International Journal of Biomedicine 15(4) (2025) 741-745
http://dx.doi.org/10.21103/Article15(4)_OA16

ORIGINAL ARTICLE

Experimental Biology

INTERNATIONAL JOURNAL OF BIOMEDICINE

The Effect of Direct Electric Current on Some Parameters of Human Blood Coagulation

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Abstract

Background: Direct current (DC) is increasingly used in medical applications, yet its effects on blood plasma hemostasis remain underexplored. This study systematically examines the effects of DC exposure on key coagulation parameters and plasma pH, highlighting their potential physiological relevance and implications for electrotherapeutic strategies.

Methods and Results: The experiments used a pooled plasma sample from healthy donors, which was subjected to electrolysis using platinum point electrodes and a DC with a voltage range of 11-19 V. A number of parameters characterizing plasma hemostasis were measured to assess the coagulation process, including recalcification time, prothrombin time, thrombin time, activated partial thromboplastin time, international normalized ratio index, fibrinogen level, pH, and absorbed current strength. Experimental data showed that, with increasing current voltage during electrolysis, plasma coagulation time exhibits nonlinear changes, some parameters change significantly, and plasma hemostasis slows down beyond a certain current voltage threshold. The obtained data can be helpful for both therapeutic and other research in this field. (**International Journal of Biomedicine. 2025;15(4):741-745.**)

Keywords: plasma • hemostasis • fibrinogen • anticoagulant action

For citation: Galstyan AZ, Paronyan ZKh, Piloyan NS, Stepanyan HA, Poghosyan DA, Arakelyan LR, Seferyan TYe. The Effect of Direct Electric Current on Some Parameters of Human Blood Coagulation. International Journal of Biomedicine. 2025;15(4):741-745. doi:10.21103/Article15(4)_OA16

Abbreviations

aPTT, activated partial thromboplastin time; **FL**, fibrinogen level; **ISI**, international sensitivity index; **INR**, international normalized ratio; **PH**, plasma hemostasis; **PT**, prothrombin time; **RT**, recalcification time; **TT**, thrombin time.

Introduction

To maintain the fluid state of blood with optimal viscosity, the body has a special functional system that includes coagulation and anticoagulation mechanisms, which are normally in a state of balance (hemostasis). It is known that disruption of hemostasis leads to undesirable pathological conditions, such as bleeding or the formation of blood clots.

Currently, numerous studies examine the effects of various physical factors on blood physiological parameters. The effects of electric current on the body are used for various purposes, such as electrotherapy, electrocoagulation, muscle stimulators, oncotherapy methods, neuropsychology, and more.[1-5] It is known that electric current affects not only tissue cells but also tissue fluids, particularly blood. Hemostasis, one of the primary physiological indicators of blood, can be altered by electrical current, with significant physiological implications when used for therapeutic purposes. Its disruptions are particularly hazardous for patients with concomitant conditions such as cancer, infectious diseases, severe trauma, and diabetes mellitus.[6,7]

The effects of direct current (DC) on body tissues can be considered the result of simplified basic reactions and phenomena of electrolysis, such as electrode reactions, a reduction in calcium concentration in the medium, and the generation of free radicals.[8]

Electrolysis of a physiological buffer solution initiates chemical reactions. Combined both half-reactions in electrodes is: $2NaCl(aq)+2H_2O(l)\rightarrow H_2(g)+Cl_2(g)+2NaOH(aq)$

During the electrolysis of saline solutions, different compounds form (O_3, O_2, H_2O_2, HClO, $HClO_2$, ClO, ClO_2, Cl_2, H_2, HO_2^-, O_2^-, H^-, ClO^-, ClO_3^-, ClO_4^-, H^-, O^-, Cl^-, OH^-, HO_2^-, $^1O_2$, ClO^-, $O_2^{-\cdot}$).[9-11] These compounds may affect hemostasis.[12] Even the electrolysis of saline, which can be considered a simple model of blood electrolysis, has many reactions.

Since Scudamore's work in 1824,[13] the effect of DC on blood coagulation has been a subject of inquiry. Hayashi[14] reviewed all relevant studies conducted between 1824 and 1964. His paper notes that Schwartz[15] found that applying a DC of 4.5 V and 5 mA for 1 hour induced thrombus formation in the superficial femoral vein of dogs. Kravitze and Wagner [16] demonstrated that a DC of 12 to 16 mA applied for 7 to 10 minutes typically resulted in coagulation on diffusely bleeding surfaces. Hayashi also reported that applying 6 V and 4 to 4.5 mA of positive DC for 9 to 12 minutes initiated thrombus formation in the mesenteric plexus blood vessels of rabbits.

Recent studies have shown that DC prolongs coagulation time and acts as a non-chemical anticoagulant.[17-19] Until now, existing studies have not systematically examined the dynamic changes in hemostasis parameters under the influence of electric current at different exposure time doses. Based on the above considerations, this study aimed to investigate the effects of DC on the main indicators of PH, including prothrombin time (PT), international normalized ratio (INR), activated partial thromboplastin time (aPTT), thrombin time (TT), recalcification time (RT), fibrinogen level (FL), and plasma pH. It is known that the pH of the medium is crucial for hemostasis; even a minor change of 0.5 can alter the timing of thrombosis by more than 25%.[19] The current intensity (mA) required for these effects was also examined.

Plasma hemostasis is part of the overall hemostatic system, which includes a cascade of protein reactions in blood plasma and is closely related to the vascular-platelet interaction and the anticoagulant system. Since the traumatic factor of hemostasis change is not present in the case of electric current exposure, it is not considered in this work.

Materials and Methods

Human plasma was obtained from the Hematology Center named after Prof. R. Yeolyan (Yerevan, Armenia). The purchase was conducted through an open sale transaction. Samples were collected in PVC bags and remained unexposed to any freeze–thaw cycles. CPDA-1 (citrate-phosphate-dextrose; RAVIMED, Poland) was used as the anticoagulant.

Plasma samples were collected from 10 healthy donors (5 men, 5 women) aged 18–50 years. No personal information was provided beyond sex and age. Equal volumes of individual plasma samples were pooled to create a composite sample. Each experiment was performed in 6 replicates.

Thromboplastin with ISI of 1.75 was obtained from Delta LTD (Armenia).Thrombin time reagents were obtained from RPA 'RENAM' (Russia). aPTT-Kaolin set was produced by BIOLABO (France).

Electrolysis and pH Measurement

Plasma electrolysis was performed using a custom electrolytic chamber consisting of a cylindrical glass cup (total volume of 15 mL) sealed with a cap housing 2 platinum dot electrodes (Gomel, Belarus) spaced 15 mm apart. A DC power supply with precise voltage regulation was connected to the electrodes. During electrolysis, the chamber was placed on a magnetic stirrer operating at low speed (30 rpm).

A volume of 4 mL of pooled plasma was placed in the electrolysis cell. DC ranging from 11 to 19 V was applied for 10 minutes. For recalcification analysis, electrolysis was performed at 11, 13, 15, 17, and 19 V. For other hemostasis parameters, voltages of 11, 15, and 19 V were used. pH and current measurements were conducted across a voltage range of 11, 13, 15, 17, 19, and 24 V. No electrolyzed plasma pool was used as a control.

The pH values of plasma were measured using a Hanna HI2002-01 pH/ORP meter (Hanna Instruments, USA). To determine the dependence of plasma pH on the duration of electrolysis, the measurement was performed directly on the electrolyzed plasma at room temperature.

Consumed power was measured using a multimeter connected in series with the electrolysis circuit. Electric current was recorded at one-minute intervals throughout the 10-minute electrolysis period at applied voltages of 11, 13, 15, 17, 19, and 24 V.

Biochemical Methods

Plasma coagulation effectiveness was measured using clot-based tests, such as RT,[20] PT/INR,[21] TT, aPTT, and FL.[22] Hemostasis parameters (RT, PT, INR, TT and aPTT) were measured using a biochemical analyzer STart Max (Stago, France).

Prothrombin time was measured using thromboplastin with an ISI of 1.75. Electrolyzed and control plasma samples were preincubated in a water bath at 37°C for 4 min. Thromboplastin was added with fast stirring, and the time was measured until fibrin filaments were observed.[23] International normalized ratio (INR) was calculated using the following formula:[21]

$$INR = \left(\frac{PT\ exp.}{PT\ control}\right)^{ISI}$$

where "PT exp." and "PT control" are prothrombin time for electrolyzed and control plasma, respectively, and ISI is the International Sensitivity Index of Thromboplastin (provided with the reagent).

For TT assay, plasma was prewarmed for 3 minutes in a 37°C water bath. The TT detection reagent ("RENAM" RPA, Russia) was prepared according to the manufacturer's instructions and added to the electrolyzed and control plasma samples. Coagulation time was measured after the addition of the thrombin reagent.

aPTT was measured using the BIO-CK aPTT-Kaolin kit (BIOLABO, France). The reagent was prepared according to the manufacturer's instructions, prewarmed to 37°C, and added to the plasma. After 3 minutes of incubation at 37°C in a water bath, 0.227% $CaCl_2$ was added, and the coagulation time was measured.

For recalcification measurement, plasma samples were mixed with 5% $CaCl_2$ (in ratio 10:1) and incubated at room

temperature without any activating factors. Coagulation time was measured from the time of $CaCl_2$ addition.

The level of fibrinogen was measured by a slightly modified gravimetric method, described in Saxena.[24] Briefly, clots were carefully removed from plasma samples after recalcification assay, compressed to expel residual plasma and reagents, thoroughly dried using filter paper, and weighed on an analytical balance.

Statistical Analysis

The results are reported as the mean ± standard error of the mean (SEM). Data were analyzed using one-way ANOVA with GraphPad Prism v.9.3 (GraphPad Software Inc., La Jolla, CA, USA). Statistical significance is indicated as follows, * - $P \leq 0.05$, ** - $P \leq 0.01$, *** - $P \leq 0.001$, and **** - $P \leq 0.0001$.

Results

Plasma hemostasis is necessary to maintain the normal fluid state of the blood and effectively stop bleeding. To obtain information on overall blood coagulation, the RT determination method was used, which correlates with the total clotting time.

Preliminary studies have shown that increasing the applied DC voltage did not result in significant changes in RT within the studied range (Figure 1A). Further studies focused on evaluating the dependence of the investigated parameters on voltage variation. When recording the RT, it was observed that as the current voltage increased during electrolysis (11–15 V), the RT initially decreased slightly (by 4.5%); a further increase in voltage (19 V) resulted in a twofold increase (by 104.2%) (Figure 1B). This suggests that within a specific voltage range, the plasma coagulation system is partially activated, but higher voltages can damage coagulation factors or alter the plasma pH, slowing down coagulation.

We found that as the current voltage increased, the rate of fibrin formation from fibrinogen decreased (from 44.2% to -62%) (Figure 1C). These changes may be the reason for the decrease in thrombin activity or structural changes in fibrinogen.

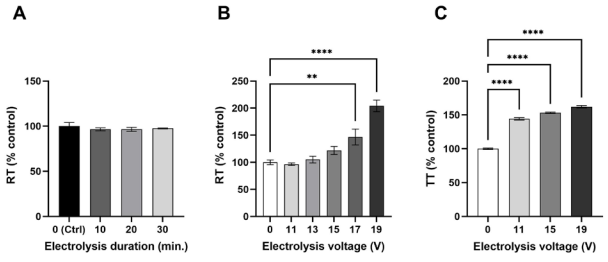

Fig. 1. *The effect of electrolysis on RT for 11V 0-30min (A), RT (B), and TT (C). Data are normalized to control and presented as the mean ± SEM, n=6. *P<0.05; **P<0.01; ***P<0.001; ****P<0.0001*

One of the important laboratory parameters characterizing the state of the blood coagulation system is PT, which is used to assess the activity of the extrinsic pathway of blood coagulation and the deficiency of factors II, X, VII, and V. Initially, PT was slightly reduced (11 V) (Figure 2A), possibly due to mild activation, but at 15 V and especially at 19 V it increased significantly, by 11% and 42.8%, respectively. This indicates the possibility of inhibiting the extrinsic pathway of blood coagulation or decreasing the activity of factors under the influence of high voltage.

Along with PT, aPTT is an essential indicator for monitoring coagulation processes (both the extrinsic and intrinsic pathways). A significant increase in aPTT (Figure 2B) during electrolysis (38.3%) at high voltages (19 V) indicates a disruption of the intrinsic coagulation pathway, which may be due to a deficiency of coagulation factors I, II, V, VII and X, as well as prekallikrein or one of the intrinsic coagulation pathway factors (VIII, IX, XI and/or XII), which may occur as a result of electrochemical reactions during electrolysis or as a result of change in pH.

The INR at 11V decreased to 0.79, which may indicate a temporary increase in prothrombin activity or partial stimulation of the coagulation system. At 15 V, the INR increased to 1.21, and at 19 V, it increased to 1.88, indicating a slowdown or disruption of the extrinsic coagulation pathway (Figure 2C).

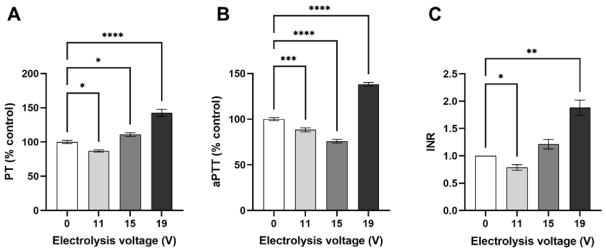

Fig. 2. *The effect of electrolysis on PT (A), aPTT (B), and INR (C). Data are presented as the mean ± SEM, n=6. *P<0.05; **P<0.01; ***P<0.001; ****P<0.0001. For PT and aPTT data, the values are normalized to the control.*

It is believed that high voltage during electrolysis can oxidize or inactivate some components of the prothrombin complex, weakening the coagulation process. When studying FL, we found that at 11 V, it decreased by 18.8%, which may be associated with fibrinogen degradation or structural changes. However, at voltages of 15 V and 19 V, FL increased by 13.6% and 23.1%, respectively (Figure 3A).

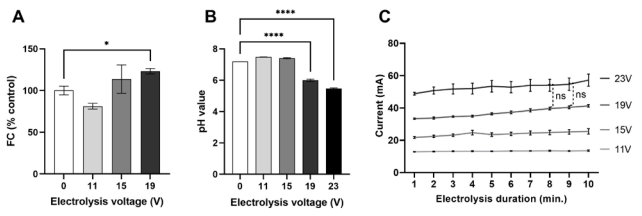

Fig. 3. *The effect of electrolysis on FL (A) and pH of plasma (B). FL is normalized to control. (C) shows power consumption during the electrolysis at different voltages. Data are presented as the mean ± SEM, n=6. *P<0.05; **P<0.01; ***P<0.001; ****P<0.0001. For (C), all differences between groups are significant except marked as "ns."*

Given the importance of pH in coagulation reactions, the possible change in pH under DC influence was observed. The pH at 11 V and 15 V shows a relative increase of 0.278 and 0.206, respectively, (Figure 3B) and at 19 V a decrease of 1.73 points, reaching 5.998. To further examine the trend in the pH indicator change, the pH indicator was also observed at 23 V, registering a lower value than those recorded at 19 V (5.462). The obtained data indicate that under the influence of electrolysis, an intensive formation of acidic or basic substances occurs, leading to disruption of the acid-base balance and exceeding the plasma's buffering capacity.

In plasma electrolysis, water is decomposed, producing hydrogen and hydroxide ions that can alter the pH balance. Plasma contains buffer systems (e.g., bicarbonate), but their ability to neutralize pH changes is limited.

Electrolysis can produce carbonic acid from carbon dioxide dissolved in water, which itself is a weak acid. Still, during intensive hydrolysis, its concentration increases, and the system becomes overloaded, which, in blood plasma, can lead to a rise in acidity and slow down the blood clotting process, especially at high voltages.[19,25]

To assess the possible correlation between the obtained data and the energy introduced into the electrolytic system and the dynamics of energy absorbed by the system, amperometric recordings of plasma electrolysis were also performed (Figure 3C). The obtained data indicate that the current in the system increases proportionally with voltage, showing a slight increase over time, reaching a maximum of 8.4 mA at 23 V. Large amperometric values and the most significant changes in the obtained indicators characterizing hemostasis are observed mainly at high voltages.

Discussion

The effect of electrolysis on the blood coagulation system has not been sufficiently studied. Our results show that changes in current voltage during electrolysis can affect hemostasis mechanisms in different ways, causing both coagulant and anticoagulant effects. The results also indicate that DC can directly affect the main PH parameters.

In electrolysis at a moderate current (up to 15 V), a slight increase in pH was observed. In contrast, at high voltages (19 V), prolonged clotting time, increased INR, increased FL, and significant changes in the intrinsic and extrinsic coagulation pathways were observed. These effects likely result from pH changes during electrolysis or from reduced activity of some coagulation factors due to the electrochemical effects. An increase in FL resulting from electrolysis, along with a rise in INR, may indicate activation of hemostasis in response to plasma damage. The INR measures the efficiency of the extrinsic coagulation pathway, and its increase may indicate a reduced activity of coagulation factors. Fibrinogen, a key component of the thrombus, may increase as part of a protective mechanism to sustain thrombus formation.[26] When low-voltage DC electricity is applied, ionized calcium, an essential element in blood coagulation, is absorbed by the negative electrode. In contrast, most blood proteins, including coagulation factors that are negatively charged at normal blood pH, can be adsorbed onto the positive electrode.[27,28] Calcium is a vital cofactor for many coagulation factors, while blood pH significantly affects the concentration of ionized calcium and the function of these factors. In acidosis, hydrogen ions displace calcium from proteins, increasing the ionized calcium concentration. Changes in calcium ion concentration can affect the activation of coagulation factors, and changes in protein concentration can affect their capacity to form clots. Conversely, as the intensity of plasma electrolysis increases, the pH decreases, creating an acidic environment that disrupts the function of enzymes and other proteins involved in hemostasis.[29]

Acidity affects the activity of clotting factors and can impair fibrinolytic activity; together, these effects create an imbalance that may increase the risk of both bleeding and thrombosis, depending on the degree and nature of the disorder.

The data indicate that, at low voltages, the examined blood plasma parameters—except TT—tend to decrease, whereas at higher voltages they increase. This suggests that plasma can resist the effects of the applied current up to a specific limit, beyond which all parameters increase along with voltage and current strength. The obtained data can be helpful for both therapeutic and other research in this field.

Sources of Funding

This work was made possible by a research grant from the Armenian National Science and Education Fund (ANSEF) based in New York, USA (hubio-3936).

Competing Interests

The authors declare that they have no competing interests.

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