Theoretical studies on capillary microviscometry of skeletal muscle actin

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(Received 11 October 1982)

For improving Ostwald’s viscometry, which is time-consuming and requires a relatively large volume of specimen to determine viscosity, we developed a capillary microviscometric method with an appropriate mathematical model, and have compared this method with Ostwald’s method.

In the field of the physiology of muscular contraction, studies on contractile proteins are important. Among these various proteins, actin has particular importance. Recently there have been many reports concerning the sol-gel transformation of actin and the many factors affecting actin gelation. Although the sol-gel transformation is of great interest, the long time required to measure the viscosity of actin solution is a major barrier to further study. Ostwald’s method (1) is generally employed as a standard method for measuring the viscosity of actin. This method, however, requires a relatively large amount of specimen and is too time-consuming for measuring sticky samples. In addition, the capillary in the viscometer often becomes clogged with protein aggregates. Thus Ostwald’s method is inadequate for the determination of actin viscosity at high protein concentrations. A simple viscometric method (capillary microviscometry) which can measure the viscosities of a large number of samples in a screening program was designed, and theoretical investigations were carried out.

This study presents a mathematical model of a viscometric method for measuring actin viscosity using a capillary and a stainless-steel ball. Fig. 1 shows a schema of the capillary microviscometer. A capillary (inner diameter, 1.4 mm; length, 100 mm), filled with actin solution and sealed with putty at its bottom end, is attached to a board; the angle of the capillary can be varied. A steel ball (diameter, 0.7 mm; density, 7.795 g/cm³) is put in the top end of the capillary. After an initial push with a thin wire to overcome the solution’s surface tension, the ball travels down the capillary; the time required for the ball to travel 8 cm is measured with a stopwatch.

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G-actin (protein concentration range, 0.49 mg/ml to 3.08 mg/ml, obtained by the method of Spudich and Watts (2), was used for the experiments. Before the start of the experiment, potassium chloride (concentration range, 0.04 mol to 0.1 mol) and magnesium chloride (0.5 mmol) were added to the G-actin solution. The apparent viscosities of the G-actin specimens were between 1.177 centi-poise and 1.456 centi-poise; these values are in good agreement with those reported by Kasai et al. (3). On gelation of the G-actin, the viscosities increased by about 11 centi-poise, as shown in Table 1.

We assumed that fluid resistance (drag), arising from viscous fluids, to the slow motion of a steel ball in fluids can be interpreted by the following equation:

$$D = k \cdot v,$$

where $D$ is drag, $v$ is the falling velocity, and $k$ is the coefficient of resistance.

The force balance for a steel ball immersed in a fluid is:

$$F + K + P + B + W + D = 0,$$

where $F$ is the force of the steel ball, $K$ is the external force, $P$ is the fluid force, $B$ is the buoyant force, $W$ is the friction force on the rotation of the steel ball, and $D$ is drag.

$P$ is the force of the fluid acting against the motion of the steel ball, and Eq. 2 is valid when the steel ball either is stationary or is moving at a constant velocity.