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ORIGINAL RESEARCH

Prediction of Hypertension Based on Anthropometric Parameters in Adolescents in Eastern Sudan: A Community-Based Study

Awab H Saad[1], Ahmed A Hassan[2], Abdullah Al-Nafeesah[3], Ashwaq AlEed[3], Ishag Adam[4]

[1]Department of Medicine, Faculty of Medicine, Gadarif University, Gadarif, 32211, Sudan; [2]Department of Medicine, Faculty of Medicine, University of Khartoum, Khartoum, Sudan; [3]Department of Pediatrics, College of Medicine, Qassim University, Buraidah, Saudi Arabia; [4]Department of Obstetrics and Gynecology, College of Medicine, Qassim University, Buraidah, Saudi Arabia

Correspondence: Ahmed A Hassan, Faculty of Medicine, University of Khartoum, Khartoum, Sudan, Email aa801181@gmail.com

Background: Anthropometric measures such as body mass index (BMI), waist circumference (WC), and waist-to-height ratio (WHtR) are associated with elevated blood pressure and hypertension in adolescents. We aimed to assess these anthropometric measures (BMI, WC, and WHtR) and examine their association with hypertension in adolescents.

Methods: Adolescents' BMI, mid-upper arm circumference (MUAC), WC, body roundness index (BRI), waist-to-hip ratio (WHR), WHtR, and a body shape index(ABSI) values were measured and calculated. Receiver operating characteristic curves (ROCs) were created to determine the discriminatory capacities of these anthropometric parameters for hypertension. The cutoff points for these parameters were identified using Youden's index.

Results: A total of 401 adolescents [186(46.4%) were females and 215 (53.6%) were males] were included. The median (interquartile range, IQR) age was 14.0 (12.1–16.2) years. Thirty-six adolescents were found to have hypertension. Among the anthropometric parameters, MUAC (area under the curve (AUC] = 0.76, at the cutoff 26.1 cm, sensitivity = 61.0, specificity = 83.0), WC (AUC= 0.74, at the cutoff 70.3 cm, sensitivity = 66.7, specificity = 77.0), BMI (AUC= 0.73, at the cutoff 17.4 kg/m^2, sensitivity = 83.3, specificity = 59.0), and hip circumference (HC) (AUC= 0.72, at the cutoff 91.0 cm, sensitivity = 55.6, specificity = 83.0) performed fairly in detecting hypertension in adolescents, whereas WHR, WHtR, ABSI, and BRI performed poorly. A univariate analysis showed that, except for WHR, all anthropometric parameters (BMI, MUAC, WC, HC, WHtR, BRI, and ABSI) were associated with hypertension. However, in a multivariate analysis, only increased MUAC (adjusted odds ratio [AOR]= 1.24, 95% CI= 1.03–1.50) was associated with hypertension.

Conclusion: This study showed that MUAC, WC, BMI, and HC could be used to detect hypertension in adolescents. Other parameters,namelyWHR, WHtR, ABSI, and BRI, perform poorly in this regard. Larger studies are needed in the future.

Keywords: age, adolescent, body mass index, hypertension, females

Introduction

Hypertension, or elevated blood pressure, is an increasing health issue among adolescents, with varying prevalence rates in different countries, including Sub-Saharan African (SSA) countries.[1–4] Recent reports have shown that there are 26.5 million adolescents with hypertension or elevated blood pressure living in different SSA countries, and this figure is liable to increase in the near future.[5] It has been estimated that the prevalence rates vary from 0.18% to 34.0% among adolescents in SSA.[6] If elevated blood pressure is not detected and managed adequately during childhood or adolescence, it could progress to hypertension and lead to associated complications, such as cardiovascular disorders and endocrine and renal diseases, in later adulthood.[3,7,8]

One of the most plausible explanations for the high prevalence of elevated blood pressure and hypertension in adolescents is the high prevalence of obesity and overweight in this age group.[9,10] Different anthropometric measures or parameters, such as body mass index (BMI), waist circumference (WC),[11,12] waist-height ratio (WHtR),[10,12] mid-upper

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arm circumference (MUAC),[13] hip circumference (HC), waist-to-hip ratio (WHR),[14] a body shape index (ABSI),[15,16] and body roundness index(BRI)[16] have been used to assess obesity and its association with hypertension and cardiovascular diseases in adolescents, with different results obtained in different populations.[17,18]

Different populations have different cutoff points for anthropometric measures, and it is recommended that these measurements be assessed in each population rather than using international cutoff points when detecting cardiometabolic diseases in adolescents. While several anthropometric parameters have been shown to yield differing results and accuracies in detecting hypertension and elevated blood pressure in different countries around the globe,[13,14,19–21] there is limited published data focusing on SSA countries.[22] There is no published data on the accuracies of different anthropometric measures in detecting hypertension in adolescents in Sudan, the third-largest African country. Therefore, this study was conducted to assess the performance of anthropometric measurements (BMI, MUAC, WC, WHtR, HC, WHR, ABSI, and BRI) in detecting hypertension in adolescents in eastern Sudan. The study findings are significant for clinicians and health planners, as the data can be used for the early detection of hypertension in adolescents and for preventing hypertension-related complications.

Methods

Study Design and Setting

A community-based cross-sectional survey was conducted from August to October 2023 in Gadarif City, the largest city in Eastern Sudan. We strictly followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines for the study.[23] The details of this survey have been mentioned before.[24]

Sampling Technique

There are four zones (Mouraba) in Gadarif City, each with 13 blocks (Hay). Guided by the WHO's estimation, we expected adolescents to comprise 20% of the population of each household.[25] We then obtained the exact population of each block from the local authorities. We targeted 384 adolescents (both male and female) and divided them proportionally to the estimated adolescent population in that block.

Inclusion and Exclusion Criteria

Our target was to recruit healthy Sudanese adolescents aged 10–19 years, so those under 10 years or above 19 years were excluded. We also excluded adolescents who or their guardians declined consent, those with known secondary hypertension or thyroid disease, and pregnant or lactating adolescents.

Sample Size Calculation

The sample size of 384 was calculated using OpenEpi Menu software[26] and the formula for the prevalence of hypertension(was it assumed to be a maximum prevalence of 50.0%s) at the community level: n = Z2pq/d2, where q = (1 − p), Z1 − α = confidence interval (CI) of 95% = 1.96, and = margin of error of 5% = 0.05. The sample size was increased to 401 adolescents to guard against missing data.

Study Variables and Measures

After the adolescents and their respective guardians signed an informed consent form, four trained medical officers (two male, two female) filled out a questionnaire through face-to-face interviews, while anthropometric measures were taken based on previously conducted studies in different populations worldwide.[13,14,19–21] The sociodemographic data included age (in years) and sex (male or female),and the anthropometric measurements included weight and height (later expressed as BMI), WC, HC, and MUAC, along with hypertension status.

Anthropometric Measurements

Each anthropometric measure was taken twice using standard procedures, and its mean was computed. If there was a considerable difference between the two readings, a third measurement was taken.

Weight and Height Measurements

The adolescent's weights were measured (in kg) using well-calibrated scales adjusted to zero before each measurement. They were weighed without shoes or excess clothes and with minimal movement. Their heights were measured while they stood straight, with their backs against a wall and feet together. BMI was computed as weight (in kg) divided by height (in m^2).[27]

MUAC was measured using a nonstretchable measuring tape. The midpoint between the acromion and olecranon processes was used as the measurement point. The nonstretchable tape was also used to measure WC and HC. WC was measured at the midpoint between the lower curvature of the last fixed rib and the superior curvature of the iliac crest, and HC was the widest diameter across the buttocks.[28]

ABSI was computed using the following formula:

$$\mathrm{ABSI} = \mathrm{WC}/\mathrm{BMI}^{0.45} \times \mathrm{Height}^{0.55}$$

WC and height were measured in meters.

BRI was calculated as follows:

$$\mathrm{BRI} = 364.2 - 365.5 \times \sqrt{\left(1 - [\mathrm{WC}/(2\pi)]^2/[0.5 \times \mathrm{Height}]^2\right)}$$

Blood Pressure Measurement

The adolescents were instructed to have a minimum resting period of 10 minutes before the blood pressure measurements were taken twice using a digital measuring device (Omron Digital HEM-907, Tokyo, Japan). The mean of the two measurements was then computed. A third measurement was taken if the difference between the two readings exceeded five mmHg. Hypertension was considered when the systolic and diastolic pressures were ≥ 95th percentile for age and sex.[29]

Ethical Statement

This study was conducted in accordance with the principles outlined in the Declaration of Helsinki and adhered to good clinical research practices. Ethical approval for the study was obtained from the ethical research committee of the Faculty of Medicine, University of Gadarif, Gadarif, Sudan (Ref. #2023, 14). All adolescents and their guardians provided written informed consent.

Statistical Analysis

The data were analyzed using SPSS for Windows, version 22.0 (IBM Corp., NY, USA). The ages and anthropometric parameters were assessed for normality using the Shapiro–Wilk test and were found to be non-normally distributed. Therefore, these data were expressed as medians (interquartile range, IQR) and compared between adolescents with and without hypertension using the nonparametric Mann–Whitney *U*-test. Spearman correlation was performed between the anthropometric parameters and systolic and diastolic blood pressures. The r-value, rather than the P value, was considered for determining correlations(if $r > 0.5$). A receiver operating characteristic (ROC) analysis was performed to assess the anthropometric parameters' under-the-curve (AUC) sensitivity, specificity, and cutoff points in detecting hypertension in adolescents. The obtained AUC were classified based on their power: 1 reflects a perfectly accurate test: >0.9 is excellent, 0.8–0.9 is good, 0.7–0.8 is fair, <0.7 is considered poor, and <0.5 suggests that the test has no discriminatory ability.[30] The ROC parameters were determined based on the highest Youden's index (YI), calculated as YI = sensitivity + specificity − 1. Univariate and multivariate analyses were performed to assess the associations between the anthropometric measures and hypertension.

Results

Of the 401 included adolescents, 186(46.4%) were females, and 215 (53.6%) were males. The median (IQR) age was 14.0 (12.1–16.2) years. The median (IQR) values for the anthropometric parameters are shown in Table 1. Based on the r value,[31] no correlation was found between BMI, MUAC, WC, HC, WHR, WHtR, BRI, ABSI, and systolic or diastolic blood pressure (Table 2).

Table 1 Comparing the Median (Interquartile Range) of the Adolescents with and without Hypertension in Eastern Sudan, 2023

Variables	Total	Adolescents with Hypertension	Adolescents Without Hypertension	P
Body mass index, kg/m^2	16.9(15.2–20.0)	20.6(17.5–24.6)	16.7(15.0–19.5)	<0.001
Waist circumference, cm	65.0(59.8–70.7)	73.8(66.6–85.1)	64.0(59.0–69.0)	<0.001
Mid-upper arm circumference, cm	22.2(20.0–25.5)	26.8(23.1–30.0)	22.0(20.0–24.0)	<0.001
Hip circumference, cm	80.0(72.5–88.6)	92.8(79.3–100.0)	79.5(72.1–86.6)	<0.001
Waist-to-hip ratio	0.81(0.77–0.76)	0.81(0.78–0.88)	0.81(0.77–0.85)	0.726
Waist-to-height ratio	0.41(0.39–0.44)	0.45(0.41–0.53)	0.41(0.39–0.44)	<0.001
Body roundness index	1.9(1.5–2.4)	2.6(1.8–3.9)	1.9(1.5–2.4)	<0.001
A body shape index	0.14(0.13–0.14)	0.14(0.13–0.18)	0.14(0.13–0.14)	0.058

Table 2 Spearman Correlation Between Anthropometric Measures, Systolic and Diastolic Blood Pressure in Adolescents in Eastern Sudan, 2023

Variable	Systolic Blood Pressure		Diastolic Blood Pressure	
	R	P	R	P
Body mass index	0.316	<0.001	0.194	<0.001
Waist circumference	0.332	<0.001	0.204	<0.001
Mid-upper arm circumference	0.315	<0.001	0.194	<0.001
Hip circumference	0.331	<0.001	0.223	<0.001
Waist-to-hip ratio	−0.007	0.888	−0.050	0.233
Waist-to-height ratio	0.253	<0.001	0.152	0.022
Body roundness index	0.253	<0.001	0.152	0.022
A body shape index	0.115	0.021	0.071	0.153

Thirty-six adolescents were found to have hypertension. The median (IQR) BMI, MUAC, WC, HC, WHtR, and BRIvalueswere significantly higher for adolescents with hypertension than for adolescents without hypertension. In contrast, theWHR and ABSI did not differ (Table 1).

Among the anthropometric parameters, MUAC (AUC= 0.76, at the cutoff 26.1cm, sensitivity = 61.0, specificity = 83.0), WC (AUC= 0.74, at the cutoff 70.3 cm, sensitivity = 66.7, specificity = 77.0), BMI (AUC=0.73, at the cutoff 17.4 kg/m^2, sensitivity = 83.3, specificity = 59.0), and HC (AUC= 0.72, at the cutoff 91.0, sensitivity = 55.6, specificity = 83.0) performed fairly in detecting hypertension in the adolescents, whereas WHR, WHtR, ABSI, and BRI performed poorly(Table 3, Figures 1 and 2). The univariate analysis showed that, except forHC and WHR, all anthropometric parameters (BMI, MUAC, WC, WHtR, BRI, and ABSI) were associated with hypertension (Table 4). However, only increased MUAC (adjusted odds ratio [AOR]= 1.24, 95% CI= 1.03–1.50) was associated with hypertension in the multivariate analysis (Table 5).

Table 3 Performance of Anthropometric Measures to Detect hypertension in Adolescents in Eastern Sudan, 2023

Variable	The Area Under the Curve	95.0% Confidence Interval	Cut-Off Point	Sensitivity	Specificity	Youden's Index
Mid-upper arm circumference	0.76	0.67–0.85	26.1 cm	61.0	83.0	0.44
Waist circumference	0.74	0.65–0.84	70.3 cm	66.7	0.77	0.43
Body mass index	0.73	0.65–0.82	17.4 kg/m^2	83.3	59.0	0.42
Hip circumference	0.72	0.62–0.81	91.0 cm	55.6	83.0	0.39
Waist-to-height ratio	0.68	0.57–0.78	45.2	55.6	80.0	0.36
Body roundness index	0.68	0.57–0.78	2.52	55.6	80.0	0.36
A body shape index	0.59	0.49–0.69	0.14	50.0	70	0.21
Waist-to-hip ratio	0.51	0.41–0.62	0.86	33.3	80.0	0.13

Discussion

In the present study,BMI, MUAC, WC, HC, WHtR, and BRI were significantly higher for adolescents with hypertension than for adolescents without hypertension. This aligns with the results of previous studies conducted in Lithuania[13] and Croatia,[14] which showed that adolescents with elevated blood pressure and hypertension had significantly higher mean MUAC, WC, BMI, and WHtR values than normotensive adolescents. Moreover, Spanish adolescents with metabolic syndrome have been reported to have higher BMI, WC, BRI, WC, WHR, WHtR, and ABSI than their peers with no metabolic syndrome.[21]

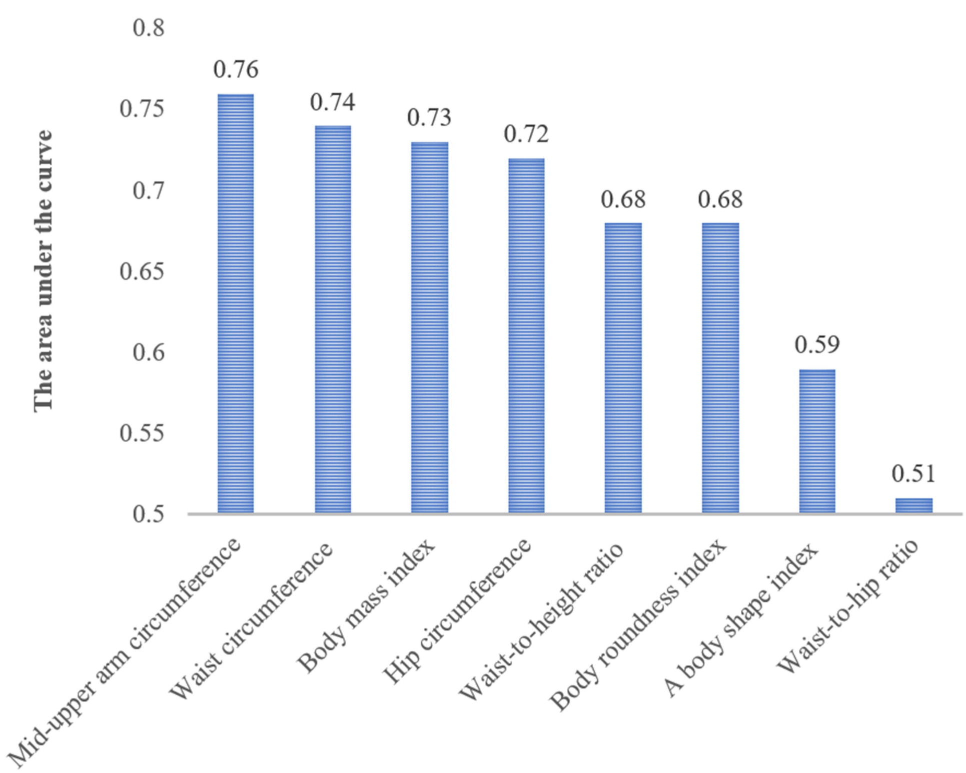

Figure 1 Area under the curve of anthropometric measures to detect hypertension in adolescents in Eastern Sudan, 2023.

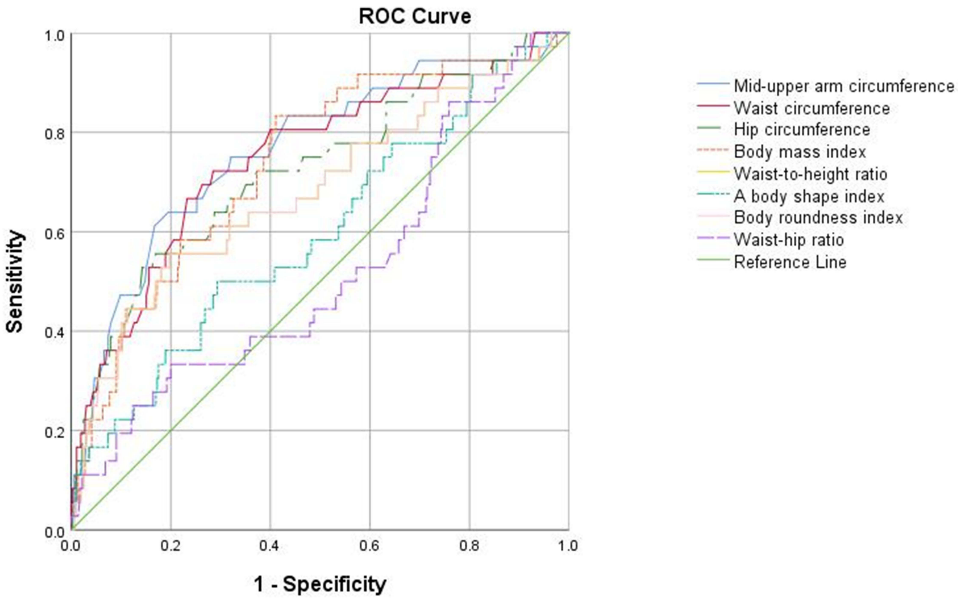

Figure 2 Receiver operating characteristic of anthropometric measures to detect hypertension in adolescents in Eastern Sudan, 2023.

Our work demonstrated no correlation (r values less than 0.5) between the studied anthropometric indices and systolic and diastolic blood pressure, which was consistent with findings documented in some studies of blood pressure.[32,33] On the other hand, recently published clinical studies in African countries showed a positive correlation between anthropometric measures and systolic and diastolic blood pressure.[34–40]

Table 4 Univariate Analysis of the Factors Associated with Hypertension Among Adolescents in Eastern Sudan, 2023

Variable	Odd Ratio	95.0% Confidence Interval	P. Value
Body mass index	1.13	1.05–2.20	<0.001
Waist circumference	1.09	1.06–1.13	<0.001
Mid-upper arm circumference	1.26	1.16–1.37	<0.001
Hip circumference	1.01	0.99–1.02	0.109
Waist-to-hip ratio	23.64	0.11–4950.0	0.248
Waist-to-height ratio	13011.0	98.77–1,714,076	<0.001
Body roundness index	1.58	1.22–2.04	0.001
A body shape index	6.01	2.99–12.70	0.041

Table 5 Multivariate Analysis of the Factors Associated with Hypertension Among Adolescents in Eastern Sudan

Variable	Odd Ratio	95.0% Confidence Interval	P. Value
Body mass index	0.88	0.73–1.06	0.205
Waist circumference	1.06	0.99–1.14	0.085
Mid-upper arm circumference	1.24	1.03–1.50	0.022

In this study, MUAC had the highest AUC among the anthropometric parameters, and it was the only parameter associated with an increased odds ratio (OR)for hypertension after removing the confounder in the multivariate analysis. This result aligns with previous studies involving adolescents in Turkey[20] and children and adolescents in Lithuania.[13] Moreover, previous studies conducted in Sudan,[41] Ethiopia,[42] and Tanzania[43] have shown that MUAC can be used to assess the nutritional status of adolescents adequately. MUAC is a good indicator not only of hypertension but also of interarm blood pressure difference, as recent reports have shown.[44] However, recent observations indicate that MUAC is associated with hypertension in adult women only, not men, in South Africa.[45]

Our study in eastern Sudan showed that BMI and WC had fair predictivity levels in detecting hypertension in adolescents, aligning with results that showed that BMI and central obesity were conducted for 908 adolescents in Pakistan.[10] These results are also compatible with previous studies in Turkey that showed that WHtR, WC, and MUAC can be used to screen for high blood pressure.[20] The 2017–2018 National Health and Nutrition Examination Survey (NHANES) assessed adolescents aged 12–19 in America; WC and BMI exhibited fair predictivity in predicting elevated blood pressure.[12] Moreover, WC has been shown to be a good tool for discriminating between adolescents with and without metabolic syndrome in Spain.[21] WC has also been positively associated with high blood pressure in adolescents in Cameron.[22] WC and BMI are associated with diastolic blood pressure. However, research in Iran revealed that with increasing age, only BMI and weight were associated with diastolic blood pressure in adolescents.[19] In a study in Malaysia, BMI and WHtR had high AUCs for predicting adolescent hypertension.[15] In a survey conducted in Lithuania, analyses of ROC curves revealed that the largest AUC value was for the BMI z-score, followed by the WC z-score, while the WHtR z-score had the lowest AUC value in predicting elevated blood pressure in both sexes separately.[46] BMI, WC, WHR, and BRI have been reported to have fair predictivity in detecting high blood pressure in Brazil.[47] In contrast, BMI and WHtR were not indicators of hypertension in research conducted in Cameroon.[22] Different cutoff points of WHtR are risk indicators for metabolic syndrome and cardiometabolic health in different populations of adolescents, so it has been recommended that each population set up its own WHtR cutoff points.[18] In China, WHtR and BRI have been recommended for identifying hypertension, dyslipidemia, abdominal obesity, and clustered cardiometabolic risk factors (CMRFs) in both genders; however, ABSI has been reported to have weak discriminative power.[16]

Unlike previous studies[16,48] which showed that BRI and ABSI have discriminatory power for hypertension in adult women and men from different populations, our results showed that BRI and ABSI have poor predictivity in detecting hypertension in adolescents. Several factors could explain the difference between the results of the present study and those of other studies, including differences in sociodemographic characteristics, nutritional statuses, and obesity types in different populations. Differences in the prevalence of elevated blood pressure and hypertension could also be a reason. Moreover, unlike most other studies, we used Youden's index to compute the cutoff points.

Limitations

This study was conducted in one region in eastern Sudan, and the findings may not apply to other areas ofSudan. Since only 36 adolescents with hypertension were present in the sample, their results might not be of value if dissected in males and females.

Conclusion

This study showed that MUAC, WC, BMI, and HC can be used to detect hypertension among adolescents. Other parameters, namely WHR, WHtR, ABSI, and BRI, perform poorly in this regard. Larger studies are needed in the future.

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Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis, and interpretation, or in all these areas; took part in drafting, revising, or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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