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Electrical resistance of gels and liquids used in electrotherapy for electrode-skin coupling

Resistência elétrica dos géis e líquidos utilizados em eletroterapia no acoplamento eletrodo-pele

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Abstract

Objective: To evaluate the initial and ongoing electrical resistance of different coupling agents used in the skin-electrode interface. The agents were submitted to electrical stimulation with biphasic and direct currents. **Methods:** The electrical resistance was calculated indirectly by Ohm's Law. The tension was generated by a constant current generator (10 mA, 100 Hz, 100 µs and symmetrical biphasic square pulse) and captured by a digital oscilloscope. Ten coupling agents (gels, n=5; liquids, n=5) were submitted to electrolysis with symmetrical biphasic square current (BC), 0.0134 mA/mm^2, 100 Hz, 100 µs or with direct current (DC) at 0.0017 mA/mm^2 for 30 minutes, being reassessed every 5 minutes. For data analysis the Friedman and Kruskal-Wallis tests were applied, followed by the rank test and the Dunn test respectively. Also, Spearman's coefficient test was used for correlation analysis (α=0.05). **Results:** The initial resistance values of the gels varied between 116.00 and 146.00 Ω and of the liquid coupling agents, between 106.00 and 4726.67 Ω, with mostly positive correlation with the time of electrolysis. **Conclusions:** We concluded that gels, drinking water and saline solution are recommended for the practice of therapeutic electrical stimulation because they maintain low resistance during stimulation. In contrast, the use of distilled or deionized water is not recommended due to the high resistance to the passage of electrical current.

Key words: electrical resistance; electrolytes; electrical stimulation.

Resumo

Objetivo: Avaliar a resistência elétrica inicial e no decorrer do tempo de agentes de acoplamento utilizados na interface eletrodo-pele submetidos a estimulação elétrica com corrente bifásica e corrente contínua. **Métodos:** A resistência elétrica foi calculada indiretamente pela Lei de Ohm, sendo a tensão elétrica gerada em um equipamento de corrente constante (10 mA, 100 Hz, 100 µs e pulso bifásico quadrado simétrico) e captada por um osciloscópio digital. Dez agentes de acoplamento (géis, n=5; líquidos, n=5) foram submetidos à eletrólise com corrente bifásica quadrática simétrica (CB), 0,0134 mA/mm^2, 100 Hz, 100 µs ou com corrente contínua (CC) a 0,0017 mA/mm^2 de densidade de corrente, durante 30 minutos, sendo reavaliados a cada 5 minutos. Para análise dos dados, aplicaram os testes de Friedman e Kruskal-Wallis, seguidos de Rank e Dunn, respectivamente, e, para a correlação, empregou-se o coeficiente de Spearman (α=0,05). **Resultados:** Os valores iniciais de resistência dos géis variaram entre 116,00 e 146,00 Ω, e dos agentes de acoplamento líquidos, entre 106,00 e 4726,67 Ω, apresentando, em sua maioria, correlação positiva com o tempo de eletrólise. **Conclusões:** Conclui-se que os géis, a água potável e a solução fisiológica são os indicados para a prática da estimulação elétrica terapêutica, pois mantêm a baixa resistência durante o período de estimulação. Por outro lado, o uso de água destilada ou desionizada não é recomendado, pois apresentam alta resistência à passagem da corrente.

Palavras-chave: resistência elétrica; eletrólitos; estimulação elétrica.

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Introduction

Technological advances in the field of electrical signal transmission and reception for therapeutic or diagnostic purposes and its growing application in health emphasize the need to evaluate the products used in these procedures[1,2] and the electrical resistance of the biological tissues[3]. In this context, coupling agents deserve special attention because they establish contact between the surface electrode and the patient and can influence the results of the procedure[4]. In spite of the assumption that the magnitude of the opposition to the electrical current may affect comfort during therapy, the selection of coupling agents and their behavior during the passage of the electrical stimulus have not been investigated in depth, and it can be considered that the passage of therapeutic electrical currents through the different coupling media may change the electrical resistance. Furthermore, there is a concern with the safety and efficacy of the treatment, given the frequent misuse of coupling agents, e.g. using deionized water in iontophoresis, which denounces lack of training and knowledge on the subject. Thus, the objective of this study was to assess the initial electrical resistance and the resistance over time of the coupling agents (gels and liquids) used at the electrode-skin interface and submitted to electrical stimulation with a biphasic current (BC) and a direct current (DC).

Methods

We analyzed ten coupling agents that can be applied to the electrode-skin interface in clinical practice and in scientific research in physical therapy. We selected the five best-selling industrial gels (G1, G2, G3, G4 and G5) in the area and the following liquids: saline solution (SF), drinking water (A1), mineral water (A2), distilled water (A3) and deionized water (A4). Saline solution is used in the coupling of electrodes to treat skin ulcers, while deionized water and distilled water are used in iontophoresis (Table 1). To avoid possible changes in the physical and chemical properties and to standardize

Table 1. Identification of the commercial name, composition and manufacturer of the assessed coupling agents.

Group	Name	Composition	Manufacturer (Address)
G1	Sonic® Gel	Deionized water, carbon-polymer, coloring, W6007, triethanolamine, phenoxyethanol, glycerin, methyldibromo glutaronitrile	Fisio Line® Cosméticos Ind. e Com Ltda. (Rua João Francisco de Oliveira, 416, Distrito Industrial Unileste, Piracicaba, SP)
G2	RMC® Clinical Gel (Clear)	Carboxyvinyl polymer, imidazolidinyl urea, methylparaben, coloring, 2-amino-2-methyl-1-propanol (AMP), deionized water	Unigel – Indústria Brasileira de Produtos Médicos Ltda. (Rua Prof. Horácio Quaglio, 138, Jd. América, Amparo, SP)
G3	RMC® Clinical Gel (Blue)	Carboxyvinyl polymer, imidazolidinyl urea, methylparaben, coloring, 2-amino-2-methyl-1-propanol (AMP), deionized water	Unigel – Indústria Brasileira de Produtos Médicos Ltda. (Rua Prof. Horácio Quaglio, 138, Jd. América, Amparo, SP)
G4	Gel Carci®	Carbon-polymer, triethanolamine, sorbitol, nipagin, QS 100, benzene-free.	Pointer Química Industrial Ltda. (Rua Prof. Nelson de Senna, 482/486, São Paulo, SP)
G5	Carbogel®	Sterile water, carboxyvinyl polymer, thickener, preservative and chelating agent.	Carbogel Ind. Com. Ltda. (Rua Itapirú, 241, Saúde, Zona Sul, São Paulo, SP)
SF	Sidepal® Saline Solution	Distilled water q.s., sodium chloride 0.9%	Sidepal Indl. e Coml. Ltda. (Av. Nova Cumbica, 920/ 930, Cumbica, Guarulhos, SP)
A1	Drinking water[A]	Chlorides 6.0ml/L; pH 8.04.	Tube well (Taquaral Campus, Universidade Metodista de Piracicaba, Piracicaba, SP)
A2	Crystal® Spal – natural mineral water[B]	Chlorides 3.0ml/L; pH 7.2; Na 35.0ml/L; K 3.4ml/L.	Spal Ind. Brasileira de Bebidas S/A. (Fonte Ycuara - Av. Francisco Ferreira Lopes, 4303, Mogi das Cruzes, SP)
A3	Distilled water[B]	Chlorides 3.0ml/L; pH 6.1; Na 2.4ml/L; K 0.4ml/L.	Biochemistry and Instrument Analysis Lab, Agroindustry, Food and Nutrition Department (Escola Superior de Agricultura "Luiz de Queiroz", Universidade de São Paulo, Piracicaba, SP)
A4	Deionized water[B]	Chlorides 2.0ml/L; pH 5.7; Na 0.1ml/L; K 0.0ml/L.	Biochemistry and Instrument Analysis Lab, Agroindustry, Food and Nutrition Department (Escola Superior de Agricultura "Luiz de Queiroz", Universidade de São Paulo, Piracicaba, SP)

[A] Analyzed by Hidrolabor Laboratório de Controle de Qualidade Ltda. Sorocaba, SP; [B] Analyzed by Laboratório de Ecologia Aplicada – ESALQ – USP. Piracicaba, SP.

the samples, the expiry dates of all products were checked and the manufacturer's storage instructions were followed, i.e. the products were kept at room temperature and away from light. Besides the precautions with storage, the liquid agents (A1, A2, A3 and A4) underwent laboratory analyses to determine their composition and for comparison with other studies and methodologies.

A system was developed to measure the electrical tension of the coupling agents and included a digital oscilloscope (TDS 210 - Tektronix®), an electrical current generator with constant intensity (Dualpex 961®, Quark®), a 100 Ω ceramic resistance, arranged in series in the channel output, and two metallic electrodes. One of the electrodes was glued to a PVC ring (38mm in diameter and 4mm in height) into which the coupling agent was introduced. The circuit was closed with another electrode on which a constant force of 5.0 N was applied to standardize the coupling. Figure 1 shows the measurement system, the area where the coupling agent was placed and exemplifies one of the electrolysis protocols with the DC generator.

During the evaluation of the electrical current, a BC was emitted with a symmetrical square pulse, 10 mA intensity, 100 Hz frequency and 100 μs phase duration. The instant values of the electrical current observed in the oscilloscope were collected, and based on these values, the electrical resistance was indirectly calculated by applying Ohm's law (U=R x i; U=electrical tension, R=resistance and i=intensity). After measuring the initial resistance, all the coupling agents were submitted to a process of electrolysis, which consisted in applying a DC emitted by an electrical generator (Dialpulsi® 990, Quark®) with 2 mA intensity equivalent to a current density of 0.0017 mA/mm^2 for 30 minutes. Coupling agents G1, G2, G3, G4 and G5 were also submitted to the passage of a BC with symmetrical square pulse, 100 Hz frequency, 100 μs phase duration and 16 mA current intensity equivalent to a current density of 0.0134 mA/mm^2 for 30 minutes. The current densities correspond to those used in clinical practice. During the procedures, the electrical resistance of the coupling agent was evaluated every five minutes, and the mean of three consecutive measurements was used for each stimulation time (T0, T5, T10, T15, T20, T25 and T30).

Five 4-mL samples of each coupling agent were analyzed. With every new sample, the electrodes were washed with a sponge and running water to remove the residue from the electrolysis and then rinsed three times with deionized water if the next substance to be tested was a gel that contained deionized water in its original composition. Otherwise, the electrodes were rinsed with the next solution to be analyzed (saline solution, drinking water, mineral water, distilled water or deionized water) and dried with absorbent paper. The sequence of the analyses was randomized by draw, both intra and intergroup, to reduce the influence of the cleansing process on the results. All collections were carried out at room temperature (23±2 °C) and humidity of 70±2%.

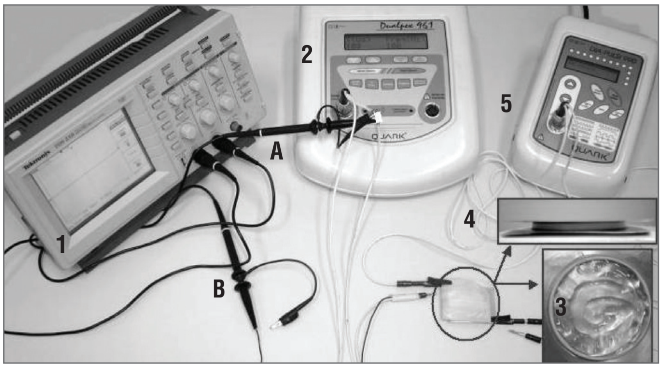

Figure 1. Measurement system of the coupling agents' electrical impedance, composed of a digital oscilloscope (1), a biphasic current generator (2), 100 Ω resistance (arrow), metal electrodes + coupling agent (overhead view – 3 and side view – 4) and direct current generator (5). (A) Monitoring of applied current and (B) reception of electrical tension.

The Shapiro-Wilk normality test was applied to all variables being analyzed, and the Friedman test with post hoc Wilcoxon signed rank test was also carried out to compare the electrical resistance values for each stimulation time. In the comparisons between the different coupling agents and between the BC and DC, we applied the Kruskal-Wallis test followed by Dunn's method. The relationship between the resistance value and the electrical stimulation time was established by Spearman's coefficient. All tests were processed in the BioEstat 4.0 software, considering $p<0.05$.

Results

Different substances, times and electrical currents were considered in the analysis of the electrical resistance of the coupling agents. Table 2 shows the results of the group of gels stimulated with DC and BC and the results of the comparisons between both procedures. In the first case, there was an increase in the resistance at T30 compared to T0 and T5 for all gels, except G3; at T25 compared to T0 for G1, G4 and G5 and compared to T5 for G5; and at T20 compared to T15 for G3. In the comparison between the different gels at the same stimulation time, a higher resistance was detected for G1 compared to G3 and G2, at every stimulation time, except T30 for G2. G5 also had higher values than G2 at every stimulation time and higher than G3 from T10 onwards. When applying a BC to the same gels, there was a change at T25 and T30 compared to T0 for G5. When all gels were compared at the same stimulation time, G1 had a higher resistance than G2 and G3 at every stimulation time. In the comparison between the effects of the BC and DC

Table 2. Median values of electrical resistance (Ω) of different coupling agents (gels) during electrolysis with direct current (DC) and with biphasic current (BC).

		T0		T05		T10	
		DC	BC	DC	BC	DC	BC
G1	MD	140.00	142.00	144.00	144.67	148.00	143.33
	IQI	6.67	7.33	4.00	4.00	6.67	4.00
G2	MD	120.00•	117.33•	120.00•	116.00•ϕ	124.00•	117.33•ϕ
	IQI	0.00	2.00	0.00	1.33	4.00	1.33
G3	MD	120.00•	118.00•	120.00•	117.33•	121.33•	117.33•
	IQI	5.33	0.67	2.67	1.33	2.67	0.67
G4	MD	132.00	134.00	132.00	132.00	132.00	132.00
	IQI	4.00	6.00	2.67	5.33	4.00	5.33
G5	MD	140.00∅	132.00	140.00∅	133.33ϕ	144.00∅º	134.00ϕ
	IQI	8.00	0.00	6.00	2.00	8.66	0.00

		T15		T20		T25		T30	
		DC	BC	DC	BC	DC	BC	DC	BC
G1	MD	160.00	146.00ϕ	176.00	143.33	188.00*	146.00ϕ	205.67*#	144.67ϕ
	IQI	12.00	2.67	8.00	6.67	0.67	3.33	12.00	3.33
G2	MD	124.00•	116.00•ϕ	124.00•	117.33•ϕ	125.33•	116.00•ϕ	126.67*#	116.67•ϕ
	IQI	4.00	0.00	0.00	1.33	1.33	2.00	4.00	1.33
G3	MD	120.00•	116.00•	124.00∇•	116.67•ϕ	124.00•	118.00•ϕ	124.00•	117.33•ϕ
	IQI	4.00	2.00	4.00	1.33	4.00	2.00	0.00	1.33
G4	MD	136.00	130.00	140.00	130.00	140.00*	130.00ϕ	144.00*#	130.00ϕ
	IQI	8.00	4.00	8.00	4.00	8.00	6.00	4.00	6.00
G5	MD	160.00∅º	134.00ϕ	174.00∅º	134.00ϕ	190.67*#∅º	135.00*ϕ	217.30*#∅º	134.00*ϕ
	IQI	24.67	2.67	18.67	1.67	26.67	2.00	28.00	3.33

*p<0.05 to corresponding T0; #p<0.05 to corresponding T5; ∇p<0.05 to corresponding T15; •p<0.05 to corresponding G1; ∅p<0.05 to corresponding G2; ºp<0.05 to corresponding G3; ϕp<0.05 to corresponding DC; G1=Sonic®; G2=RMC® (clear); G3=RMC® (blue); G4=Carci®; G5=Carbogel®; T=stimulation time (minutes); MD=median; IQI=interquartile interval. n=5.

on the electrical resistance of the gels, DC had higher values for all groups at T25 and T30; for G1, G2, G3, and G5 at T20; for G1, G2 and G5 at T15; and for G2 and G5 at T10 and T5.

Table 3 shows the results of the electrical resistance of the liquid coupling agents (saline solution, drinking water, mineral water, distilled water, and deionized water) during electrolysis with a DC. In the intragroup comparison, there were higher values at T30 and T25 compared to T0 for A1, A2 and A3; at T20 compared to T0 for A1; at T30 compared to T5 for A1, A2 and A3; and at T25 compared to T5 for A3. The resistance of the saline solution (SF) did not change over time. In the intergroup comparison, there was lower resistance at every stimulation time for SF compared to A2 and A3 and for A1 compared to A3, at the respective times. Deionized water had a great internal variation in electrical resistance, therefore it was not compared with the other coupling agents. In the intragroup comparison, no significant changes were observed in its resistance over time.

In the correlation between the electrical resistance values of the coupling agents and the stimulation time using DC, there were positive results for all gels and for A1, A2 and A3. Conversely, when BC was used, this correlation was only positive for G5, as shown in Table 4.

Discussion

Given the importance of the studies that reproduce clinical conditions without compromising methodology,

Table 3. Median values of the electrical resistance (Ω) of different coupling agents (liquids) during electrolysis with direct current.

		T0	T05	T10	T15	T20	T25	T30
SF	MD	106.00	110.00	124.00	108.00	108.00	108.00	110.00
	IQI	0.00	9.33	10.67	2.00	8.00	4.00	4.00
A1	MD	150.00	160.67	174.00	192.00	213.33*	229.33*	244.00$^{*\#}$
	IQI	2.00	1.33	4.00	4.00	12.00	17.34	24.00
A2	MD	228.00$^{\varnothing}$	264.00$^{\varnothing}$	288.00$^{\varnothing}$	356.00$^{\varnothing}$	432.00$^{\varnothing}$	536.00$^{*\varnothing}$	650.67$^{*\#\varnothing}$
	IQI	4.00	20.00	12.00	12.00	80.00	32.00	74.67
A3	MD	648.00$^{\varnothing\nabla}$	746.67$^{\varnothing\nabla}$	1113.33$^{\varnothing\nabla}$	1500.00$^{\varnothing\nabla}$	1853.33$^{\varnothing\nabla}$	1913.33$^{*\#\varnothing\nabla}$	1973.33$^{*\#\varnothing\nabla}$
	IQI	40.33	69.33	512.67	66.67	66.67	1700.00	2753.33
A4	MD	4726.67	3880.00	3413.33	3563.67	4026.67	3493.33	2613.33
	IQI	480.00	1146.67	2140.00	3093.33	2420.00	3326.67	3900.00

$^{*}p<0.05$ to corresponding T0; $^{\#}p<0.05$ to corresponding T5; $^{\varnothing}p<0.05$ to corresponding SF; $^{\nabla}p<0.05$ to corresponding A1. SF=Sidepal® saline solution; A1=drinking water; A2=Crystal® Spal mineral water; A3=distilled water; A4=deionized water; T=stimulation time (minutes); MD=median; IQI=interquartile interval. n=5.

special attention was given to: (1) the maintenance of uniform contact during the measurement of the resistance and the passage of the electrical flow[1] and; (2) the release of a current density that was compatible with clinical levels, i.e. below 0.0050 mA/mm^2 when applying DC[5] and between the sensitivity and motor thresholds when applying BC, because in this case the intensity of the maximal current depends on the aim of the treatment[6-8]. The concern about the effective transmission of the electrical current to the patient is emphasized in the literature[4], however most studies on coupling agents focus on the determination of their acoustic impedance, which is relevant in the application of therapeutic ultrasound[9,10], and on their influence on the production of noise during the collection of biological signals[2]. Only one study[1] provided specific references concerning the assessment of the resistance of coupling agents using the passage of the electrical stimulation, and it limited itself to comparing the data obtained by presuppositions described in textbooks. The lack of studies, in spite of the importance of considering the influence of the coupling agent during the therapy, was a crucial factor in the decision to carry out the present study.

The values of the electrical resistance of the gels showed that all of them were efficient in transmitting an electrical current due to the presence of one or more ionizing agents, i.e. methyldibromo glutaronitrile, carbon polymer (sodium carboxymethyl cellulose), methylparaben, the chelating agent, among others. The differences observed are probably related to the concentration of these components according to the manufacturer, because the greater the amount of ions, the lower the opposition to the electrical current[11].

Table 4. Correlation between electrical resistance values (Ω) of the coupling agents and the stimulation time with biphasic current (BC) and with direct current (DC).

	DC		BC	
	R	P	R	P
G1	0.9442	<0.0001	0.1375	0.4310
G2	0.6452	<0.0001	-0.0038	0.9826
G3	0.3639	0.0316	-0.0968	0.5801
G4	0.6385	<0.0001	-0.2743	0.1107
G5	0.9190	<0.0001	0.4327	0.0094
SF	0.1004	0.5660		
A1	0.9317	<0.001		
A2	0.9779	<0.001		
A3	0.8374	<0.001		
A4	-0.0191	0.9133		

G1=Sonic®; G2=RMC® (clear); G3=RMC® (blue); G4=Carci®; G5=Carbogel®; SF=Sidepal® saline solution; A1=drinking water; A2=Crystal® Spal mineral water; A3=distilled water; A4=deionized water. n=5.

In practice, the low resistance offered by the clear and blue RMC® gels could determine a more comfortable stimulation, especially in sensitive patients[12] or tissues with higher impedance, as occurs with low frequency currents or greater distance between electrodes[3].

The maintenance of the values during the time of stimulation with a BC reinforces the application of gels with this type of current. The increase in the resistance of the Carbogel® after

25 minutes may be due to less stability after longer periods of stimulation. This reduced stability is confirmed by the early premature change with the DC compared to the other gels.

The significant variations in the resistance of the gels when stimulated by the DC were expected due to its uninterrupted and unidirectional transmission, which speeds up electrolysis[5]. Nonetheless, this change did not occur at the same stimulation time for all products, which indicates that the differences in their formula change the susceptibility to the ionizing action. An example of this is the behavior shown by the clear and blue RMC® gels. Despite the same composition and possibly the same concentration of ionizing agents, in the clear gel the difference between the resistance values occurred earlier when comparing both stimulating procedures. In this case, it can be suggested that the blue coloring provided greater stability during electrolysis.

Likewise, most liquid coupling agents had an increased resistance over time with DC stimulation. This change began at T20 for drinking water and at T25 for mineral water and distilled water due to the higher electrical conductivity of the former, possibly explained by its greater ionic concentration as seen in the physical-chemical analysis. The lack of variation in the electrical resistance of the saline solution and the deionized water reflects the extreme ionic concentrations of these substances. It is believed that, due to the high ionic concentration in the saline solution, the stimulation time was insufficient to separate the ions to the point of changing their resistance. In contrast, electrolysis was less evident in the deionized water because of its low ionic concentration. The lower resistance and greater stability of the saline solution make it the ideal agent to soak the sponges in treatments with DC. The second option is drinking water, because it showed no difference in electrical resistance compared to the saline solution and it had the least intragroup variation compared to mineral water and distilled water. The use of drinking water instead of distilled water is also advocated by Robinson[13].

Starkey[12] reported no differences between the electrical resistance of hydrosoluble gels and drinking water, considering that the option between them must be in accordance with the electrode employed in the stimulation. The data obtained in the present study indicated that this was only applicable to one gel (Carbogel®), which prevents the generalization of the results to the other products. However, we endorse the author's claim that the chemical properties of the gels allow prolonged use with little decomposition associated with current flow or evaporation given the later alterations in their electrical resistance values. In contrast, Alon, Kantor and Ho[1] observed that the combination of silicon-carbon electrodes and gel results in a better conduction of the electrical current than the combination of the same electrode and a water-soaked sponge, but the distribution of the current was more uniform in the latter and required further investigation.

As with distilled water, it should be noted that deionized water is contraindicated for the transmission of electrical currents. Its high resistance is related to the low concentration of ions in such solutions. Under these conditions, their application might increase discomfort and reduce the efficacy of the treatment with an electrical current. However, they can be used in therapies with ionized pharmaceuticals, particularly to increase electrostatic repulsion[14,15].

In general, it can be concluded that the coupling agents differ in relation to electrical resistance that gradually increases when submitted to electrolysis. Among the gels analyzed, the blue RMC® was the least resistant initially and remained so over time. The saline solution and the drinking water were the best coupling agents to soak the sponges, because they offered the least opposition to the electrical flow. The electrical resistance of the saline solution remained unchanged throughout the electrolysis, which indicates greater electrical stability compared to the other agents. The use of distilled or deionized water is not recommended because of their high resistance to the passage of the electrical flow, except when their application could benefit the repulsion of the therapeutic ion.

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