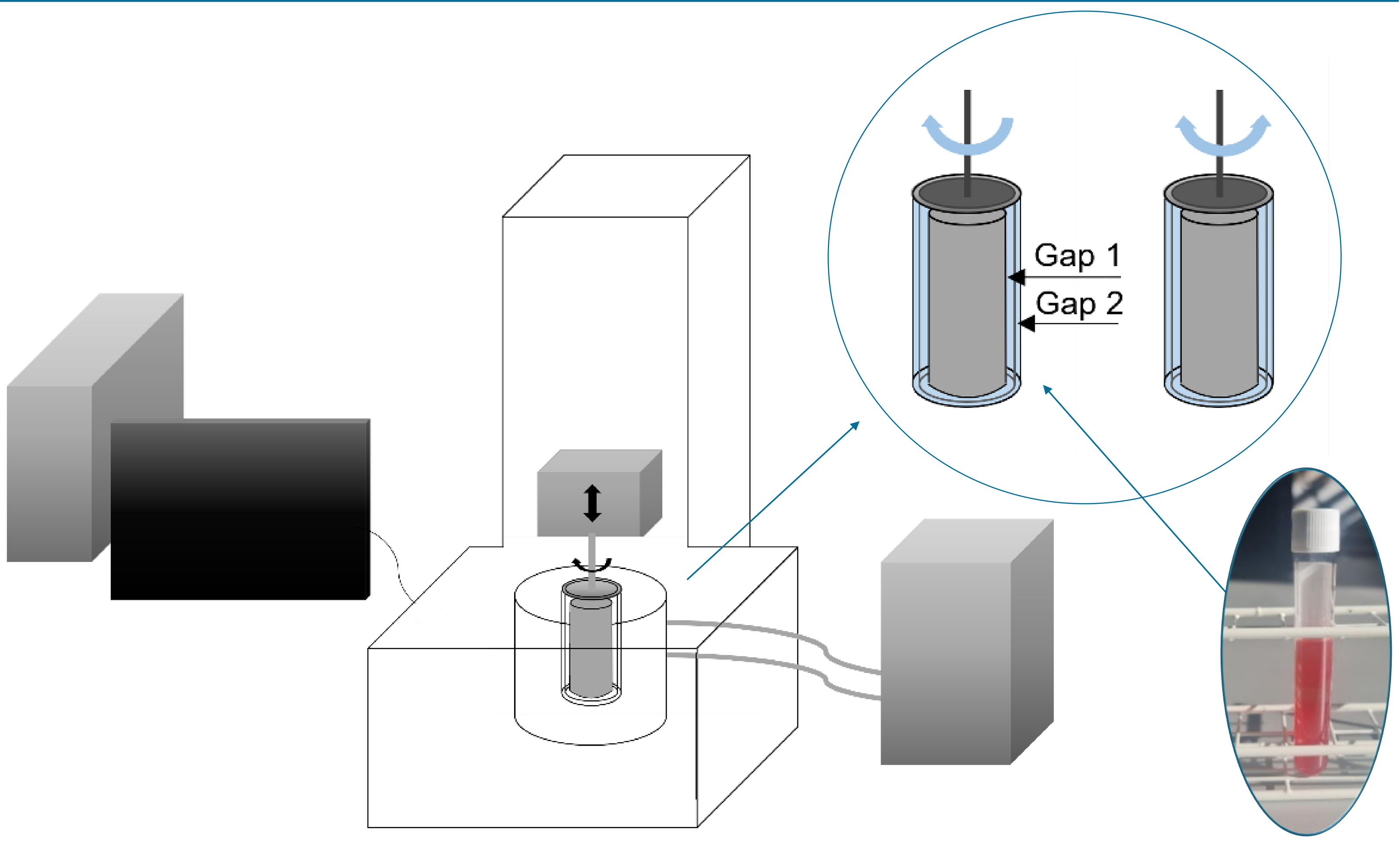

Figure 1: Rheometer setup, equipped with double gap geometry and schematical double gap geometry, on the left side rotational mode – rotation in only one direction, on the right side oscillation mode – upper part oscillates in sinus motion.

RESULTS AND DISCUSSION

Rotational test in Fig.2 showed in the low shear rate range a non-Newtonian behavior and for higher shear rates it acts as a so called Newtonian fluid, which means the viscosity is independent of the applied force. The frequency test in Fig.3 is performed in a oscillating mode to get information about the storage modulus (elastic part) and the loss modulus (viscous part). In the CSF the elastic properties are more present due to the high storage modulus curve at lower frequencies. The complex viscosity shows shear thinning behavior till a certain point where dynamic flow phenomena are present. In order to compare laboratory parameters of the CSF to viscoelastic flow behavior specific cumulative factors were calculated, based on the data received from the frequency tests. The general equation of the cumulative storage factor can be found in Eq.1. [1] The cumulative storage factor is the relation of the integral over a certain angular frequency range of the storage (G`) and loss modulus curves (G``). [1] The cumulative loss factor has the inverse relation and the cumulative complex viscosity is the integral over the complex viscosity curve of a certain angular frequency range. [1] Fig.4 shows the correlation of the cumulative storage factor to the cumulative complex viscosity. A high cumulative factor indicates a high rigidity behavior and therefore strong interactions in the sample. High correlations between the laboratory diagnostic important parameters and the cumulative storage factor were achieved and were investigated using linear regression analysis, which can be seen in Fig.5.

$$cumulative\ storage\ factor = \int_{0.1\,rad/s}^{628\,rad/s} G` \Big/ \int_{0.1\,rad/s}^{628\,rad/s} G`` \qquad \text{(Eq. 1) [1]}$$

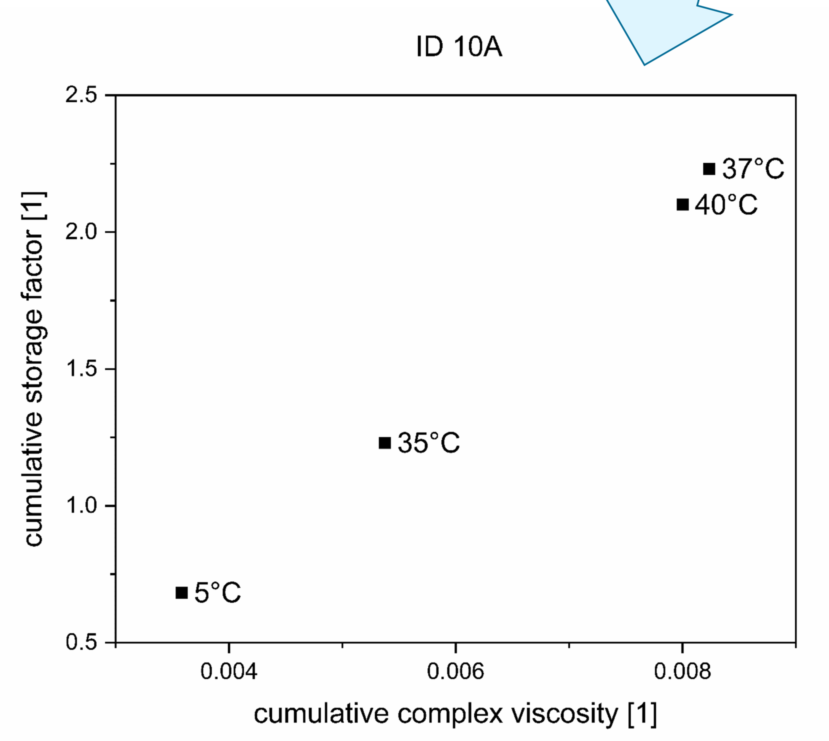

Figure 4: Cumulative storage factor vs. cumulative complex viscosity.

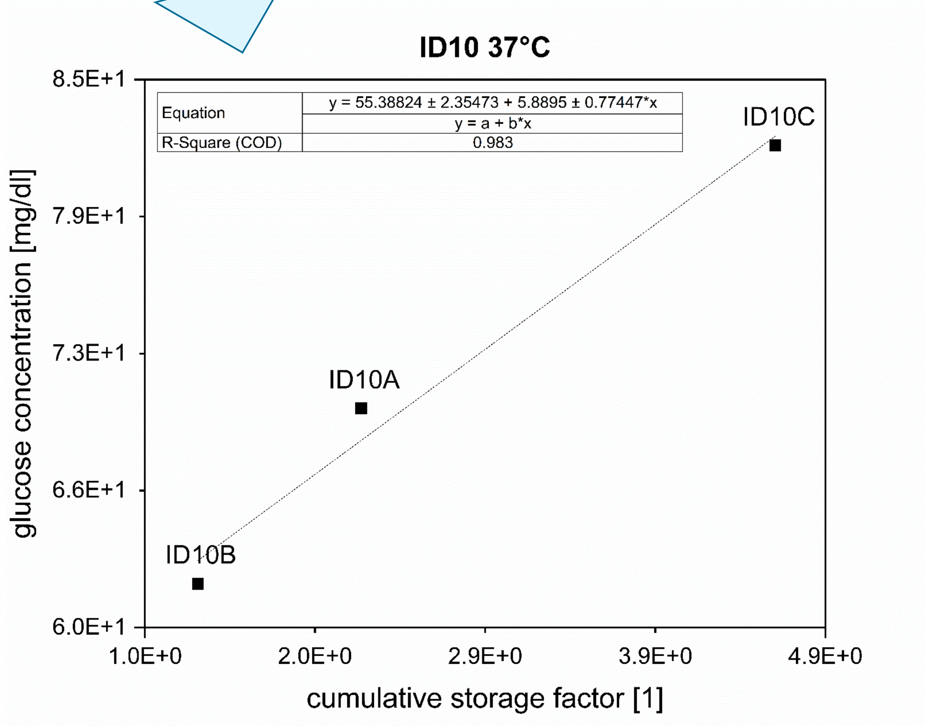

Figure 5: Correlation of ID10 glucose concentration and cumulative storage factor.

CONCLUSION

The flow behaviour of CSF can be characterised by rheological measurements. The cumulative storage factor makes it possible to correlate viscoelastic parameters described by frequency test curves with laboratory parameters of the clinical routine. Further investigations should evaluate whether these rheological parameters may aid in shunt prediction for hydrocephalus patients.

[1] Kracalik, M. Recycled clay/PET nanocomposites evaluated by novel rheological analysis approach. Applied Clay Science 2018, 166, 181–184. https://doi.org/10.1016/j.clay.2018.09.007.

ACKNOWLEDGEMENT

Anton Paar
Kepler Universitäts Klinikum
JKU Institute of Polymer Science

Impetus, Faculty of Medicine Johannes Kepler University Linz, project number: I-10-22
LIT Institute of Technology Johannes Kepler University Linz, project number: LIT-2022-11-SEE-123

contact: thessa-carina.bauer@jku.at