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INFLUENCE OF PERFLUORODECALIN CONTENT ON THE PROPERTIES OF BLOOD SUBSTITUTE

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Abstract: Blood is a vital part of our circulatory system. It is responsible for transporting oxygen and nutrients, regulating body temperature, and fighting infections. However, any imbalances in blood composition or disruptions in the blood production process can affect the body's overall functioning. Anemia is one of the most common blood diseases diagnosed worldwide. It is characterized by a deficiency of red blood cells or hemoglobin, which reduces the body's ability to transport oxygen. To address this issue, researchers are developing blood substitutes with artificial oxygen carriers that can replace or support the natural function of red blood cells in oxygen transport. Perfluorocarbon-based oxygen carriers (PFCs) such as perfluorodecalin (PFD) are promising for treating severe blood disorders because they can deliver O2 to tissues in various conditions. PFCs have higher storage stability than other oxygen carriers due to their bilayer sphere structure. In this study, we aimed to explore the effects of different concentrations of PFD (1%wt., 2%wt.) and storage time (7, 14, 21, 28 days) on the properties of blood substitutes, including its physicochemical (pH, surface tension, electrolytic conductivity, contact angle, redox potential, oxygen content) and rheological characteristics. The results show that the PFD concentration did not have a statistically significant effect on most of the tested properties, except for the oxygen content, which was higher for the 2%wt. solution after 28 days of incubation. The incubation time significantly impacts the change in surface tension, contact angle, redox potential, and oxygen content. The obtained results are essential due to the use of perfluorodecalin in medicine as an oxygen carrier.

Key words: artificial blood, perfluorodecalin, physicochemical properties, blood viscosity

1. INTRODUCTION

Blood is a liquid tissue that plays a vital role in the circulatory system, carrying out several essential functions. Blood plays a crucial role in maintaining homeostasis in the human body. Pleiotropic properties of blood provide many functions, such as delivery of necessary substances (such as nutrients and oxygen) to the body's cells, transport of waste products away from cells, immunological functions (circulation of white blood cells, detection of foreign material by antibodies), coagulation (body's self-repair mechanism), information functions (transport of hormones and the signaling of tissue damage) and regulation of body pH and temperature [1].

Blood comprises two primary components: liquid plasma and morphotic elements such as erythrocytes, lymphocytes, and platelets. Plasma, mostly made up of water, proteins, mineral salts, lipids, and glucose, is the primary component of blood and constitutes more than half of its volume [2]. Erythrocytes, also known as red blood cells, are the blood's most numerous morphotic elements, accounting for 44% of its volume. They have a disc-like shape flattened on both sides, which gives them a more favorable surface-to-volume ratio for gas exchange. Erythrocytes are blood cells that contain hemoglobin and non-hemoglobin proteins [3]. Hemoglobin is made up of two components: globin and heme. Globin is composed of four polypeptide chains that are held together by ionic bonds. On the other hand, heme is a pigment consisting of four pyrrole rings with an iron atom at its center. This iron atom binds with oxygen or carbon dioxide to transport them throughout the body. The production of erythrocytes occurs mainly in the bone marrow and spleen. However, any disruptions to the blood production process can affect the body's functioning.

Anemia is one of the most commonly diagnosed blood diseases affecting people worldwide [4]. It is characterized by a deficiency of red blood cells or hemoglobin, which results in a decreased ability of the body to transport oxygen. The treatment methods for anemia vary depending on the severity and underlying cause of the disease. Oral or intravenous iron supplementation is usually the preferred treatment for iron deficiency anemia. Transfusion therapies or bone marrow transplantation may be necessary for other types of anemia. Despite advances in our understanding of blood diseases and the development of new drugs, treating hematological diseases remains a significant challenge for medical professionals.

Additionally, due to the aging population and other factors, there is a growing need for more blood donors [5]. An alternative to conventional methods of treating blood diseases is artificial blood products. Jägers et al. [6] rightly note that interdisciplinary cooperation is needed. For this reason, numerous works have been done to develop blood substitutes that can support or replace blood in performing its functions [7–9]. Their primary purpose is to ensure oxygen transport by artificial oxygen carriers (AOCs). AOCs are essential in managing blood conditions for patients with serious illnesses. The primary types of AOCs are Hemoglobin-based Oxygen Carriers (HBOCs) [10] and Perfluorocarbon-based Oxygen Carriers (PFCs) [11]. The former refers to the covalent linkage of oxygen and Hb, while the latter involves oxygen dissolution within

a perfluorocarbon (PFC) [12]. HBOCs were first tested in the 1930s using cell-free hemoglobin on a cat with renal toxicity by Amberson et al. [13]. The first modified HBOC, HemAssist, was licensed in 1985, followed by Polyheme, a polymerized Hb clinically developed in 1996 [14]. The concept of PFCs as oxygen carriers started in 1966. A human serum albumin-derived PFC-based AOC, considered a cutting-edge technology [15], was utilized in various in vivo studies and began in 2017 [16]. Since then, work has been underway to obtain a stable albumin-perfluorocarbon emulsion [17].

PFCs dissolve respiratory gases like oxygen, CO, CO2, and NO [6]. When both PFC and RBC are present in the circulation, PFC protects Hb-bound oxygen until it reaches hypoxic tissues [18]. PFCs are more resilient than AOCs to pH and temperature changes. They are not affected by pharmacological, environmental, and chemical changes. PFCs are chemically resistant to heat and do not undergo metabolic transformation in vivo, making them safer than HBOCs as AOCs. HBOCs tend to have side effects such as immune reactions, high blood pressure, and a short half-life [19]. The advantages of PFCs are their long shelf-life and ability to penetrate small blood vessels and arterial blockages for oxygen transport [20]. PFCs have higher storage stability than other oxygen carriers due to their bilayer sphere structure, where there is a PFC-nucleus in the center. A shell around this surface is a thin layer of surfactant. The stability of PFC emulsions depends on the sample surface layer elasticity of the surfactant around the particles [19]. A good example of this group is perfluorodecalin (PFD), a type of PFC, a hydrocarbon-based compound in which all hydrogen atoms are replaced by fluorine atoms (Fig. 1).

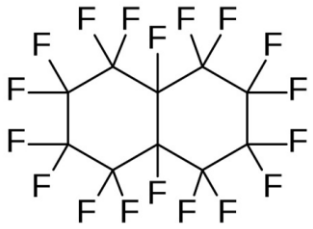

Fig. 1. The structural formula of perfluorodecalin

To the best of our knowledge, no publications have assessed the individual impact of PFDs on synthetic blood preparations' physicochemical and rheological properties. The work aimed to verify the effects of PFD on the properties of artificial blood, including its chemical, physical, and rheological characteristics. The original chemical compositions of the blood solutions were selected experimentally.

2. MATERIALS AND METHODS

2.1. Perfluorodecalin-based artificial blood solutions

Based on the literature [21], a base solution imitating human plasma was developed (Tab. 1). Organic ingredients (e.g., glucose, albumin, glycerin, cholesterol) and inorganic ingredients (inorganic salts) were dissolved in deionized water. The organic components were used as emulsifiers, cryoprotectants, and consistency modifiers. Their role is to maintain the osmotic pressure, ensure appropriate viscosity, and prevent the formation of clots. Inorganic salts regulate ionic balance, pH, and osmotic pressure.

Then, 1%wt. or 2%wt. perfluorodecalin (PFD) (samples indicated as 1PFD and 2PFD respectively) was added into the plasma solution (control sample indicated as C). Then, the 100 µL of each sample was vortexed for 30 s to obtain a homogeneous solution. The prepared samples were stored static in a refrigerator at 2°C.

Tab. 1. Composition of the base solution imitating human plasma

Ingredient	Concentration (g/L)	Function
water	920	solvent
albumin	57	emulsifier, maintaining osmotic pressure
glycerine	8	cryoprotectant, ensuring appropriate viscosity
glucose	1	nutritional properties
cholesterol	4.5	preventing the formation of clots, regulating blood pressure
cholesterol oleate	1.5	emulsifier, viscosity regulator
NaCl	5.2	ionic balance, pH, and osmotic pressure constancy
$NaHCO_3$	1.8	ionic balance, pH, and osmotic pressure constancy
$MgCl_2$	0.38	ionic balance, pH, and osmotic pressure constancy
$CaCl_2$	0.33	ionic balance, pH, and osmotic pressure constancy
KCl	0.30	ionic balance, pH, and osmotic pressure constancy

2.2. Physicochemical and rheological tests

The study tested an artificial blood that contained varying concentrations of perfluorodecalin. The physicochemical and rheological properties of the preparations were tested at different intervals after their preparation (0, 7, 14, 21, and 28 days). The measurements were conducted at a laboratory temperature of 23°C using various instruments, including the SevenMulti (Mettler Toledo, Columbus, OH, USA) multifunctional ionoconductometer for pH, conductivity, and redox potential measurements. The Oxygen Meter CO-105 electrode (Elmetron, Poland) was used for oxygen concentration testing and the STA1 tensiometer for surface tension analysis. The Contact Angle Goniometer (Ossila, UK) determined the tested preparations' contact angle (θ) in contact with PDMS surface. The viscosity tests were performed using the HAAKE Rheostress 6000 rheometer (Thermo Fisher Scientific, Waltham, MA, USA) with plate-plate (35 mm diameter) system in a shear rate range of 10 to 200 1/s in 37°C. All measurements were conducted five times for each case. The study aimed to determine whether perfluorodecalin and storage time impacted the properties of artificial plasma preparations.

The statistical analysis was performed using Statistica software (TIBCO Statistica® software version 14.0.1, Palo Alto, CA, USA). The average value and standard deviation were calculated based on the results obtained from at least five repeatable test attempts under the same conditions. The results are presented as mean value ± SD. One-way ANOVA tests were used to analyze the statistical significance of differences.

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3. RESULTS

Analysis of pH test results (Fig. 2a) indicates that up to 2% of PFD content in artificial plasma preparations does not significantly affect the pH value. It was observed that the pH of tested samples (7.41-7.43) was within the pH range of natural blood (pH = 7.35-7.43, Tab. 2) for up to 7 days from preparing blood substitutes. Static storage of prepared solutions increases the pH to 7.5-7.6, 7.59-7.65, 7.43-7.67 after 14, 21, and 28 days for tested preparations, respectively. The electrolytic conductivity value of tested PFD-based blood preparations was in the range κ = 11.7 - 12.7 mS/cm (Fig. 2b), within the physiological range. We observed significant differences ($p < 0.05$) in freshly prepared solutions between C (κ = 11.7±1.1 mS/cm), 1PFD (κ = 12.3±1.1 mS/cm), and 2PFD (κ = 12.4±1.0 mS/cm). The electrolytic conductivity did not change significantly until 14 days after their preparation. The surface tension results (as shown in Fig. 2c) indicate that this parameter for the tested solutions increased over time. On day 0, the surface tension was approximately σ = 35 mN/m, while after 28 days of storage, it increased to approximately σ = 55 mN/m. The greatest surface tension increase was observed during the first week of incubation, where it increased to about 50 mN/m, which was statistically significant ($p < 0.05$). In the case of the contact angle values (Fig. 2d), the lowest values were also obtained on day 0. The contact angle for the control sample (θ =7.7±0.2°) was statistically lower ($p < 0.05$) in comparison to 1PFD (θ =28.3±0.8°) and 2PFD (θ =29.6±0.9°). Even 1%wt. addition of PFD statistically influences this parameter. On day 7, the contact angles increased to θ = 48° - 55° and were similar to the preparations tested after 14 days. The values were statistically higher ($p < 0.05$) than those obtained after 7 days of storage. Then, the contact angle increased, and the highest angle value (θ ~ 60°) was obtained after 28 days of storage, which was statistically higher than the contact angle measured after 7 days of incubation.

The redox potential data (Fig. 3a) show that all values were positive, meaning that tested solutions have oxidizing properties. The redox potential was in the E = 160-169 mV range on their preparation day. The highest redox potential (E = 213±4 mV) was obtained for sample 2PFD after 7 days of incubation and was statistically higher ($p < 0.05$) in comparison to the control sample and solution with 1%wt. of PFD addition, which was E=190±4 mV. The lowest values (E = 90-120 mV) were obtained on day 14 for the tested samples. The redox potential increased until day 7, then decreased significantly on day 14 and increased again during measurements on day 21. After 28 days, the redox potential for the control sample and PFD-based solutions was in the E = 130-140 mV range. It was statistically lower than solutions tested on their preparation day and after 7 days of storage.

The oxygen concentration results shown in Fig. 3b indicate that the increase in PFD content and the duration of storage of artificial blood solutions are directly proportional to the increase of this parameter for the developed substitutes. On the day of solution preparation, the lowest oxygen content (5.67±0.31 mg/L) was observed for the control solution (Fig. 3b). For the PFD-based preparations, the oxygen content for 1PFD and 2PFD was ~7.5 mg/L and ~8.1 mg/L, respectively, and were statistically higher than the solution without PFD addition. After 28 days of storage, the oxygen concentration increased for all tested solutions, and in the case of the sample without PFD and for samples 1PFD and 2PFD, this parameter was 6.66±0.31 mg/L, 10.12±0.5 mg/L, and 11.66±0.58 mg/L, respectively. The oxygen content after 28 days for tested PFD-based solutions was statistically higher than that of the control sample. The highest oxygen concentration (~11.66±0.58 mg/L) was obtained for sample 2PFD after 28 days of storage and was statistically higher than that of sample 2PFD tested after 7 days of incubation.

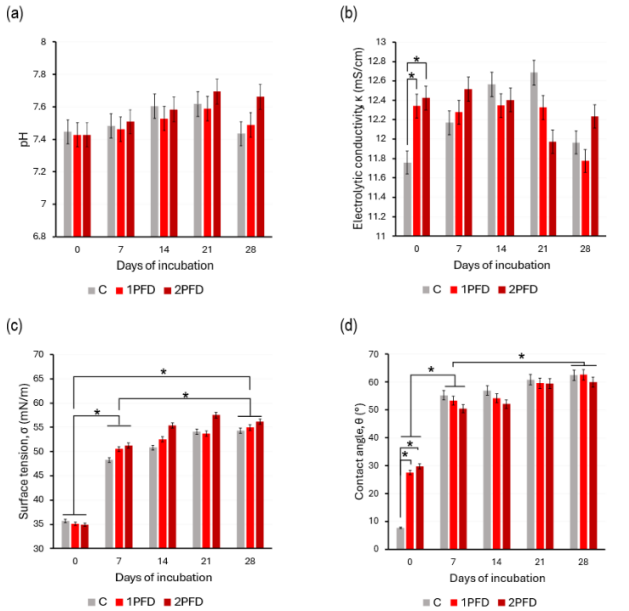

Fig. 2. Results of a) pH, b) electrolytic conductivity, c) surface tension, and d) contact angle measurements for perfluorodecalin-based solutions after 7, 14, 21, and 28 days. Mean values with ± standard deviation for 5 measurements are presented. The abbreviations C, 1PFD, and 2PFD denote control samples containing no PFD and samples containing 1% and 2% PFD, respectively. (*) statistically significant differences $p < 0.05$

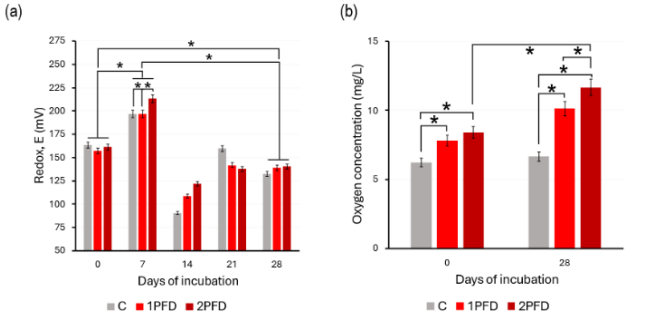

Fig. 3. Results of (a) redox potential (after 7, 14, 21, and 28 days); and (b) oxygen content measurements (after 28 days) for perfluorodecalin-based solutions. Mean values with ± standard deviation for 5 measurements are presented. The abbreviations C, 1PFD, and 2PFD denote control samples containing no PFD and samples containing 1% and 2% PFD, respectively. (*) statistically significant differences $p < 0.05$

Viscosity tests (Fig. 4) showed that the obtained preparations are non-Newtonian, pseudoplastic fluids, just like natural blood. For all solutions tested on the day of preparation (Fig. 4a), the viscosity was in the range of η = 2.2-2.8 mPas at the shear rate γ ≥ 60 s-1. After 28 days of storage, the viscosity for control samples was about η ~ 3 mPas, and for PFD-based solutions was in the range of η ~ 2-2.2 mPas at the shear rate γ ≥ 60 s-1. The dynamic viscosity values are similar to those of natural blood or plasma (η ~2-

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5 mPas) in the entire range of tested shear rates tested, without incubation and after 28 days of storage. Moreover, PFD had no visible effect on the viscosity of non-incubated samples, but after 28 days of incubation, the PFD reduced the viscosity.

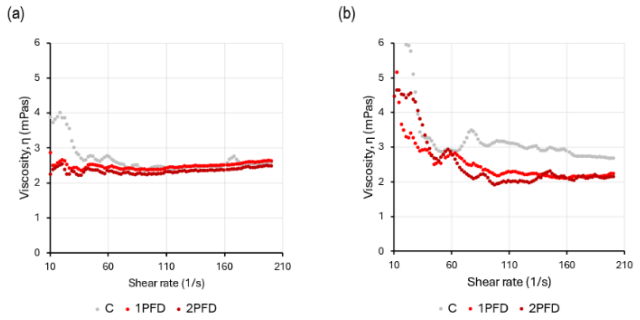

Fig. 4. Results of viscosity measurements for perfluorodecalin-based solutions: (a) with no incubation; (b) after 28 days of incubation. Mean values for 5 measurements are presented. The abbreviations C, 1PFD, and 2PFD denote control samples containing no PFD and samples containing 1% and 2% PFD, respectively

4. DISCUSSION

The result of impaired function of the natural blood is a pathogenesis of various disorders. Treatment of blood disorders involves pharmacological therapy or replacement therapy, which is based on the use of artificial substitutes. However, no blood substitutes meet the biological criteria and maintain favorable physicochemical properties and rheological parameters. Directions for improving the biofunctional properties of such preparations should consider their chemical modification. This mainly concerns oxygen carriers, where selecting their type and concentration will enable obtaining a biocompatible preparation. Appropriate selection of artificial blood ingredients makes it possible to influence the kinetics and mechanism of oxygen transport and properties similar to natural blood (Tab. 2). It is also responsible for modifying the biofunctional properties of blood and, concerning the subject of the work, physicochemical and rheological characteristics.

Tab. 2. Human blood parameters [22–25]

Parameter	Value
color	red
smell	specific, metallic
taste	sweet and salty
pH	7.35-7.43
osmotic pressure	300 mOsm/L
oxygen capacity	20.1 ml O_2 / 100 ml blood
surface tension	53.45-55.35 mN/m
electrolytic conductivity	10-20 mS/cm
contact angle	40-75°
viscosity	3.5-5.5 mPas

The pH values of tested preparations are 7.41-7.67 during the tested period. The pH of own-prepared blood substitutes increased with time and was higher for higher PFD content. After 28 days of storage, the pH of the tested preparations decreased. The optimal pH value of human blood is in the range of 7.35-7.43 (Table 2), which is of great biological importance because even slight changes in the acidic or alkaline direction can lead to disturbances in many physiological processes, including the functioning of the nervous system, causing disturbances in consciousness, convulsions, enzyme functioning, and substance transport. Responsible for the stability of hydrogen ions include, among others, carbon dioxide (CO2), sodium bicarbonate (NaHCO3), sodium salts of phosphoric acid (Na2HPO4, NaH2PO4), plasma proteins, and hemoglobin. Lowering the pH value of blood may result in an increased breathing rate to remove excess carbon dioxide, which, together with water, forms acid anhydride, which lowers the pH value. The human blood pH values below 6.8 and above 7.8 can be fatal, as many metabolic processes are disturbed [26]. The obtained results indicate the need to modify the composition of blood products to get a solution with a lower initial pH and better buffering properties.

Natural blood, as a liquid based on water and different electrolytes, has conductivity in the range of κ =10 - 20 mS/cm (Table 2). Electrolytes, especially Na+, K+, Ca2+, Mg2+, Cl-, and HCO3-, properly conduct electrical impulses in nerves and muscles. Due to electrolytic conductivity, blood can maintain an osmotic balance. Blood's osmotic pressure is related to the concentration of electrolytes in the blood, particularly Na+ and K+ ions and plasma proteins [26], and is approximately 300 mOsm/L (Table 2). However, it is characterized by slight fluctuations related to food and drink intake. The values of electrolytic conductivity (11.7-12.7 mS/cm) for tested substitutes determine increased ionic activity. We think this might positively influence ions' transport and diffusion (penetration), which is essential from the point of view of blood functions [27].

The value of blood surface tension depends on the type of food consumed and the amount of fluids. A diet high in fat reduces, while protein-rich increases its value. On average, the surface tension of natural blood is σ = 53.45-55.35 mN/m (Table 2) and is slightly higher in women than in men, because of less RBC accumulation and less hematocrit [28]. The measured surface tension values for tested preparations (~55 mN/m) are lower but get closer to this result over time. Surfactants decrease, and inactive agents increase the surface tension of liquids. Surface-active compounds include hydrophilic (e.g., OH) and hydrophobic (e.g., CH3) groups. Such substances in the developed preparation include glucose, albumin, glycerin, and cholesterol. Ionic compounds are mainly responsible for increasing their value, i.e., the salts NaCl, NaHCO3, MgCl2, CaCl2, and KCl. The increasing surface tension value may be related to the progressive dissociation of these salts. This property is also fundamental in the breathing process because the appropriate surface tension of blood in the alveoli is essential for proper gas exchange. Due to surface tension properties, the alveoli are kept open, facilitating oxygen absorption into the blood and the release of carbon dioxide. Surface tension also helps maintain the integrity of the blood clot [29–31].

In the literature (Table 2), the value of the blood contact angle is in the range θ = 40-75°, depending on the material used for tests [32–34]. This means that blood has good wetting properties so blood cells can adhere well to the vessel walls during clot formation. The wettability angle of blood depends on the type of surface used for tests. The results obtained in this work on day 0 (θ ~29°) are lower than those in the literature, while those obtained for 7-28 days (θ~60°) are similar to natural blood. The obtained results of the contact angle measurement indicate that the storage time of the obtained solutions affect the increase of the value of this parameter. The contact angle of the tested solutions increased with time, which may indicate condensation [35]. However, no effect of PFD concentration on the contact angle value was observed. The contact angle

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values are similar to the values of natural blood (θ >40°) observed after 7 days from the moment of preparation and increase to approx. θ ~ 60° after 28 days, which is still within the physiological values. Contact angle tests showed values lower than θ = 90°, which means that the tested solutions are characterized by good wettability. This property is advantageous because it might reduce the friction between the walls of blood vessels and the flowing fluid.

The tested samples' redox potential (E = 75.1-213.1 mV) increases until day 7, then decreases on day 14 and increases again. This may indicate that an oxidation reaction has occurred in the tested solutions, as all results are positive. The differences between the solutions are low, meaning that PFD does not affect the redox potential value. This is related to the oxidation and reduction reactions in the tested solutions, resulting from their chemical composition and pH value. These changes may be related to oxidation-reduction reactions between glucose characterized by reducing properties and metal ions, such as Mg2+ or Ca2+, which are electron acceptors. These reactions can affect the redox potential by changing ion concentrations [36, 37].

The oxygen concentration of the solutions increases with increasing PFD content and storage time. The perfluorodecalin (C10F18) is characterized by high oxygen-carrying capacity, dissolving 49 ml of oxygen per 100 ml of PFD, almost 40% more than water or plasma. Kim et al. [38] stated that PFOCs-based blood substitutes can dissolve 40 to 70% of oxygen at room temperature. This binding capacity results from fluorine's low polarizability and the ability of perfluorodecalin (C10F18) to form complexes with oxygen through electrostatic and dipole interactions [39]. The fluorine atoms in perfluorodecalin molecules have a partially negative electrical charge that attracts partially positively charged oxygen molecules. As a result of these interactions, a complex is formed (perfluorodecalin oxide - C10F18O), in which perfluorodecalin molecules surround the oxygen molecule. Fluosol-DA is a PFC-based blood substitute that can carry oxygen. Its emulsion contains 14% perfluorodecalin and 6% perfluorotripropylamine. However, its oxygen-carrying capacity is only 7.2% at 37°C, which is lower than RBCs [40]. Experimental studies using Flucosol-DA doses of 20–500 mL demonstrated no negative effects (side effects) on the heart, liver, kidneys, and hematological function [41]. However, one of the problems is the poor stability of this product, so it must be modified by other ingredients. In the presented work, we examined the effect of deficient PFD concentrations to assess the impact on individual physicochemical properties, which have been evaluated using various methods over the years. According to our results, achieving oxygen concentration in the blood substitute similar to natural blood requires using much higher PFC concentrations of PFCs. An example of a widely tested blood substitute is the Perftoran, which contains PFD and FMCP as the PFCs. However, its composition can be problematic and decrease the stability of the emulsion to approximately one month at 4–8°C, which is too short to be used as a blood substitute [42]. Thus, second-generation PFCs were developed to eliminate the problems of first-generation products, taking into account the nature and content of the fluorocarbons, which are 2 to 4 times higher in comparison to first-generation PFCs products. Also, they use natural phospholipids as an emulsifier instead of a water-soluble emulsifier and should be stored without freezing [43].

Blood is a stable suspension composed of plasma and solid substances with anti-adhesive properties. The circulatory system can be compared to the capillary system, and blood is classified as a non-Newtonian fluid with thixotropic and viscoelastic properties [44]. Blood viscosity depends on temperature, degree of hydration, number of blood cells, and the diameter of the vessel through which it flows. Viscosity is a fundamental property because it influences blood flow through blood vessels, thus the transport of oxygen and nutrients. The increase in viscosity may lead to the formation of clots and place a heavy burden on the heart muscle, causing cardiovascular diseases [45, 46]. The plasma solutions prepared using PFD are non-Newtonian, shear-thinning fluids with a viscosity similar to that of blood. However, these liquids are structurally different, and the rheological behavior of whole blood results from different phenomena. Human blood plasma is a Newtonian fluid with a viscosity of 1.2 mPa·s at 37°C. The presence of a second phase, mainly composed of RBCs, is responsible for the non-Newtonian behavior of whole blood [47]. RBC aggregation causes a significant increase in viscosity at low shear rates. Additionally, fibrinogen and globular proteins present in plasma promote RBC aggregation. Shear stress breaks up the RBC clusters bound by these proteins, resulting in reduced viscosity at higher shear rates. At even higher shear rates, only individual cells remain from the aggregates, which deform at critical shear rates above 100 1/s, leading to a further reduction in viscosity [48]. The artificial blood studied in this work is a two-phase composition of molecules without cellular elements. Shear-thinning arises from the agglomeration of molecules at lower shear rates, the breaking of these aggregates, and the formation of shear planes at higher shear rates, resulting in decreased viscosity [49]. Concurrently, short-lived clusters/inhomogeneities form due to the emulsive nature of the PFD-solutions in water, causing temporary increases in viscosity.

PFD, along with other elements in the plasma, are not soluble or only slightly soluble in water, thus necessitating proper emulsification. The decline in solution stability can be seen as a rise in solution viscosity at low shear rates, a change we noted after 28 days of incubation. The increase in viscosity caused by solution stability loss was noted in highly concentrated PFD solutions (34%) [50]. A potential remedy for emulsion instability is creating a nanoemulsion through ultrasonication with surfactants Tween 80 and (1H, 1H, 2H, 2H-perfluorooctyl)phosphocholine [51].

5. CONCLUSIONS

A vital impulse for developing artificial blood preparations is the need for an alternative form of patient treatment when traditional transfusion is impossible or involves risk. Moreover, these preparations may be used in rescue situations. The physicochemical and rheological properties of the tested perfluorodecalin-based preparations are similar to those of natural blood and should be safe for humans. The electrolytic conductivity changes over time due to the formation of complexes by ions in the solutions, but it is in the natural blood conductivity range. This means the prepared solutions allow the proper exchange of ions between blood and tissues, and PFD does not affect the values of this property—the surface tension increases with higher PFD content. The contact angle increases over time but is lower than θ = 90°, proving good wetting properties. The results demonstrate that perfluorodecalin is a neutral compound that does not significantly affect the tested properties of prepared blood substitutes but only increases the concentration of oxygen dissolved in them. These features are essential due to the use of perfluorodecalin in medicine as an oxygen carrier. The obtained results may encourage further experimental research by using higher concentrations of PFD oxygen carriers and other oxygen carriers to find any synergetic effects, aiming to develop a safe

oxygen-carrying agent that can be used by patients requiring this type of supportive therapy.

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