

# Evaluation of a torsional-vibrating technique for the hemorheological characterization

Valter Travagli<sup>1</sup>, Iacopo Zanardi<sup>1</sup>, Letizia Boschi<sup>2</sup>, Vera Turchetti<sup>2</sup>, Sandro Forconi<sup>2</sup>

<sup>1</sup> Dipartimento Farmaco Chimico Tecnologico – Università degli Studi di Siena, Italy  
<sup>2</sup> Dipartimento di Medicina Interna, Cardiovascolare e Geriatrica – Università degli Studi di Siena, Italy

## INTRODUCTION

Clinical measurement of blood viscosity is an important parameter in the diagnosis of different diseases (eg diabetes, hypertension, cardiovascular diseases). Furthermore, the significance of the blood viscosity in the microcirculatory flow is of great importance. Thus, a simple and accurate evaluation of hemorheological properties could be an important challenge in clinical practice.

Nowadays, validated measurements of blood viscosity is commonly carried out with rotational viscometers or a tube-type viscometer with relation to the various geometric configurations, see Figure 1 [1, 2]. However, red blood cells deform under mechanical force and this aspect could lead to an artificial variation in the apparent viscosity. Furthermore, an aspect of a certain importance under the various adopted experimental conditions is the classification of the blood both as Newtonian or non-Newtonian fluid as regards the shear rates. In particular, typical experiments have been carried out under constant shear rate [3] and under constant shear stress [4].

An evaluation of the application of a new technique for the viscosity determination is here presented. In particular, a torsional-vibrating viscometer (VM10AL, CBC Europe) in the presence and in the absence of stirring conditions at thermostatted conditions ( $37 \pm 0.1$  °C) was adopted. The profile of the rheological behaviour as a function of time was recorded and compared with that obtained using a cone-plate rotational viscometer (AR500, TA Instrument).



Figure 1 - Schematic representation of a classical (left) and innovative (right) cone-plate viscometer with cone angle  $\alpha$  and radius  $R$ . In the cartesian coordinate system,  $Z$  coincides with the cone axis, and  $X$  and  $Y$  lie on the plate surface. The spherical coordinate system is defined by the axes  $(r, \theta, \phi)$ .  $\dot{\Omega}$  is the angular velocity of the cone about  $Z$ . The angle  $\beta$  is defined as  $\pi/2 - \theta$ ,  $\beta$  varies from 0 at the plate surface to  $\alpha$  at the cone surface.

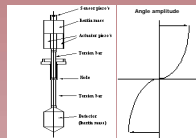


Figure 2 - Schematic representation of the principal components of VM10AL and theoretical background

## MATERIALS AND METHODS

**VM10AL**, CBC Europe. Torsional-vibrating viscometer. Range = 0.4 – 1000 mPa·s. Precision =  $\pm 5\%$ . Probe dimension = 9 mm.

It is a torsional oscillation viscometer (see Figure 2) characterized by constant shear stress systems driven by a piezoelectric ceramic source. This instruments accurately measure viscosity by sensing a change in oscillation amplitude of a liquid-immersed detector, based on constant input voltage. Angular acceleration of the detector is measured and reported as dynamic viscosity.

The probe is a balanced structure in terms of inertia mass and vibration. The upper portion, comprised of sensor and actuator piezo's, vibrates in exact opposite angular momentum to the lower detector. A fixed node in the middle of the torsion bar is the point where torsion displacement is zero. This node is welded to probe housing and absorbs any outside noise or vibration common to process systems; the weld further serves to hermetically seal the structure.

An original phase locked loop circuit maintains instrument resonant frequency of 1kHz; the detector oscillation amplitude with no resistance is  $1\mu\text{m}$ .

All the determinations were conducted in Kartell vessels. In the case of stirring, PTFE micro magnetic stirring bars (3 x 3 mm) were adopted.

**AR500**, TA Instrument. Stress-controlled rheometer. The steady state shear flow and dynamic rheology of blood were studied using a cone-plate geometry of radius 40 mm and angle  $2^\circ$ . No prevention loss of water due to evaporation was adopted. Continuous profile of shear stress and shear rate was recorded. After a given time, the shear rate is increased to its next higher value. This is repeated until the highest shear rate is reached and the system is sheared to its equilibrium shear stress. The process is reversed in the next step. The shear rate is reduced stepwise and stress measured continuously until the minimum shear rate is reached. One milliliter of blood was used to determine whole blood viscosity. Viscosity was measured at shear rates of 10 and  $25 \text{ s}^{-1}$  (unless otherwise stated; upward curve). The value corresponding to the last point after which viscosity tends to increase abruptly (downward curve) at  $37$  °C was also considered for an overall comparison [5].

**Blood collection.** Draw blood using a 20 or 21 G needle with limited occlusion of the arm by the tourniquet. The blood is added to the EDTA anticoagulant, using a lavender-topped EDTA Vacutainer® tube (5 mL tube). Blood collection tubes with anticoagulant were gently inverted as soon after collection as possible to prevent clotting.

## RESULTS AND DISCUSSION

Graphical representations show the typology of rheological behaviour as obtained by the two technique. In particular, for what concern the cone-plate determination, the typical shear stress vs shear rate and viscosity vs shear rate plots are indicated. In the case of vibro-torsional viscometer, absolute viscosity values are related with respect to the time. For a better comparison, results are also indicated in the double-y graphs. As it is possible to observe, two trends are evidenced: the first one with little similarity among data and the second one more comparable. It is possible to relate these trends with the hysteresis area. In fact, the wider the hysteresis loops, the closer the viscosity data by the two technique appear. In Table I are summarized all the obtained data in the presence of stirring. A very similar trend in the absence of stirring was also collected (data not shown). They confirm the potential application of the vibro-torsional evaluation for viscosity measurements, also in consideration of the direct and immediate rheological parameter determinations in the absence of mechanical solicitation. Furthermore, from a perspective point of view, the definition of a database for each patient appears to be of interest in the rheological characterization of whole blood samples. In particular, the correlation among age, microscopical hematological parameters, pathological aspects and concomitant therapy are under investigation.

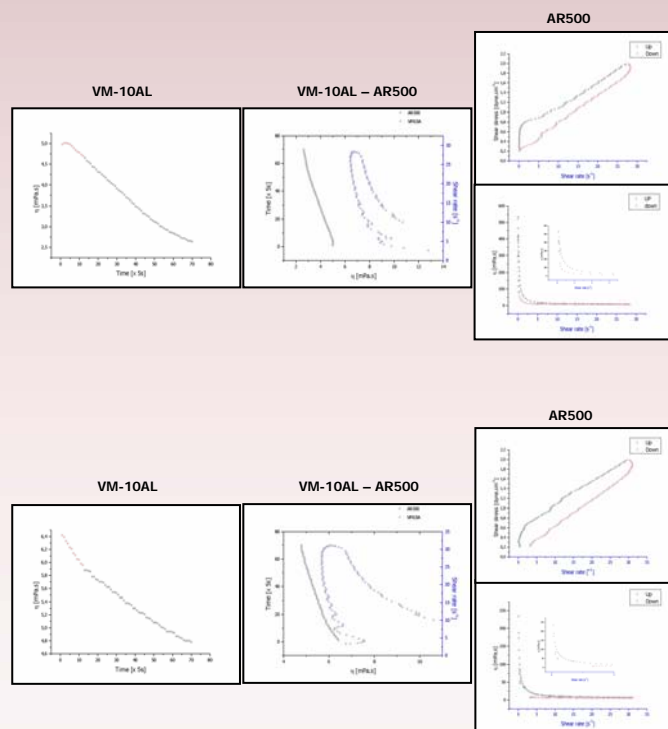


Table I – Viscosity values as obtained by the two adopted techniques

Sample	$\eta$ VM-10AL [mPa·s]		$\eta$ AR500 [mPa·s]		
	Initial	After 6 min	Upward curve		Downward curve
			Shear rate $10 \text{ s}^{-1}$	Shear rate $25 \text{ s}^{-1}$ (unless otherwise stated)	
1	11.5	9.35	14	9.5	15
2	6.80	4.32	10.6	7.5	10.8
3	6.21	3.54	10.5	7.0	6.6
4	6.20	4.40	9.5	7.2	9.5
5	6.60	4.95	11.0	7.1	9.9
6	6.72	4.88	10.8	8.1 (19.8 s <sup>-1</sup> )	8.8
7	7.84	5.19	13.5	10.1 (19.6 s <sup>-1</sup> )	13.5
8	8.50	6.59	15.7	13.4 (15 s <sup>-1</sup> )	19.3
9	7.33	6.18	13.5	9.9 (19.8 s <sup>-1</sup> )	7.41
10	5.54	2.96	10.4	7.2	7.6
11	4.63	2.95	9.5	6.4	6.0
12	5.35	2.99	10.1	7.1	9.5
13	6.42	4.63	10.6	7.1	6.8
14	5.82	2.79	9.3	6.4	6.3
15	8.35	4.94	16.2	11.7 (17 s <sup>-1</sup> )	15.2
16	5.67	4.94	10.8	7.2	7.6
17	4.75	3.35	9.3	6.9	7.5
18	4.98	2.64	10.7	7.5	8.9
19	5.19	2.92	9.5	7.2	7.5
20	5.10	3.30	11.5	7.1	7.5
21	5.93	2.85	12.0	7.6	14.9

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