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ORIGINAL

Multifactorial Analysis of Chronic Energy Deficiency in Adolescent Girls: Innovative RF-AR App for Early Detection and Effective Intervention

Análisis Multifactorial del Déficit Crónico de Energía en Chicas Adolescentes: Innovadora aplicación RF-AR para la detección precoz y la intervención eficaz

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ABSTRACT

Introduction: chronic Energy Deficiency (CED) in adolescent girls remains a significant public health concern influenced by various interrelated factors. This study aimed to analyze the multifactorial determinants of CED and to develop an innovative health intervention using the RF-AR application for early detection and effective management.
Method: an observational analytic study with a cross-sectional design was conducted involving adolescent girls from diverse socioeconomic and geographic backgrounds. Data were collected through structured surveys. Multifactorial analysis encompassed genetic, environmental, lifestyle, and psychological factors. The data were analyzed using univariate, bivariate, and multivariate approaches to identify significant predictors of CED.
Results: the study revealed that poor nutritional intake, limited access to health information, and low socioeconomic status were significantly associated with higher rates of CED among adolescent girls. The multifactorial model underscored the complexity of CED etiology. Additionally, the RF-AR application demonstrated potential as a supportive tool for early screening and individualized intervention planning.
Conclusions: the findings confirmed that adolescent girls with inadequate nutrient intake are at a greater risk of developing CED. A multifactorial intervention strategy, supported by technological tools like the RF-AR app, offers a promising approach to early detection and effective prevention of CED at a broader scale.

Keywords: Chronic Energy Deficiency; Adolescent Girls; Multifactorial Analysis; Nutritional Status; Socioeconomic Factors; Rf-AR Application.

RESUMEN

Introducción: la Deficiencia Crónica de Energía (DCE) en chicas adolescentes sigue siendo un importante problema de salud pública en el que influyen diversos factores interrelacionados. Este estudio pretende analizar los determinantes multifactoriales del DCE y desarrollar una intervención sanitaria innovadora utilizando la aplicación RF-AR para la detección precoz y el tratamiento eficaz.
Método: se realizó un estudio analítico observacional con un diseño transversal en el que participaron chicas adolescentes de diversos entornos socioeconómicos y geográficos. Los datos se recogieron mediante encuestas estructuradas. El análisis multifactorial abarcó factores genéticos, ambientales, de estilo de vida

y psicológicos. Los datos se analizaron utilizando enfoques univariantes, bivariantes y multivariantes para identificar predictores significativos del CED.
Resultados: el estudio reveló que la ingesta nutricional deficiente, el acceso limitado a la información sanitaria y el bajo nivel socioeconómico se asociaron significativamente con tasas más elevadas de CED entre las adolescentes. El modelo multifactorial subrayó la complejidad de la etiología del CED. Además, la aplicación RF-AR demostró su potencial como herramienta de apoyo para la detección precoz y la planificación de intervenciones individualizadas.
Conclusiones: los hallazgos confirmaron que las adolescentes con una ingesta inadecuada de nutrientes tienen un mayor riesgo de desarrollar CED. Una estrategia de intervención multifactorial, apoyada por herramientas tecnológicas como la app RF-AR, ofrece un enfoque prometedor para la detección precoz y la prevención eficaz del CED a mayor escala.

Palabras clave: Deficiencia Energética Crónica; Chicas Adolescentes; Análisis Multifactorial; Estado Nutricional; Factores Socioeconómicos; Aplicación RF-AR.

INTRODUCTION

Chronic Energy Deficiency (CED) in adolescent girls is operationally defined as a condition characterized by a Body Mass Index (BMI)-for-age below the 5th percentile based on WHO growth reference standards.[1,2] In this study, CED is identified when an adolescent girl has a BMI less than 18,5 kg/m^2, indicating a long-term lack of energy and nutrient intake that may impact physical development and health outcomes.[3]

Chronic energy deficiency (CED) is a serious nutritional problem among adolescent girls, especially in developing countries.[1,4] This condition not only affects their physical growth and reproductive health, but also impacts their cognitive abilities and academic performance.[5,6] The factors that cause CED in adolescent girls are diverse,[1,7] including limited access to adequate nutrition, economic status, nutrition education, and unbalanced diets.[8] While various interventions have been made, effective and sustainable approaches are still needed to address these issues.[9] In today's digital age, mobile health (mHealth) technologies offer new opportunities to improve early detection and intervention of health problems.[1,9,10]

CED is a serious nutritional problem among adolescent girls, especially in developing countries.[1,4] It not only affects their physical growth and reproductive health, but also impacts their cognitive abilities and academic performance.[11,12] Factors contributing to CED in adolescent girls are diverse, including limited access to adequate nutrition, economic status, nutrition education, and unbalanced.[13,14] Despite various interventions, effective and sustainable approaches are still needed to address this issue.[15,16]

Based on the 2018 Riskesdas data, the proportion of nutritional status of adolescent girls aged 13-18 years based on Body Mass Index by Age (IMT/U) in the very thin and thin categories in Indonesia was 9,7 % and Lampung province was 16,3 %.[17] In Lampung province, the prevalence of chronic energy deficiency (CED) among adolescents aged 15-19 years was 36,93 %. The prevalence of chronic energy deficiency (CED) in women of childbearing age who are not pregnant in Pesawaran district is 19,02 %, which is quite high.[12,18] The condition of adolescents with chronic energy deficiency (CED) increases the risk of various infectious diseases and hormonal disorders that have a negative impact on health.[2,6]

A significant gap in this case is its understanding and management.[19,20] One of the major gaps is the lack of comprehensive and representative data on the prevalence of CED in different regions, especially in developing countries.[21,22] In addition, there is limited understanding of the complex interactions between factors that contribute to CED, such as access to nutritious food, economic status, nutrition education and food culture.[22,23] Many existing studies tend to focus on one or a few factors alone, without considering how the combination of these factors holistically affects the condition of CED in adolescent girls.[24,25] Another gap is the lack of long-term evaluation of the effectiveness of interventions, making it difficult to determine which strategies are truly effective in reducing CED in a sustainable manner.[26] The lack of contextualized and locally tailored approaches is also an obstacle to preventing and tackling CED.[27]

Factors that determine the chronic energy deficiency (CED) status of adolescent girls consist of direct and indirect factors.[7,27] Direct factors consist of food intake and disease. Indirect factors are factors that influence the eating behavior or intake of adolescent girls themselves.[28] Indirect factors consist of predisposing factors (knowledge, age, nutritional status, personality, body image), supporting factors (socio-economic, mass media influence, influence of idol figures) and push factors (family, peers).[29,30]

Early detection of chronic energy deficiency (CED) in adolescent girls requires a prediction model of chronic energy deficiency in adolescent girls.[3,6] This model is built based on direct and indirect factors that affect chronic energy deficiency (CED) in adolescent girls, then applied in a computer program in the form of mobile health.[31] Mobile health, commonly known as m-health, is a form of e-health innovation that can be utilized for early detection, prediction, data recording, and reporting within healthcare programs.[32,33]

In today's digital age, mobile health (mHealth) technologies offer new opportunities to improve early detection and intervention of health problems.[34,35] The RF-AR (Rapid Feedback-Augmented Reality) app is one innovation in this field that has the potential to facilitate nutrition education, health monitoring, and personalized interventions for adolescent girls.[36,37] By utilizing AR technology and interactive features, this app can increase awareness of the importance of good nutrition and help adolescents make healthier decisions.[37,38]

This study aims to analyze the multifactorial factors that influence CED in adolescent girls and develop innovative intervention strategies through RF-AR applications. The study will explore how this application can be used for early detection and effective intervention, thus contributing to the improvement of nutritional status and overall health of adolescent girls. By understanding the complexity of the causes of CED and integrating technological solutions, this study is expected to make a meaningful contribution to the field.

METHOD

Procedure

This study employed a purposive sampling technique to recruit 100 undernourished adolescent girls aged 15–19 years living in the Pesawaran District, with data collected between September 2023 and February 2024. Participants were included based on informed consent. Although purposive sampling limits the ability to infer causality and reduces the generalizability of findings, this method was intentionally selected to focus on a specific high-risk population that is most relevant to the study's objectives and intervention design.

Data were collected through a structured questionnaire containing questions on demographic factors, dietary habits, physical activity, nutritional status, and the use of information technology in the context of health. The data obtained were then analyzed using descriptive and inferential statistical techniques to identify factors correlated with chronic energy deficiency in participants.

The expected output of this research is the development of a RF-AR (Rapid Feedback-Augmented Reality) mobile health application designed for early detection and effective intervention against chronic energy deficiency. This application is expected to provide appropriate and interactive nutrition information, as well as increase awareness and understanding of adolescent girls about the importance of a balanced diet and healthy lifestyle. Evaluation of the effectiveness of the application will be conducted through field trials and feedback from users.

Instruments and Data Collection Personnel

The This survey used a structured questionnaire that covered various aspects such as sociodemographic characteristics (school, grade, residential location, father's occupation, mother's occupation, father's education, mother's education), disease history (history of TB, history of worms), dietary behavior (daily food frequency, dietary restrictions, consumption of animal side dishes, consumption of green vegetables), BMI, and knowledge level. All questionnaire items were adapted from the Anemia Survey of Adolescent Girls in Pesawaran. To ensure relevance for assessing Chronic Energy Deficiency (CED), the instrument underwent content validation by experts and reliability testing, yielding a Cronbach's alpha value 0,78, indicating acceptable internal consistency. The questionnaire was entered into the CommCare application, which was operated using an Android-based device. Trained interviewers conducted the interviews and electronically recorded the respondents' answers.

In addition to interviews, blood hemoglobin (Hb) levels and anthropometry (upper arm circumference, height, and weight) were checked. Hb levels were measured using a HemoCue Hb 301. Body weight was measured using a body weight scale. Height was measured using a Gea Medical microtoise with an accuracy of 0,1 cm. Height measurement was carried out with the subject standing upright against the wall (subscapular, buttocks, and heels against the wall) then the microtoise was lowered to touch the cranium to read the measurement results. Upper arm circumference was measured using a metline (0,1 cm accuracy). Measurement of upper arm circumference is carried out by standing upright but relaxed, not holding anything, and not tensing arm muscles, then measured between the acromion process and olecranon process of the less dominant arm, usually on the left arm. The training program covered detailed explanations of the questionnaire questions, how to take blood Hb and anthropometric measurements, and the use of Commcare.

RF-AR Application Design and Prototype

The RF-AR (Rapid Feedback–Augmented Reality) mobile health application was developed as an innovative educational tool to support early detection and intervention for Chronic Energy Deficiency (CED) among adolescent girls. The application was designed using Android Studio for app development and Unity 3D with Vuforia SDK to enable augmented reality features. It is compatible with Android-based smartphones running version 7.0 or higher with ARCore support.

The prototype consists of the following key features: Augmented Reality (AR) Modules: Interactive 3D visualization of healthy foods and balanced meals to increase user engagement and comprehension. Personalized feedback is generated based on user-inputted data, such as upper arm circumference, body mass index, and hemoglobin level, to help users understand their nutritional status and risk of Chronic Energy Deficiency (CED). Educational Content: Easy-to-understand explanations about CED, anemia, balanced nutrition, and healthy habits tailored for adolescent users. Reminder System: Daily tips and reminders to support behavior change and consistent monitoring of nutritional status.

To provide a clearer understanding of the prototype, figure 1 illustrates the user interface and augmented reality features of the RF-AR application. These visuals demonstrate how the application integrates educational content with interactive elements to promote awareness and behavioral change among adolescent users.

Figure 1. Home screen and main navigation of the RF-AR mobile application

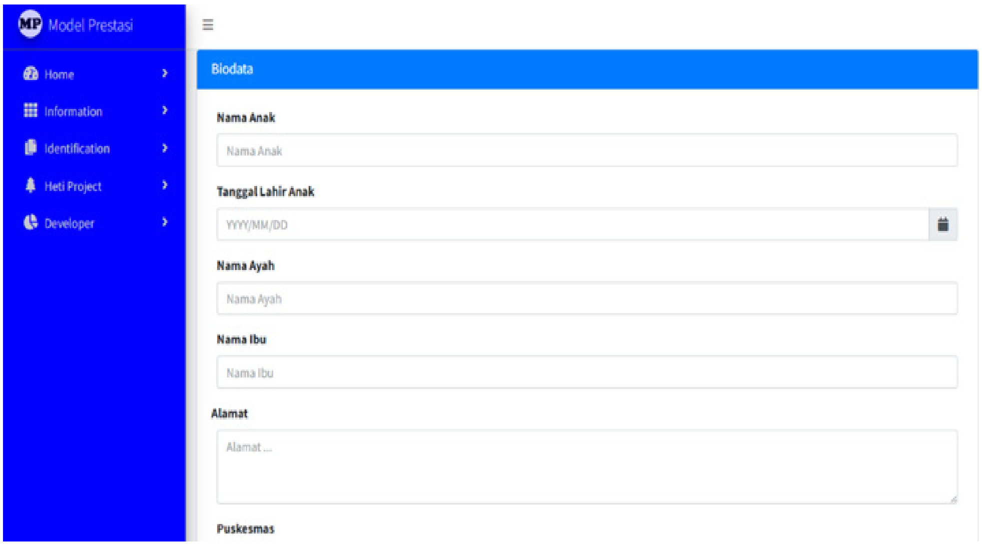

Figure 2. User Interface of the Identification Feature in the RF-AR Mobile Health Application

Data collection

The licensing process was conducted with the school to communicate with parents. Parents who objected to their children being involved in this study were not included in the survey. For students whose parents were willing to be involved in the survey, at the time of data collection, the interviewerfirst explained the purpose of the interview and once again asked about the willingness of prospective respondents to be interviewed and blood Hb and anthropometric checks (upper arm circumference, height, and weight) were carried out.

Variables

The dependent variable in this study was CED (based on measurement of upper arm circumference <23,5 cm). Several independent variables were considered, including sociodemographic characteristics (such as school, class, location of residence, father's occupation, mother's occupation, father's education, and mother's education), history of illness (TB and worm infection), dietary behavior (frequency of daily meals, dietary restrictions, consumption of animal side dishes, consumption of green vegetables), BMI, and the level of knowledge of respondents regarding anemia..

Data analysis

In this study, descriptive presentation of the frequency distribution of each variable was conducted in this study, univariate, bivariate (chi square) and multivariate (mathematical model logistic regression) analyses were then conducted to identify factors associated with CED in adolescent girls. Bivariate analyses were conducted to examine the association between one variable and CED without controlling for other variables using a significance value of 0,05).

Data were analysed in stages including univariate, bivariate and multivariate analyses. Univariate analysis was conducted to obtain information about the risk categories of the dependent variable and of each independent variable. In addition, the data were relatively homogeneous if the proportion of one of the categories was ≤ 15 %. Bivariate analysis aimed to determine the significance of the relationship between each independent variable and the dependent variable and at the same time calculate the magnitude of risk using the Prevalence Odds Ratio (POR) indicator.

The significance of the relationship is known by 1) using the Chi Square test where p≤0,05 means significant, or p>0,05 means not significant; 2) Determining the 95 % Confidence Interval (CI) of the POR; if 95 % CI: POR: >1->1 means significant, if 95 % CI: POR: <1-<1 means inversely significant, if 95 % CI: POR: <1->1 means not significant. Multivariate analysis aims to determine the most dominant variable and which is truly related to the dependent variable. To perform multivariate analysis of the dependent variable with categorical data, multiple logistic regression test was used.

Bivariate Selection, After performing bivariate analysis between each independent variable and its dependent variable, if the bivariate test results have a p value ≤ 0,25, then the independent variable is included in the multivariate modelling. For independent variables whose bivariate p > 0,25 but are considered substantively important, they can be included in the multivariate model.

Multivariate Modelling, Selecting variables that are considered important in the model, by retaining independent variables that have p ≤ 0,05 and removing p > 0,05 but gradually starting from the variable that has the largest p value to the smallest p value. After exclusion, the change in POR was examined; if the change in POR was >10 %, the variable became a confounding variable and was still included in the multivariate modelling; if the change in POR was <10 %, the independent variable was removed from the model.

RESULTS

Univariate Analysis

Risk of CED, Most individuals were not at risk of Chronic Energy Deficiency (CED). However, there are still some individuals who are at risk, so special attention needs to be paid to this group in terms of nutritional monitoring and nutritional interventions.

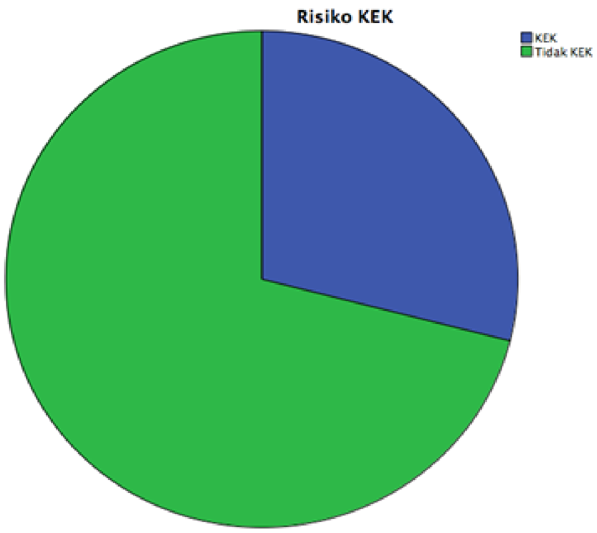

Figure 3. Initial network visualization

Bivariate Analysis

The association of several independent variables with the provision of basic munisation can be seen in the table 1. Frequency distribution of CED factors with CED risk.

Table 1. Frequency distribution of CED factors with CED risk

Variables	Risk of CED				Total		
	KEK		tdk KEK				
	f	%	f	%	f	%	P Value
Energy Intake							
Less	17	58,6	58	81,7	75	100	0,016
Enough-More	12	41,4	13	18,3	25	100	
Asupan Protein							
Less	9	31,1	35	49,3	44	100	0,095
Enough-More	20	69,0	36	50,7	56	100	
Aaupan Karbohidrat							
Less	15	51,7	54	76,1	69	100	0,017
Enough-More	14	48,3	17	23,9	31	100	
Asupan Lemak							
Less	17	58,6	58	81,7	75	100	0,016
Enough-More	12	41,4	13	18,3	25	100	
Asupan Zat Besi (Fe)							
Less	23	79,3	59	83,1	82	100	0,655
Enough-More	6	20,7	12	16,9	18	100	
Kategori Pengetahuan							
Less	19	65,5	37	52,1	56	100	0,220
Good	10	34,5	34	47,9	44	100	
Kategori Usia							
Early Adolescence	5	17,2	9	8,5	11	100	0,202
Middle Adolescence	24	82,8	65	91,5	89	100	
Status Gizi							
Underweight	13	44,8	1	1,4	14	100	
Normal-Overweight	16	55,2	70	98,6	86	100	0,000
Kepribadian							
Not good	16	55,2	35	49,3	51	100	0,594
Good	13	44,8	36	50,7	49	100	
Citra Tubuh							
Not Satisfied	18	62,1	32	45,1	50	100	0,123
Satisfied	11	37,9	39	54,9	50	100	
Media Sosial							
Influential	15	51,7	39	54,9	54	100	0,770
No	14	48,3	32	45,1	46	100	
Tokoh Idola							
Influential	19	65,5	36	50,7	55	100	0,177
No	10	34,5	35	49,3	45	100	
Keluarga							
Influential	20	69,0	50	70,4	70	100	0,885
No	9	31,0	21	29,6	30	100	
Teman sebaya							
Influential	20	69,0	46	64,8	66	100	0,689
No	9	31,0	25	35,2	34	100	
Aktifitas fisik							
Mild	19	65,5	45	63,4	64	100	0,840
Medium	10	34,5	26	36,6	36	100	

Table 1, shows that three variables were not significantly associated with the provision of basic immunisation (knowledge, age and trust), while four other variables (energy intake, carbohydrate intake, fat intake and nutritional status) were significantly associated with Chronic Energy Deficiency in Adolescent Girls.

This pie chart shows the distribution of Chronic Energy Deficiency (CED) risk within the analysed cohort. The blue section represents the percentage of individuals at risk of CED, while the green section shows those who are not at risk. It can be seen that most individuals in this cohort are not at risk of CED, with a much larger percentage than those at risk. In conclusion, while the majority of individuals have adequate nutritional status, there are still some who are at risk of CED and require special attention. Appropriate nutrition interventions can help reduce this risk, favouring improvements in the overall health status of the group.

Multivariate Analysis

Hypothesis testing to find the strength of the association between energy, carbohydrate, and fat intake and risk of CED. The analysis used SPSS version 24.0. The results of the analysis using multiple logistic regression were as follows: There is a significant relationship between energy, carbohydrate, and fat intake with the risk of CED.

Table 2. Multivariate analysis (first modelling) of factors associated with Chronic Energy Deficiency

Variables in the Equation		B	S.E.	Wald	df	Sig.	Exp(B)	95 % C.I.for EXP(B)	
								Lower	Upper
Step 1[a]	AsupanEnergi	0,144	1,005	0,021	1	0,886	1,155	0,161	8,284
	AsupanProtein	-0,526	0,726	0,526	1	0,468	0,591	0,142	2,451
	AsupanKH	-0,334	0,772	0,188	1	0,665	0,716	0,158	3,251
	AsupanLemak	-0,694	0,841	0,682	1	0,409	0,500	0,096	2,595
	StGz	4,312	1,162	13,775	1	0,000	74,592	7,651	727,175
	KatCitra	1,454	0,643	5,122	1	0,024	4,282	1,215	15,090
	Constant	-7,200	2,777	6,723	1	0,010	0,001		

Table 2, shows the results of Energy Intake, Protein Intake, KH Intake, Fat Intake: Each is the intake of nutrients (energy, protein, carbohydrate, and fat). The B coefficient is negative or close to zero and the p value (Sig.) is high, indicating that there is insufficient evidence to suggest that these variables significantly affect the risk of SEZ. StGz (Nutritional Status): This variable has a very high and positive B value, with a Sig. value of less than 0,05. This result indicates that nutritional status significantly increases the odds of a particular outcome. The very high odds ratio (74,592) indicates that nutritional status is a strong predictor. KatCitra (Self-Image Category): This variable is also significant (Sig. = 0,024), with an odds ratio of 4,282, indicating that self-image category has a significant effect on the dependent variable.

Constant, this is the constant or intercept of the regression model. The B value is negative and significant, indicating that when all independent variables are zero, the log-odds of the dependent variable is -7,200. Based on the results of this logistic regression model analysis, the variables 'Nutritional Status' (StGz) and 'Self-Image Category' (KatCitra) were significant predictors of CED risk. Energy, protein, carbohydrate, and fat intake did not contribute significantly to the model. The model suggests that individuals with good nutritional status or a particular self-image category have a much higher likelihood of achieving the outcomes predicted by the model.

Table 3. Multivariate analysis (second modelling) of factors associated with Chronic Energy Deficiency

Variables in the Equation		B	S.E.	Wald	df	Sig.	Exp(B)	95 % C.I.for EXP(B)	
								Lower	Upper
Step 2[a]	AsupanProtein	-0,504	0,710	0,504	1	0,478	0,604	0,150	2,430
	AsupanKH	-0,286	0,696	0,169	1	0,681	0,751	0,192	2,937
	AsupanLemak	-0,621	0,672	0,855	1	0,355	0,537	0,144	2,004
	StGz	4,300	1,157	13,824	1	0,000	73,696	7,639	710,990
	KatCitra	1,447	0,640	5,114	1	0,024	4,249	1,213	14,884
	Constant	-7,176	2,767	6,725	1	0,010	0,001		

Table 3, shows that 1) Protein Intake with Coefficient B (-0,504) means that an increase in protein intake slightly decreases the log-odds of the dependent variable. Sig. (0,478) is not statistically significant, indicating that the effect of protein intake is not strong enough to be considered important with SEZ risk. Odds Ratio (0,604), indicating a decrease in the odds of CED risk when protein intake increases, but not

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significant. 2) Carbohydrate intake, with Coefficient B (-0,286), also showed a slight decrease in the log-odds of the dependent variable with an increase in carbohydrate intake. The Sig. (0,681) is not significant, indicating that carbohydrate intake does not significantly affect the risk of CED. Odds Ratio (0,751), slightly reduced the risk of CED, but the effect was not significant. 3) Fat intake, with Coefficient B (-0,621) indicating a decrease in the log-odds of the dependent variable with an increase in fat intake. The Sig. value of (0,355) is not significant, indicating that fat intake is not strong enough to significantly affect the risk of CED. Odds Ratio (0,537), Reduced risk of CED, but not significant. 4) StGz (Nutritional Status), with Coefficient B (4,300) indicates that nutritional status significantly increases the log-odds of the predicted outcome. With a Sig. value of (0,000) it is highly significant, indicating that nutritional status is a strong predictor of the risk of CED. Odds Ratio (73,696), very high, indicates a large increase in the risk of CED with an increase in nutritional status.5) KatCitra (Self-Image Category), Coefficient B (1,447) indicates that self-image category significantly increases the log-odds of CED risk. Sig. (0,024), Significant, indicates the effect of self-image category on the risk of CED. Odds Ratio (4,249): Indicates an increase in CED risk, and the effect is significant. Constant, Coefficient B (-7,176): Indicates that when all independent variables are zero, the log-odds of the outcome is -7,176. Sig. (0,010): Significant, indicating that the constant has an effect in this model.

Based on the results of the logistic regression model analysis, the variables 'Nutritional Status' (StGz) and 'Self-Image Category' (KatCitra) remained significant predictors of CED Risk. Protein, carbohydrate, and fat intake were all insignificant, meaning they did not make an important contribution to predicting SEZ in this model. These results are consistent with the results from Step 1a, showing that nutritional status and self-image are important factors in the model, while other nutrient intakes are not significant.

Table 4. Multivariate analysis (third modelling) of factors associated with Chronic Energy Deficiency

Variables in the Equation								95 % C.I.for EXP(B)	
		B	S.E.	Wald	df	Sig.	Exp(B)	Lower	Upper
Step 3a	AsupanProtein	-0,639	0,626	1,043	1	0,307	0,528	0,155	1,799
	AsupanLemak	-0,658	0,663	0,984	1	0,321	0,518	0,141	1,900
	StGz	4,350	1,152	14,249	1	0,000	77,509	8,097	741,924
	KatCitra	1,482	0,636	5,433	1	0,020	4,401	1,266	15,302
	Constant	-7,440	2,708	7,548	1	0,006	0,001		

Table 4, shows that 1) Protein Intake, Coefficient B (-0,639) means that an increase in protein intake is associated with a decrease in the log-odds of the dependent variable. Sig. (0,307) is insignificant, indicating that the effect of protein intake on outcome is not strong enough to be considered important in this model. Odds Ratio (0,528), indicates a decrease in the odds of the outcome as protein intake increases, but the effect is not significant. 2) Fat intake with coefficient B (-0,658): Indicates that an increase in fat intake is also associated with a decrease in the log-odds of the outcome. Sig. (0,321) is not significant, indicating that the effect of fat intake on outcome is not strong enough in this model. Odds Ratio (0,518): Reduced odds of outcome, but not significant. 3) StGz (Nutritional Status), Coefficient B (4,350): Indicates that nutritional status has a very strong significant effect in increasing the log-odds of the outcome. Sig. (0,000): Highly significant, showing that nutritional status is a strong predictor in this model. Odds Ratio (77,509): Very high, indicating a large increase in the odds of the outcome with an increase in nutritional status. 4) KatCitra (Self-Image Category), Coefficient B (1,482), indicates that self-image category significantly increases the log-odds of the outcome. Sig. (0,020): Significant, indicating that self-image category has a significant effect on the outcome. Odds Ratio (4,401), indicating an increase in the odds of the outcome, and the effect is significant. 5) Constant, Coefficient B (-7,440), indicates that when all independent variables are zero, the log-odds of the outcome is -7,440. Sig. (0,006): Significant, indicating that the constant is important in this model.

Based on the results of Step 3a analysis, the logistic regression model showed that the variables 'Nutritional Status' (StGz) and 'Self-Image Category' (KatCitra) remained highly significant predictors of the outcome. Protein and fat intake, despite having a negative influence on the log-odds of the outcome, remained statistically insignificant. This model further reinforces the finding that nutritional status and self-image are the main factors in influencing the predicted outcomes, while other nutrient intakes such as protein and fat do not make a significant contribution. This suggests that for certain outcomes, nutritional status and self-image may be more important than more specific nutrient intake patterns.

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Table 5. Multivariate analysis (fourth modelling) of factors associated with Chronic Energy Deficiency

Variables in the Equation		B	S.E.	Wald	df	Sig.	Exp(B)	95 % C.I.for EXP(B)	
								Lower	Upper
Step 4	Protein Intake	-0,850	0,583	2,123	1	0,145	0,428	0,136	1,341
	StGz	4,450	1,146	15,084	1	0,000	85,664	9,066	809,425
	KatCitra	1,466	0,631	5,405	1	0,020	4,331	1,259	14,906
	Constant	-8,110	2,667	9,245	1	0,002	0,000		

Table 5, shows 1) Protein Intake, Coefficient B (-0,850), indicates that an increase in protein intake is associated with a decrease in the log-odds of the outcome. Sig. (0,145): Not statistically significant (p value > 0,05), indicating that the effect of protein intake on outcome is not strong enough to be considered important in this model. Odds Ratio (0,428): Indicates a decrease in odds of outcome as protein intake increases, however the effect is not significant. 2) StGz (Nutritional Status), Coefficient B (4,450): Indicates that nutritional status is highly influential in increasing the log-odds of the outcome. Sig. (0,000): Highly statistically significant, indicating that nutritional status is a strong predictor in this model. Odds Ratio (85,664): Very high, indicating that improving nutritional status drastically increases the odds of the outcome. 3) KatCitra (Self-Image Category), Coefficient B (1,466) indicates that self-image category also significantly increases the log-odds of the outcome. Sig. (0,020): Statistically significant, indicating that self-image category has an important influence on the outcome. Odds Ratio (4,331), indicating that individuals with certain self-image categories have greater odds of the outcome, and this effect is significant.

4) Constant, Coefficient B (-8,110) indicates that when all independent variables are zero, the log-odds of the outcome is -8,110. Sig. (0,002): Statistically significant, indicating that this constant is important in this model. Based on the results of the analysis in Step 4a, the logistic regression model simplifies the variables considered and still shows that “Nutritional Status” (StGz) and “Self-Image Category” (KatCitra) are highly significant predictors of the outcome. Protein intake, despite showing a negative association with outcome, was not statistically significant in this model. This model further confirms that nutritional status and self-image have an important role in influencing the predicted outcomes. With a very high odds ratio for nutritional status, the model suggests that nutritional status is the main determinant, while protein intake does not play a significant role. This indicates that interventions that focus on improving both nutritional status and perceived self-image may be more effective in achieving the desired outcome than simply addressing protein intake.

Table 6. Multivariate analysis (fifth modeling) of factors associated with Chronic Energy Deficiency

Variables in the Equation		B	S.E.	Wald	df	Sig.	Exp(B)	95 % C.I.for EXP(B)	
								Lower	Upper
Step 5[a]	StGz	4,464	1,135	15,482	1	0,000	86,844	9,397	802,557
	KatCitra	1,340	0,617	4,723	1	0,030	3,819	1,141	12,785
	Constant	-9,307	2,562	13,197	1	0,000	0,000		

Table 6, shows 1 StGz (Nutritional Status) with coefficient B (4,464) indicates that nutritional status has a very strong influence in increasing the log-odds of the outcome. Sig. (0,000) means highly statistically significant, confirming that nutritional status is a very strong predictor in this model. Odds Ratio (86,844): Very high, indicating that improving nutritional status drastically increases the odds of the outcome. This confirms that nutritional status is a key factor in determining the outcome. 2) KatCitra (Self-Image Category) Coefficient B (1,340) indicates that self-image category also has a significant influence in increasing the log-odds of the outcome. Sig. (0,030) is statistically significant, indicating that self-image category is an important variable in this model. The Odds Ratio (3,819) indicates that individuals with a certain self-image category have a greater chance of the outcome, and this effect is significant. 3)Constant coefficient B (-9,307) indicates that when all independent variables are zero, the log-odds of the outcome is -9,307. Sig value. (0,000): Highly statistically significant, indicating that this constant is important in this model.

As a result of this Step 5a analysis, the logistic regression model shows a highly simplified result with only two variables remaining: “Nutritional Status” (StGz) and ‘Self-Image Category’ (KatCitra). Both are highly significant predictors of the outcome, with nutritional status having a very strong effect and self-image also having a significant effect.

The model confirms that for predicting desired outcomes, nutritional status is the main determinant, with a very high odds ratio indicating that improvements in nutritional status greatly increase the likelihood of a positive outcome. The self-image category is also important, although its influence is not as great as nutritional status. As such, interventions focused on improving nutritional status and self-image are likely to be highly effective in achieving the desired outcome.

DISCUSSION

The findings extend a previous cross-sectional study of adolescent girls aged 15-19 with 100 samples. Chronic Energy Deficiency (CED) in adolescent girls is a serious health problem, especially in developing countries.[3] Factors that influence CED include nutrient intake, nutritional status, and various social and psychological aspects. Analyses showed that several nutritional factors, such as energy, carbohydrate and fat intake, had significant associations with CED risk.[1,19] Nutritional status is also a strong predictor of CED risk, with underweight adolescent girls being more vulnerable.[39] Other factors such as knowledge, personality, and social influence (social media, family, and peers) did not show a significant association with CED risk.[40]

Based on the results of the bivariate analysis conducted, it was found that energy, carbohydrate, and fat intake had a significant association with the risk of CED. Adolescent girls with deficient intake in these three aspects have a higher risk of developing CED.[2,44] Relevant research supports these findings by showing that inadequate energy intake contributes to an increased risk of CED, especially among adolescents.[5] For example, a study by [5,45] found that caloric déficit significantly increased the risk of CED in the adolescent population. In addition, a study by [43] showed that adequate carbohydrate intake plays an important role in preventing CED, as complex carbohydrates help fulfil daily energy needs and support optimal health. Similarly, research by [44] revealed that fat, as an important source of energy, also contributes to the prevention of CED, with fat deficiency exacerbating the risk of CED.

These findings emphasise the importance of ensuring adequate intake of energy, carbohydrates and fats to prevent CED and support healthy nutritional status.[45,46] The analysis showed the importance of ensuring adequate nutrient intake in the prevention of CED. Nutritional status also emerged as a significant factor, with adolescents with underweight nutritional status having a higher risk of developing CED. Relevant research supports these findings by highlighting the role of nutrient intake in the prevention of CED. The study by [10] showed that robust energy intake significantly reduced the risk of CED in adolescents. Research by [6] also found that a lack of carbohydrates and fat in the diet can increase the risk of CED, underscoring the need for adequate nutrition in the daily diet. In addition, nutritional status acts as a significant factor in the risk of SEE (Severe Eating Disorder); adolescents with underweight nutritional status show a higher risk of experiencing SEE, as found in the study by [41,49] The findings emphasise the need for attention to nutritional status and adequate nutrient intake for CED prevention as well as long-term health support in adolescents.[50,51] The findings underscore the importance of ensuring adequate nutrient intake to prevent CED and also emphasise the need for attention to the nutritional status of adolescents.[52,53]

These factors are highly relevant to consider in the development of RF-AR applications. The app can be optimised with features that monitor the user's daily nutrient intake and provide appropriate dietary recommendations to reduce the risk of CED.[51] By utilising real-time data from the user, the app can provide alerts if there are indications of insufficient nutrient intake, thus enabling early intervention.[55,56] Furthermore, while social and psychological factors such as personality, body image, and influences from social media, family, and peers did not show significant associations with CED risk in this analysis, they remain important to consider in a broader context. Supported by a study by [54] found that psychosocial factors may influence eating behavior and nutritional status; however, their association with the risk of Chronic Energy Deficiency (CED) was not statistically significant. The study by [54] also confirmed that although influences from social media and social environment may affect diet, a direct relationship between these factors and CED risk was not found in their data. This suggests that while social and psychological factors may have an impact on other aspects of health, in the context of CED, they do not contribute significantly to increased risk.[59,60] These factors may influence adolescents' eating behaviours and perceptions of their health and weight, which in turn may influence their nutritional status and risk of CED.[58]

The RF-AR app can incorporate educational modules and psychological support to help young women understand the importance of adequate nutrition and building a positive body image.[59] Thus, the app not only focuses on the physical aspect but also on the mental and emotional aspects of the user. The development of mobile health applications such as RF-AR is very relevant in today's digital era.[59] It can be an effective tool for early detection and intervention of CED, especially among vulnerable adolescent girls. With features such as nutrition tracking, food intake reminders, and dietary guidance, as well as integration with other health data, this app can provide comprehensive support for adolescent girls to prevent CED.[60]

The findings of this study indicate that it is necessary to develop RF-AR applications with features designed for 1) Early detection, using user input data to monitor nutritional intake and nutritional status in real-time, providing early warnings if there are indications of CED. 2)Effective Intervention, providing educational information and personalised advice to increase nutritional intake and improve nutritional status. 3)Engagement, using Augmented Reality technology to make the user experience more interesting and interactive, motivating adolescent girls to improve their eating habits.

This study faced some important limitations that need to be noted. The cross-sectional approach limits the ability to establish cause-and-effect relationships or observe changes over time in Chronic Energy Deficiency (CED). Although it involved samples from different socioeconomic and geographic backgrounds, its representativeness may be limited, and insufficient sample size may affect the generalizability of the results. Data collection through surveys may be affected by respondent bias and self-report inaccuracies, while multifactorial analysis may not cover all relevant factors. The effectiveness of RF-AR application as a CED prevention and treatment tool needs to be further tested in longitudinal studies and clinical trials. Limited time and resources may also affect the depth of the study, while ethical considerations related to adolescent girls add complexity to data collection and interpretation of results. To address these limitations, Future studies should aim to overcome these limitations by adopting longitudinal and mixed-method designs, increasing sample diversity, and further evaluating the RF-AR application in broader, real-world contexts.

CONCLUSION

This study reveals that Chronic Energy Deficiency (CED) in adolescent girls is strongly influenced by inadequate nutrient intake, particularly energy, carbohydrates, and fats, along with a low nutritional status. Findings indicate that adolescents with deficient nutrient intake and an underweight status are at a higher risk for CED. Although psychosocial factors like social media, family, and peer influence did not show a significant association with CED risk, they remain relevant in shaping eating behaviors and health perceptions. These insights underscore the potential of the RF-AR mobile health application as an effective tool for early detection and intervention in CED prevention, using real-time nutrition monitoring, educational modules, and interactive augmented reality features. However, the study's limitations, including its cross-sectional design and reliance on self-reported data, suggest the need for further research through longitudinal studies and clinical trials to validate the app's effectiveness. Overall, ensuring adequate nutrient intake and improving nutritional status are essential for CED prevention, and digital solutions like the RF-AR app present an innovative approach to supporting adolescent girls' nutritional health comprehensively.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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