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Temperature Dependence of Blood Surface Tension

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Summary

Whole blood surface tension of 15 healthy subjects recorded by the ring method was investigated in the temperature range from 20 to 40 °C. The surface tension σ as a function of temperature t (°C) is described by an equation of linear regression as $\sigma(t) = (-0.473\ t + 70.105) \times 10^{-3}$ N/m. Blood serum surface tension in the range from 20 to 40 °C is described by linear regression equation $\sigma(t) = (-0.368\ t + 66.072) \times 10^{-3}$ N/m and linear regression function of blood sediment surface tension is $\sigma(t) = (-0.423\ t + 67.223) \times 10^{-3}$ N/m.

Key words

Surface tension • Human blood serum • Sediment • Temperature

Introduction

Blood surface tension, as one of the crucial blood parameters, affects many vital functions of human body. Over the time human body undergoes different natural thermal conditions. Therefore the knowledge about temperature dependence of blood surface tension is important. In textbooks of physiology or hematology the surface tension of blood is usually not mentioned (nor that of other body fluids or tissues). There are few articles related to the surface tension and even fewer to the surface tension of human blood. In addition we did not find any paper about the thermal dependence of human blood surface tension.

The usefulness of surface tension as a parameter in forensic experiments was evaluated by various authors. Raymond *et al*. (1996) used surface tension among other physical parameters (viscosity and density) to support the use of porcine blood in representing freshly spilled human blood in crime-related cases. The influence of surface tension and its relation to the blood/bile ethanol ratio were evaluated by Winek *et al*. (1983).

The use of alumina as a material for cardiovascular applications was investigated on the basis of protein adsorption and thrombus formation on the material using also surface tension as one of the critical parameters (de-Queiroz *et al*. 1994).

Geertsma *et al*. (1993) investigated the effects of surfactant, known to lower the surface tension in alveoli and which affects the antibacterial functions of alveolar and peritoneal macrophages, on the bactericidal functions and oxidative metabolism of human blood monocytes and

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granulocytes.

The influence of surface tension on slow venous bleeding caused coating of syringe surfaces and formed a dome over the skin laceration bleeding site; it was investigated by blood flow simulation performed by McCuaig *et al*. (1992).

Chemistry of blood platelet-rich plasma including surface tension values at 37 °C and 25 °C was examined by Baier *et al*. (1985) with the aim of examining a method of estimating apparent blood compatibility of new biomaterials. Nevertheless, the work did not encompass the larger temperature interval for serum values.

Surface tension and viscosity of plasma were found to be critical parameters in the use of new synthetic materials for platelet quality control. Two synthetic approaches to platelet products are described by Lott *et al*. (1983).

Amorphous hydrogenated carbon (a-C:H), potential material in biomedical devices such as artificial heart valves, bone implants, etc. was investigated and checked because of its chemical inertness, low coefficient of friction, high wear resistance, and good biocompatibility. The results of experiments with hemocompatibility of nitrogen-doped, hydrogen-free diamond-like carbon performed by Kwok *at al*. (2004) were found to be consistent with the relative theory of interfacial energy and surface tension, including both dispersion and polar components, but the evaluation of temperature dependance of those parameters was not evaluated.

Methods

Surface tension theory

Molecules of liquid state experience strong intermolecular attractive forces. When those forces are between identical molecules, they are referred to as cohesive forces and the especially strong cohesive forces at the surface constitute surface tension. When the attractive forces are between unlike molecules, they are said to be adhesive forces. The attractive forces between molecules in a liquid can be viewed as residual electrostatic forces and are sometimes called van der Waals forces or van der Waals bonds. In the bulk of the liquid each molecule is pulled equally in all directions by neighboring liquid molecules, resulting in a net force of zero. At the surface of the liquid, the molecules are pulled inward by other molecules deeper inside the liquid, but there are no liquid molecules on the outside to balance these forces, so the surface molecules are subject to an inward force of molecular attraction, which is balanced by the resistance of the liquid to compression. There may also be a small outward attraction caused by air molecules, but, as air is much less dense than the liquid, this force is negligible. Surface tension is measured in newtons per meter (N/m), and is defined as the force along a line of unit length perpendicular to the surface, or work done per unit area. According to the work-energy theorem the surface tension can also be considered as surface energy, which is required to change the form of this surface. If a surface with surface tension σ is expanded by a unit area, then the increase in the surface's stored energy is also equal to σ.

Surface tension measurement

The surface tension of blood was measured by TD1 tensiometer made by Lauda GmbH, Germany, which allows to record surface tension by different methods. In the ring method we used, the liquid is raised until contact with the surface is registered. The sample is then slowly lowered again so that the liquid film produced beneath the ring is stretched. Maximum pull exerted on the ring by the surface is measured. The surface and interfacial tension σ are calculated from maximal force F_{max} acting on the length of the ring,

$$\sigma = \frac{F_{\max}}{4\pi R f_{corr}(r, R, \rho)}$$

where R is the ring diameter, r is the diameter of the wire the ring is made from and f_{corr} is ring correction factor dependent on ring geometry and density ρ. The tensiometry method using the ring does not allow direct measurement of absolute values of maximum force F_{max}, because surface tension measured by this method also involves the gravitation measure of the liquid pulled by the ring out of the liquid surface. To eliminate gravitational force from the measured value there is a multiplicative correction factor, which is a function of ring density and diameter, wire diameter and gravitational constant. Calibration constant force F_{cal}, in our experiments with calibration weight G_{cal} equal to 500 mg, was calculated from the equation:

$$F_{cal} = G_{cal}\, g / 2\pi d$$

where g is the gravitation constant and d is the ring

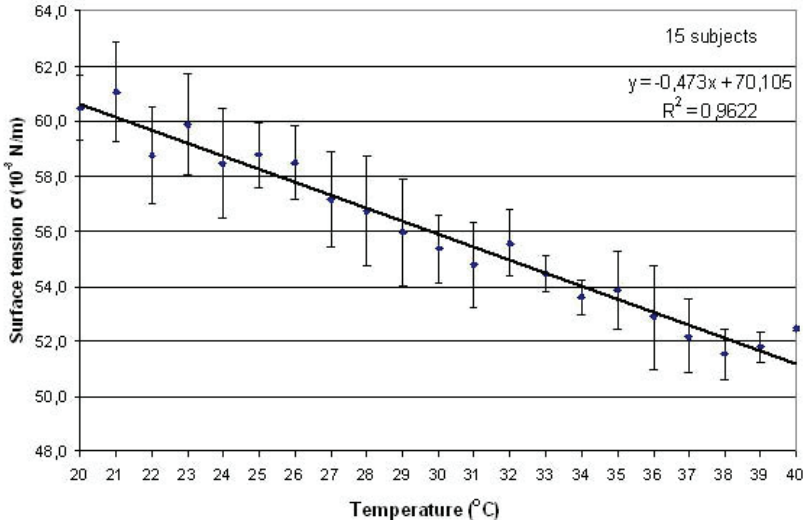

Fig. 1. Dependence of blood surface tension on temperature.

diameter. According to the manual of the TD1 tensiometer by Lauda, the correction factor of the ring in our experiments was

$$f = 0.8759 + (0.0009188\ \sigma) / D$$

where σ is the surface tension without correction and D is liquid density.

Material

The whole blood experiments were performed with blood samples taken from 15 patients of the hospital attached to the Third Medical Faculty of Charles University in Prague (Clinical Department of Anesthesiology FNKV). The blood-donating patients were healthy in terms of blood parameters with no indication of blood-related disease. Immediately after donation an anticoagulant agent (3.8 % sodium citrate) was added to each sample of 20 ml of blood and then it was transferred to the experimental lab and underwent the procedure of surface tension measurement. Eleven out of 15 blood samples taken into the statistics came with all basic characteristics of both the patient (gender, age, weight, height) and the blood (hematocrit, Quick, APTT, urea, creatine, bilirubin, cholesterol).

The blood sediment and serum experiments were performed on samples of 12 different healthy subjects. The sediment and serum were extracted from the blood by means of natural blood sedimentation in 2 h. Both the sediment and the serum part underwent the same procedure of surface tension measure as the whole blood.

Measurement conditions

All experiments were performed with blood in a glass jar with diameter large enough (40 mm) to allow the effect of borders to be neglected. The jar was immersed in a plastic container (bath) filled with water. Both the change of water bath temperature and the stirring of blood allowed to measure the blood surface tension under temperatures from 20 to 40 °C. Temperature was measured in the blood surface layer with a calibrated thermistor at the time when maximum force F_{max} was reached.

Calculations

Surface tension was measured under different temperatures between 20 and 40 °C with the aim of covering the whole interval as much as possible. Surface tension values of blood collected from different subjects were afterwards put together, sorted according to the temperature and clustered by "whole number" temperature points (20 °C, 21 °C, 22 °C etc.). For example, surface tension value and its standard deviation S.D. for 35 °C were calculated from T values recorded for the temperature interval from 34.6 °C to 35.5 °C. The resulting values with S.D. were put into a graph. In addition, each graph comprises an equation of linear regression line and trend line reliability value (R).

Results

To evaluate the whole blood surface tension as a function of temperature in the range from 20 to 40 °C the blood of 15 subjects was used. In each blood sample the

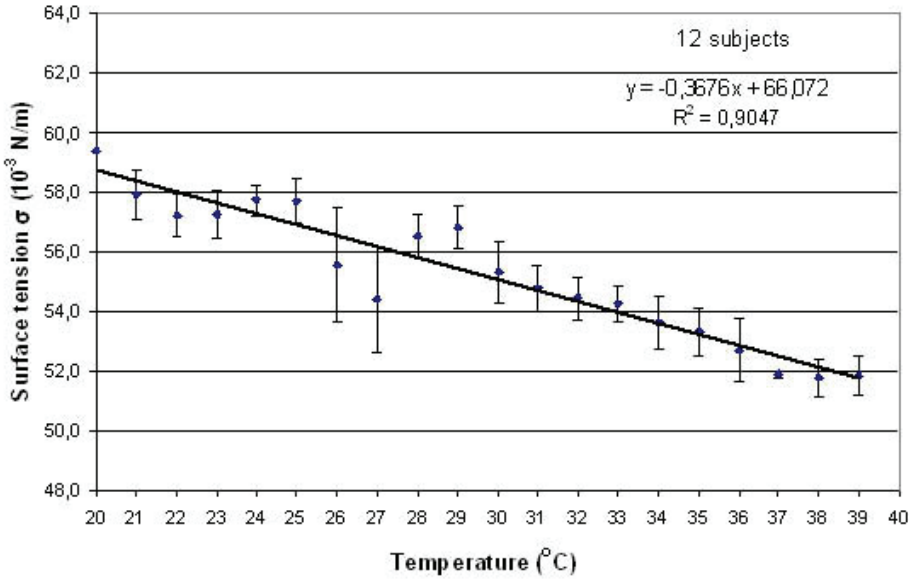

Fig. 2. Dependence of blood serum surface tension on temperature.

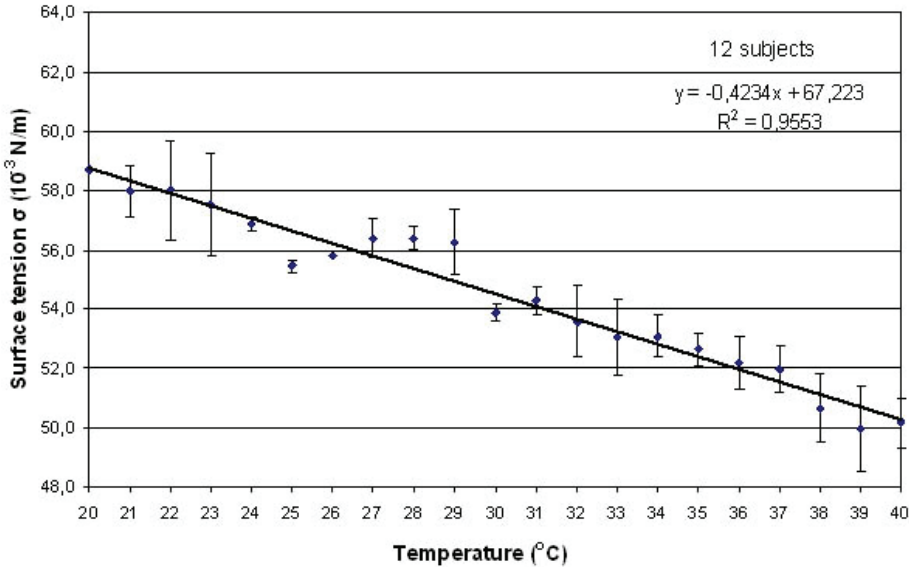

Fig. 3. Dependence of blood sediment surface tension on temperature.

values of surface tension were recorded at 12 different temperatures on the average. Fig. 1 illustrates the whole blood surface tension values for temperatures from 20 to 40 °C. In addition, a line of linear regression function of whole blood surface tension $\sigma(t)$ = (–0.473 t + 70.105) $\times 10^{-3}$ N/m in the temperature range from 20 to 40 °C is drawn. Good reliability of the regression trend line is expressed by line reliability value *R* being close to 1.

Fig. 2 illustrates the blood serum surface tension as a function of temperature in the range from 20 to 40 °C. The blood samples were donated by 12 healthy subjects. After a 2-h period of sedimentation the same procedure as in the whole blood sample was applied, i.e. in each blood sample the values of surface tension were recorded at 12 different temperatures on the average. The line of linear regression function of blood serum surface tension is seen to be $\sigma(t)$ = (–0.3676 t + 66.072) $\times 10^{-3}$ N/m in the temperature range from 20 to 40 °C. The trend line reliability value R is again close to unity (R^2 = 0.9047).

Complementary to the blood serum experiments we did experiments with blood sediment. The same 12 blood samples used for serum were utilized for surface tension measure of blood sediment. In Fig. 3 the blood sediment surface tension as a function of temperature is shown. Surface tension was recorded at 12 different

temperatures on the average after a 2-h period of sedimentation. The line of linear regression function of blood sediment surface tension is seen to bes $\sigma(t)$ = (-0.423 t + 67.223) × 10^{-3} N/m. The trend line is highly reliable (R^2 = 0.955).

Discussion

The importance of surface tension of the blood and its temperature dependence was found in different areas of biomedical investigation. Mottaghy *et al*. (1989), trying to solve the leakage of capillary membrane oxygenators for long-term extracorporeal lung support, found the blood surface tension to be one of the critical factors at the micropores, besides temperature conditions of the gas, the blood and the circuit environment but no special recording of blood surface as a temperature function was done.

Comparing blood surface tension value at 22 °C recorded by the ring method presented in this paper (Fig. 1), $\sigma(22)$ = (58.74 ± 1.77) × 10^{-3} N/m, with the value recorded at 22 °C by the drop method by Hrnčíř and Rosina (1997), $\sigma(22)$ = (55.89 ± 3.57) × 10^{-3} N/m, it is obvious they are in good agreement. Their results did not correlate with age or sex of the examined subjects or with any of the following variables: red cell sedimentation rate, blood hemoglobin levels, number of erythrocytes, total serum cholesterol, total serum triacylglycerols, creatinine blood levels, ALT and AST activity.

Interactions between hematological derivatives and their implications for adult respiratory distress syndrome were examined by Banerjee (2004). His experiments were performed with whole blood, membranes obtained from whole blood cells, lysed blood, homogenized blood clot, serum, platelet-rich plasma, platelet-poor plasma and individual plasma proteins at physiological temperature (37 °C). He evaluated the surface properties of dipalmitoyl phosphatidylcholine (DPPC) monolayers, the main component of lung surfactant in the presence of blood and its components. Cell membranes were found to be the most inhibitory agent for DPPC surface activity as evidenced by an increase in the minimum surface tension (from 0.818 ± 0.219 to 7.373 ± 0.854 mN/m) and percentage area change required to reduce the surface tension from 30 to 10 mN/m (from 21.24 ± 0.99 to 66.83 ± 4.44). The inhibitory potential of pure plasma proteins differed from that of more complex blood derivatives, such as platelet-rich plasma and serum. Whole blood and platelet-poor plasma were non-inhibitory but serum, platelet-rich plasma and clot significantly increased the minimum surface tension of DPPC to 6.819 ± 0.925, 6.625 ± 2.261 and 6.060 ± 0.640 mN/m, respectively.

Knowledge of normal physiological values of blood surface tension seems to be very important. There is evidence that the blood surface tension shows higher values for patients with acute myocardial infarction compared to the control group (Esitashvili and Msuknishvili 2002). The surface tension of blood can also play a role in the stabilization of microbubbles in diagnostics using ultrasound with contrast and so improve the ultrasound imaging (Liew and Raychaudhuri 1997). We also suggest that blood surface tension monitoring could serve for the adjustment of therapeutic levels of rheological pharmaceuticals.

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