Evaluation of sensitivity and specificity of ECG left ventricular hypertrophy criteria in obese and hypertensive patients

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Abstract

Background: Left ventricular hypertrophy (LVH) is a well-known risk factor for cardiovascular events. Even though, there are many electrocardiographic (ECG) criteria for LVH, they still provide poor performance, especially among obese patients. The aim of this study was to examine the sensitivity and specificity in obese and nonobese patients, with obesity defined using body mass index (BMI), visceral fat level (VFATL) and waist hip ratio (WHR).

Material and methods: Overall, 1722 patients were included in the study. All patients underwent complete physical examination, office blood pressure measurement, analysis of body composition, 12-lead ECG, M-mode two-dimensional echocardiography. Six standard ECG criteria for LVH were analyzed, including: Cornell voltage criteria, Cornell duration criteria, Sokolow- Lyon voltage criteria, Sokolow-Lyon product criteria, R I + S III and R wave of aVL. Sensitivity and specificity of those criteria was evaluated for patients with and without obesity. Transthoracic echocardiography was used as a reference method to detect LVH.

Results: In obese patients, Cornell duration criteria showed the best performance and should be used in detecting LVH. Increased amount of adipose tissue and presence of obesity, defined by different indicators, decreased sensitivity and specificity values of ECG criteria; however, only several criteria showed statistical significance. Sokolov-Lyon voltage and Cornel voltage were evaluated to have good sensitivity in nonobese women patients, but their performance was insufficient in obese women.

Conclusion: LVH should not be diagnosed using ECG criteria without assessment of patients obesity. Preferred parameter, from discussed in this study, to assess patients obesity is VFATL.

Key words: obesity; left ventricular hypertrophy; electrocardiography; hypertension

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Introduction

Obesity has been shown to be one of the major problems of nowadays public health as it affects all socioeconomic groups of people. It is associated with cardiovascular disease and diabetes [1–3]. Left ventricular hypertrophy (LVH) is a common issue among obese individuals [4]. Thus, identification of LVH in electrocardiography (ECG) in this group has been an assignment to solve [5]. Among

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obese individuals ECG criteria values for LVH are weakened [6]. Most of the ECG criteria used for detecting LVH have high specificity compared to low sensitivity [7]. It has been proven that these criteria can be more precise when they are corrected by the visceral fat level (VFATL) or body mass index (BMI); however, the VFATL-corrected indexes have better sensitivity than BMI-corrected [8]. BMI is a costless index which can be calculated for every individual without any advanced equipment. The most precise outcomes in detecting LVH are shown when magnetic resonance imaging (MRI) or echocardiography methods are used while MRI is referred as a "gold standard". These methods on one hand are the most accurate, on the other require well-educated personnel and expensive devices [9].

The aim of our study was to reveal the best ECG criteria for LVH and differences between criteria in groups divided by gender, low and high BMI, waist-hip ratio (WHR) and VFATL level. The outcome of our study may lead to better accessibility in detecting LVH among obese patients using ECG criteria as it still remains major issue.

Material and methods

Study population

The results were derived from a study conducted on a group of 1722 consecutive adults suffering from hypertension, aged between 40 and 70 years old.

After being informed about the aim of the study and providing their written consent, patients were invited to the clinic in order to undergo a clinical evaluation. The initial examination included a complete physical examination, office blood pressure measurement, analysis of body composition, 12-lead ECG, M-mode two-dimensional echocardiography. Patients with the following ECG findings were excluded from the study: left bundle branch block, right bundle branch block, Wolf-Parkinson-White syndrome and atrial fibrillation.

Electrocardiography

Standard 12-lead ECG was recorded at 25 mm/s and 1.0 mV/cm. For the purpose of this study, six most widely used ECG criteria for LVH were investigated. The analyzed criteria are listed in Table 1.

Echocardiography

The transthoracic two-dimensional M-mode echocardiography was performed, by one specialist using one device in all patients, to evaluate left ventricular mass (LVM). LVM was assessed using ASE (American Society of Echocardiography) formula:

Table 1. Left ventricular hypertrophy electrocardiography (ECG) criteria

Cornell voltage criteria: $RaV_L + SV_3 \geq 20$ mm for women and ≥ 28 mm for men
Cornell criteria duration: ($RaV_L + SV_3$ + for women, add 8 mm) × QRS duration ≥ 2440 mm × ms
Sokolow-Lyon voltage criteria: $SV_1 + RV_5$ or $V_6 \geq 35$ mm
Sokolow-Lyon product criteria: ($SV_1 + RV_5$ or V_6) × QRS duration ≥ 3710 mm × ms
R I + S III > 25 mm
R wave of aVL > 11 mm

$$LVM\ (g) = 0.8 \times \{1.04 \times [(LVIDd + PW + IVSd)^3 - (LVIDd)^3]\} + 0.6$$

and indexed to body surface area [10]; where LVIDd — left ventricle internal dimension diastole, PW — posterior wall thickness, IVSd — inter-ventricular septum diastole.

According to ASE/EACVI (European Association of Cardiovascular Imaging) 2015 guidelines, LVH was diagnosed in individuals with left ventricular mass index (LVMI) > 115 g/m^2 in men, and > 95 g/m^2 in women [10]. Echocardiographic LVH was used as a reference standard to compare the quality of ECG LVH criteria.

However, in case of obese patients LVM was indexed to height raised to the allometric power of 2,7 (height^{2,7}). According to previous studies in this group prevalence of LVH is significantly higher while normalized to height compared to BSA indexation [11, 12].

Echocardiographic LVH was used as a reference standard to compare the quality of ECG LVH criteria.

Analysis of body composition

The body composition analysis was performed using a Multi-Frequency Body Composition Analyzer (MC-180MA, Tanita, Tokyo, Japan). The body composition was estimated by measuring the body's bioelectrical impedance using 8 points of tactile electrodes (two thumbs, two palms, two fronts soles, two heels). Participants were standing barefoot on the device with electrodes placed in both hands. All testing was performed according to the instruction of the manufacturer. Before the test patients were informed that intense exercise or excessive consumption was prohibited prior to the examination. The evaluated data included BMI, fat %, fat mass, visceral fat

level, muscle mass, non-fat components, bone mass, and total body water weight. VFATL is an index of fat level in the internal abdominal cavity. VFATL, which was estimated by bioelectrical impedance analysis, is rating from 1 to 59. The calculating equation was derived from multiple regression analysis.

Anthropometric data

WHR was calculated as waist circumference divided by hip circumference. Waist circumference was measured at the umbilical level halfway between the lower ribs and the iliac crest, while that of the hip at the largest circumference around the buttocks. Both measurements were performed in standing position using nonstretch tape to the nearest 0.1 cm.

BMI was calculated by dividing body mass in kilograms by the square of height in meters.

Statistical analysis

Statistical analysis was conducted using Statsoft Statistica 13.3 software (TIBCO Software Inc., 2017). P-value < 0.05 was considered statistically significant. The expression of categorical variables was shown as numbers and percentages (presented in parentheses). Continuous variables were displayed as mean ± standard deviation (SD). Our population was divided into groups of obese and nonobese evaluated using different indicators (BMI, VFATL and WHR). The study population was divided into groups with BMI ≤ 25 kg/m^2 and ≥ 30 kg/m^2, with WHR ≤ 0.8 and ≥ 0.9 in women, with WHR ≤ 0.9 and ≥1 in men, with VFATL in lowest and highest quartile for men and women. Sensitivities of electrocardiographic criteria achieved in groups mentioned above were compared using the z-test for proportions.

Results

Our study included 1722 patients and 352 individuals (20.4%) had LVH diagnosis based on LVMI measurement. Women group consisted of 832 (12.6% with LVH). Men group consisted of 890 (27.8% with LVH).

BMI women

In ≤ 25 kg/m^2 BMI group the highest sensitivity was for Cornell criteria duration 23.5% (with 93.9% specificity).

In ≥ 30 kg/m^2 BMI group also the highest sensitivity was for Cornell voltage criteria 33.3% (with 87.36% specificity).

The differences in sensitivity of Cornell voltage criteria, Cornell criteria duration, Sokolov-Lyon voltage criteria, Sokolov-Lyon product criteria and R wave of aVL > 11 and specificity of Cornell voltage criteria, Cornell criteria duration between compared groups were statistically significant (p-value < 0.05).

BMI Men

In ≤ 25 kg/m^2 BMI group the highest sensitivity was for Sokolov Lyon voltage criteria and Sokolov-Ly-

Table 2. Characteristics of the study population (n = 1722 participants of the study)

Variable	All	LVH	No LVH
Female sex, No. (%)	832 (48.3)	105 (29.8)	727 (53.1)
Age [years]	55.26 ± 15.05	60.48 ± 12.6	53.92 ± 15.33
BMI [kg/m^2]	28.76 ± 14.31	30.5 ± 5.49	27.80 ± 4.91
SBP [mm Hg]	144.25 ± 22.41	156.15 ± 24.59	141.20 ± 20.75
DBP [mm Hg]	83.73 ± 13.52	87.82 ± 14.83	82.69 ± 12.66
VFATL	9.49 ± 4.65	12.36 ± 4.79	8.75 ± 4.32
LVM ASE [g]	192.06 ± 63.51	280.40 ± 57.82	169.36 ± 41.13
LVMI ASE, g/m^2	97.43 ± 26.72	136.76 ± 23.09	87.32 ± 16.15
BMI ≥ 30 kg/m^2, No. (%)	582 (33.8)	188 (53.4)	394 (28.8)
Cornell voltage [μV]	16.86 ± 6.24	19.92 ± 7.05	16.07 ± 5.76
Cornell product [μV ms]	1670.39 ± 737.89	2080.13 ± 925.40	1563.90 ± 639.59
Sokolov-Lyon voltage [μV]	22.43 ± 7.34	24.32 ± 8.52	21.93 ± 6.92
Sokolov-Lyon product [μV ms]	2196.33 ± 789.44	2507.91 ± 942.32	2115.36 ± 723.39
R I + S III [μV]	12.43 ± 5.94	14.32 ± 6.52	11.77 ± 5.52
R wave of aVL [μV]	5.53 ± 3.37	6.16 ± 4.42	4.37 ± 2.97

DBP — diastolic blood pressure; HTN — hypertension; LVH — left ventricular hypertrophy; LVM — left ventricular mass; LVMI — left ventricular mass index; SBP — systolic blood pressure; VFATL — visceral fat level; ASE — American Society of Echocardiography; BMI — body mass index

Table 3. Performance of sensitivity and specificity of all electrocardiography (ECG) indexes for detection of left ventricular hypertrophy (LVH) in body mass index (BMI) ≤ 25 kg/m^2 and ≥ 30 kg/m^2 female and male groups. Results of comparison (p-values)

	BMI					
	Sensitivity			Specificity		
	≤ 25 kg/m^2	≥ 30 kg/m^2	p-value	≤ 25 kg/m^2	≥ 30 kg/m^2	p-value
Women						
Cornell voltage criteria	0.176	0.058	0.001	0.962	0.976	0.529
Cornell criteria duration	0.235	0.132	0.004	0.939	0.989	0.006
Sokolov-Lyon voltage criteria	0.176	0.016	0.001	0.977	0.977	1.000
Sokolov-Lyon product criteria	0.059	0.008	0.003	0.989	1.000	0.128
R I + S III > 25 mm	0.059	0.047	0.545	0.989	1.000	0.128
R wave of aVL > 11	0.059	0.124	0.012	0.977	0.977	1.000
Men						
Cornell voltage criteria	0.100	0.075	0.4077	0.876	0.939	0.035
Cornell criteria duration	0.300	0.237	0.187	0.848	0.842	0.882
Sokolov-Lyon voltage criteria	0.450	0.069	0.001	0.762	0.965	0.001
Sokolov-Lyon product criteria	0.450	0.075	0.001	0.829	0.983	0.001
R I + S III > 25 mm	0	0.052	0.011	0.094	0.947	0.001
R wave of aVL > 11	0	0.087	0.001	0.933	0.904	0.340

on product criteria 45% (with 76.2% and 82.9% specificity respectively).

In ≥ 30 kg/m^2 BMI group the highest sensitivity was for Cornell criteria duration 23.7% (with 84.21% specificity). The differences in sensitivity of Sokolov-Lyon voltage criteria and Sokolov-Lyon duration criteria and specificity of Sokolov-Lyon voltage criteria, Sokolov-Lyon duration criteria, Cornell voltage criteria and R I + S III > 25 mm between compared groups were statistically significant (p-value < 0.05).

VFATL women

For low VFATL group 3 indexes reached 33.3% (Cornell voltage criteria, Cornell criteria duration and Sokolov-Lyon voltage criteria) sensitivity. Cornell voltage criteria reached 35.03% sensitivity in high VFATL group. Cornell voltage criteria specificity in nonobese and obese patients was respectively 97.5% and 89.17%.

Cornell voltage criteria sensitivity values had statistical significance differences in specificity.

Cornell criteria duration and Sokolov Lyon voltage criteria in high VFATL group reached widely lower values of sensitivity (respectively 12.1% and 1.2%) than Cornell voltage criteria (25.03%). Differences between these indexes are statistically significant (p-value < 0.05).

VFATL men

In low VFATL group the highest sensitivity was for Cornell criteria duration 53.9% (with 87.3% specificity).

In high VFATL group also the highest sensitivity was for Cornell criteria duration 21.85% with 88.42% specificity.

There is a difference in statistical significance (p-value < 0.05) sensitivity values in these groups for Cornell criteria duration.

WHR women

The highest sensitivity for ≤ 0.8 WHR group was reached in two indexes (30.8% for Cornell voltage criteria and Cornell criteria duration) and one of them, Cornell voltage criteria, reached the highest sensitivity in ≥ 0.9 WHR group (39.18%). Specificity was respectively 97.5% and 92.93%.

There was no significant differences (p-value > 0.05) in specificity values between those groups.

For ≥ 0.9 group Cornell criteria duration, Sokolov-Lyon voltage criteria, Sokolov- Lyon product criteria, R I +S III > 25 mm and R wave of

Table 4. Performance of sensitivity and specificity of all electrocardiography (ECG) indexes for detection of left ventricular hypertrophy (LVH) in visceral fat level (VFATL) lower quartile and fourth quartile female and male groups. Results of comparison (p-values)

	VFATL					
	Sensitivity			Specificity		
	≤ 6	≥ 9	p-value	≤ 6	≥ 9	p-value
Women						
Cornell voltage criteria	0.333	0.039	0.001	0.975	1.000	0.318
Cornell criteria duration	0.333	0.121	0.008	0.956	0.992	0.287
Sokolov-Lyon voltage criteria	0.333	0.013	0.001	0.971	1.000	0.282
Sokolov-Lyon product criteria	0.111	0.006	0.040	0.985	1.000	0.441
R I + S III > 25 mm	0.111	0.051	0.254	0.99	0.983	0.713
R wave of aVL > 11	0.111	0.089	0.686	0.99	0.975	0.435
Men						
Cornell voltage criteria	0.231	0.080	0.001	0.916	0.979	0.054
Cornell criteria duration	0.539	0.219	0.001	0.873	0.884	0.779
Sokolov-Lyon voltage criteria	0.308	0.066	0.001	0.775	0.990	0.001
Sokolov-Lyon product criteria	0.385	0.066	0.001	0.831	0.990	0.001
R I + S III > 25 mm	0	0.066	0.016	0.972	0.990	0.233
R wave of aVL > 11	0	0.093	0.001	0.972	0.937	0.213

Table 5. Performance of sensitivity and specificity of all electrocardiography (ECG) indexes for detection of left ventricular hypertrophy (LVH) in waist-to-hip ratio (WHR) ≤ 0.8 and ≥ 0.9 female groups. Results of comparison (p-values)

	WHR					
	Sensitivity			Specificity		
	≤ 0.8	≥ 0.9	p-value	≤ 0.8	≥ 0.9	p-value
Women						
Cornell voltage criteria	0.308	0.027	0.001	0.975	0.987	0.100
Cornell criteria duration	0.308	0.124	0.006	0.936	0.979	0.220
Sokolov-Lyon voltage criteria	0.077	0.021	0.137	0.984	1.000	0.358
Sokolov-Lyon product criteria	0.077	0	0.038	0.984	1.000	0.358
R I + S III > 25 mm	0.154	0.031	0.017	0.984	1.000	0.358
R wave of aVL > 11	0.231	0.083	0.015	0.995	0.990	0.649
Men						
Cornell voltage criteria	0.208	0.088	0.024	0.925	0.953	0.468
Cornell criteria duration	0.375	0.237	0.073	0.867	0.852	0.807
Sokolov-Lyon voltage criteria	0.167	0.088	0.130	0.817	0.977	0.001
Sokolov-Lyon product criteria	0.125	0.095	0.565	0.900	0.977	0.013
R I + S III > 25 mm	0.042	0.047	0.888	0.983	0.953	0.413
R wave of aVL > 11	0.042	0.088	0.352	0.967	0.906	0.228

aVL > 11 for that index there is statistical significance difference in sensitivity between lean and obese group (p-value < 0.05).

WHR men

In WHR ≤ 0.9 group the highest sensitivity was for Cornell criteria duration 37.5% (with 86.7% specificity).

In WHR ≥ 1 group also the highest sensitivity was for Cornell criteria duration 23.65% (with 85.16% specificity).

There was significant difference (p-value < 0.05) sensitivity values in these groups for Cornell voltage criteria.

Discussion

Obese patients tend to have lower voltage of QRS complexes both in precordial and limb leads [13]. The most important reason behind this phenomenon is higher amount of adipose tissue inside the chest cavity and around it. Adipose tissue around chest cavity consist of subcutaneous adipose tissue, epicardial adipose tissue (EAT) and adipose tissue located within the thorax [14]. The impact that is influenced by adipose tissue is reduction of the electric signals that are received on the skin level by ECG electrodes, because of increased distance between heart and electrodes [14]. The reason behind disturbed ECG parameters is not only insulating phenomenon. Rodrigues et al. proved that obese patients have abnormal ventricular structure defined by no LVH but with elevated mass:volume ratio with reduced cavity of left ventricle comparing to nonobese individuals [6]. The main ECG changes related to LVH are increased QRS voltage and QRS duration [15–17]. Although, obesity is the most common cause of the decreased QRS voltage in precordial leads, it is known that QRS amplitude also depends on many other factors such as heart size, age, sex, race, body habitus, anatomical variability or even electrode placement [18, 19]. In obese patients, adipose tissue plays dual role. It not only has insulating effect but also in obese patients there is higher prevalence of LV axis shifted to the left. This shift also affects QRS amplitude in precordial leads. Yet it doesn't affect limb leads such as aVL used in Cornell duration criterion. Such shift might be relative and dependable on electrode placement adding human factor to the poor ECG-LVH criteria performance [20–23]. Another reason why voltage-only criteria might be insufficient is that enlarged heart in LVH not only consist of more and enlarged heart muscle cells which are responsible for creating higher voltage than normal but also consist of excessive fibrous tissue which reduces and slows down electric potential leading to decrease in QRS amplitude but also QRS prolongation. It shows that there are many various factors acting differently on QRS amplitude, some enhancing, some weakening. It suggests that QRS duration is more independent and stable factor in contrast to QRS amplitude [22, 24]. Domain et al. proved that QRS duration lengthens with increase of LVM in LVH [24]. Combination of aspects mentioned above contributes to worse performance of ECG criteria in detecting LVH in obese patients what is confirmed in many studies that claim reduced sensitivity and specificity rates of ECG criteria. Our study confirmed this thesis and our results are consistent with other studies [25–29]. However, most studies assessed obesity using only BMI, despite the fact it is known that different indicators can superiorly predict the cardiometabolic risk [30]. In comparison we analyzed 3 different indicators of obesity. What is more our study was based on larger group of patients and analyzed more ECG criteria of LVH than most of discussed studies. The adjustment of ECG criteria of LVH is desired due to their pure performance. Some studies showed possible ways how to adjust ECG criteria to achieve better sensitivity and specificity. The methods of correction of ECG LVH criteria presented in the literature were plural, parameters used for adjustment of the criteria were spatial QRS-T angle, BMI, VFATL [8, 31, 32]. Our previous research proved that adjusting ECG criteria using VFATL and BMI improves detectability of LVH [8]. What is more, differences in sensitivity and specificity between certain methods of determining obesity were obtained. This phenomenon might be due to the fact that methods of determining obesity have differently indicated the amount of the adipose tissue. VFATL is the best factor to determine the amount of adipose tissue around chest cavity which has impact on precordial leads. What is also visible when we consider cardiometabolic risk and the influence of visceral fat on other comorbidities [33, 34]. In current research we established highest sensitivity from examined criteria was achieved by Cornell duration criteria. This conclusion was confirmed in both groups of patients obese and nonobese. This result does not differ in other methods of determining obesity (BMI, VFATL, WHR). Molloy et al. also obtained the same observation [35]. But our study also established that some ECG criteria are more efficient for obese and other ECG crite-

ria are more efficient for nonobese individuals. In women subjects with low fat amount, defined with VFATL and BMI, besides Cornell criteria duration two criteria were evaluated to have adequate sensitivity — Cornell voltage and Sokolov-Lyon voltage. In women with high degrees of adipose tissue these two criteria were insufficient with significantly lower sensitivity rates comparing to patients with normal amount of adipose tissue. Nevertheless, in obese women (defined by BMI, VFATL and WHR) we established that R wave of aVL > 11 criteria has moderately good performance in detecting LVH. What is more R wave of aVL > 11 criteria in nonobese women should be rarely used due to insufficient performance comparing to other criteria. In normal BMI man, both Sokolov-Lyon voltage criteria and Sokolov-Lyon product criteria showed the highest sensitivity with the advantage of Sokolov-Lyon product criteria in specificity. Yet, in obese man these two criteria proved to be inferior to Cornell duration criteria which showed the best sensitivity in this group. If VFATL is taken into consideration, the best sensitivity in both groups, increased and normal VFATL, is also obtained by Cornell duration criteria. However, in group of high VFATL man, sensitivity is significantly lower than in man with not increased VFATL. In our study, Cornell duration criterion which is composed of limb lead, precordial lead and QRS duration demonstrated the best performance in both, obese man and obese woman. Similar results were obtained in other studies [29, 36]. This leads to conclusion that in obese subjects Cornell duration criteria should be used to asses LVH. Trying to explain our findings we unfolded Cornell duration into its three components. According to Courand et al. R wave in aVL is the best performer in assessing LVH, possible to use in two step approach witch Cornell product to increase performance [37]. Alike in our study, we also proved that R wave in aVL is moderately good. However, combining QRS duration, QRS amplitude in limb leads and in precordial leads gives the best outcomes. Also, only Cornell voltage and Cornell duration criteria include sex differences. This may provoke reflection of the search of different, sex-specific cut-off points in other criteria.

Limitations

Our study has some limitations. First of all, our participants are hypertensive patients. We can only refer to LVH in the course of arterial hypertension. Another thing is that there is no norm for VFATL. VFAT cut-off levels in our study were determined by highest and lowest quartiles in our group.

Conclusions

Increased amount of adipose tissue and presence of obesity, defined by different indicators (BMI, VFATL, WHR), decreased sensitivity and specificity values of ECG criteria.

R wave of aVL > 11 criteria was evaluated to be good in detecting LVH in obese women patient, but should be rarely used in nonobese women patients due to poor performance in this group.

Sokolov-Lyon voltage and Cornel voltage were evaluated to have moderately good sensitivity in nonobese women patients, but their performance was insufficient in obese women.

In obese women and men Cornell duration criteria showed the best performance and should be used in detecting LVH.

In nonobese men with BMI ≤ 25 kg/m^2 Sokolov-Lyon product criteria could be used but if VFATL is low Cornel duration criteria showed better performance and should be used in priority.

LVH should not be diagnosed using ECG criteria without assessment of patients obesity. Preferred parameter, from discussed in this study, to assess patients obesity is VFATL.

Data availability statement

The data that support the findings of this study are available from the corresponding author, SS, upon reasonable request.

Ethics statement

Informed consent was obtained from all participants. The study has been accepted by local ethical commitee.

Author contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by all authors. The first draft of the manuscript was written by S.S., I.J., F.D., M.M., A.T. and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Conflict of interest

None declared. All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

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