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Quality of Iron Tablet Consumption and Sleep Quality as Predictors of Anemia among Adolescent Girls

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ABSTRACT

Anemia remains a major public health concern among adolescent girls in Indonesia. It can impair growth and concentration and may have long-term consequences, including complications during pregnancy and childbirth and adverse health outcomes for offspring. The reported prevalence of anemia among adolescent girls is 35.5% nationally and 11.47% in Mojokerto Regency in 2024. This case-control study examined the associations of iron (Fe) tablet consumption quality, sleep quality, body mass index (BMI), mid-upper arm circumference (MUAC), and family income with anemia among female senior high school students. A total of 342 participants, comprising 171 girls with anemia and 171 without anemia, were randomly selected from 3,038 girls who underwent hemoglobin testing at community health centers. Data were collected through interviews conducted between June and July 2026. Anemia status was obtained from secondary health center records, sleep quality was assessed using the Pittsburgh Sleep Quality Index (PSQI), and Fe tablet consumption quality was measured using a checklist. Data were analyzed using chi-square tests and multivariable logistic regression in SPSS version 25. Poor sleep quality (adjusted odds ratio [AOR] = 7.463; 95% CI: 3.817–14.706), at-risk BMI (AOR = 3.460; 95% CI: 2.083–5.747), family income below the regional minimum wage (AOR = 2.004; 95% CI: 1.206–3.333), and poor Fe tablet consumption quality (AOR = 1.866; 95% CI: 1.121–3.106) were significantly associated with anemia, whereas MUAC was not (p = 0.729). In conclusion, poor sleep quality, at-risk BMI, lower family income, and poor Fe tablet consumption quality were independently associated with anemia among adolescent girls in the study population.

INTRODUCTION

Anemia is a condition in which the number or size of red blood cells, or the hemoglobin concentration, falls below standard normal. The World Health Organization (WHO) defines anemia as a hemoglobin concentration below 12.0 g/dL in non-pregnant girls and women aged 12 years and older, and below 13.0 g/dL in men aged 15 years and older[1]. Iron deficiency is the most common cause of anemia worldwide, arising from inadequate dietary iron, increased physiological requirements, and blood loss. Among adolescents, anemia is more common in girls than in boys. This difference largely stems from iron loss during menstruation, which increases adolescent girls' iron needs[2]. A study carried out by Zhu et al. on adolescents in western China showed that adolescent girls had a risk of anemia 1.73 times greater than that of adolescent boys[3]. This is because adolescent girls need to take in more iron in order to support the growth of their reproductive organs, to replace

the blood lost during menstruation, and to make up for the fact that their dietary patterns tend to involve a greater reliance on plant-based foods which have a lower iron content[4].

Accordingly, the Indonesian recommended dietary allowance for iron rises from 8 mg/day for girls aged 10–12 years to 15 mg/day for girls aged 13–18 years. The Ministry of Health standard issued specifies a tablet containing 60 mg of elemental iron and 0.4 mg of folic acid, taken once a week and once daily during menstruation[5]. Anemia makes it harder for blood to carry oxygen, which can lower concentration, physical endurance, and activity in adolescents. For girls, anemia can also affect cognitive development, physical growth, and future pregnancies, raising health risks for both mother and child[6]. Adolescent girls with anemia who later become pregnant may be unable to meet their own nutritional needs and those of the fetus, thereby increasing the risk of pregnancy and delivery complications, maternal mortality, prematurity, stunting, low birth weight, and perinatal mortality[7].

Globally, the number of anemia cases increased from 1.42 billion in 1990 to 1.74 billion in 2019 across 204 countries, with West Africa, South Asia, and Central Africa contributing the highest burden. In 2019, the point prevalence of anemia among females was highest in the 15–19-year age group[8]. The WHO estimated that about 30% of women aged 15–49 years worldwide were anemic in 2019, while the prevalence among Indonesian women of this age was 31.2%[9]. The 2018 Basic Health Research (Riskesdas) reported an anemia prevalence of 23.7% in the Indonesian population overall (27.2% in females and 20.3% in males), 32.0% among those aged 15–24 years, and 48.9% among pregnant women. In 2018, 76.2% of adolescent girls received tablets, but only a very small proportion (below 3%) consumed the recommended 52 tablets per year[10]. At the regional level, in 2020, there was an anemia prevalence of 42% among adolescent girls in East Java[11]. In Mojokerto Regency, where this study was conducted, the anemia prevalence among adolescent girls was 13.41% in 2023 and 11.47% in 2024, with the highest proportion found among high school students[12].

The quality of Fe tablet consumption affects anemia in adolescent girls, both in the amount consumed and how they take them. Adolescent girls who do not regularly consume Fe tablets have a 3.375-fold higher risk of anemia[13]. Vitamin C enhances the absorption of non-heme iron, and combining iron with vitamin C improved iron status in young women in a dietary intervention study[14]. Diet also shapes adolescent iron status: among adolescent girls in West Java, lower consumption of meat, chicken, and fish was correlated with anemia[15]. Nutritional status and socioeconomic circumstances may also be related to anemia. Low body mass index (BMI) and low mid-upper arm circumference (MUAC) are markers of chronic energy and protein inadequacy, which often co-occurs with a low intake of iron-rich foods, and both indicators have been proposed as initial screening tools for anemia risk in adolescent girls[16]. A meta-analysis of studies from six countries found that underweight girls had higher odds of anemia than girls with normal BMI[17].[19] Lower household income

has likewise been associated with anemia among adolescent girls in several settings[18]. These factors can be viewed as acting mainly through iron supply relative to need: family income shapes access to iron-rich foods, BMI and MUAC reflect the adequacy of energy and protein intake, and Fe tablets supplement the diet.

Sleep quality is a less established correlate. Poor sleep quality and depressive symptoms were associated with lower hemoglobin concentration among Indonesian adolescents aged 10–19 years during the COVID-19 pandemic[19], and a cross-sectional study of Indonesian adolescent girls linked anemia to both diet and sleep quality[20]. The direction of this association is uncertain, however: iron deficiency has itself been associated with disturbed sleep[21], and a recent cross-sectional study found that lower hemoglobin was associated with poorer sleep quality among adolescent girls[22]. Proposed pathways from poor sleep to anemia include altered appetite and dietary intake and heightened stress and inflammatory responses that can impair iron utilization. In contrast, iron deficiency may in turn disturb sleep, so the relationship is plausibly bidirectional. Few studies have examined sleep quality alongside Fe tablet use among Indonesian adolescents, and evidence on how sleep relates to anemia after accounting for Fe tablet use is scarce. Our contribution is therefore a local, adjusted estimate of these associations and not a new mechanism. This study aimed to examine the association of Fe tablet consumption quality and sleep quality, the two primary exposures, with anemia among senior high school girls in Mojokerto Regency. We included BMI, MUAC, and family income as secondary exposures. Dietary iron intake and menstrual characteristics were unavailable for analysis, and the consequences of this limitation are discussed.

MATERIALS AND METHODS

This study employed an analytical observational design with a retrospective case-control approach. The study began by identifying adolescent girls with anemia (case group) and adolescent girls without anemia (control group), followed by a retrospective inquiry into Fe tablet consumption and sleep quality, which were compared between the two groups, together with BMI, MUAC, and family income, to assess the magnitude of association with anemia. The study was conducted in Mojokerto Regency, East Java. The study population comprised 3,038 high school girls who underwent hemoglobin testing at community health centers in Mojokerto Regency in 2025; those with anemia formed the case group, and those without anemia formed the control group.

The sampling frame was the list of these 3,038 girls with their hemoglobin results, obtained from the nutrition program coordinator at the community health centers. We selected case and control samples from this list through simple random sampling using the case-control sample size formula, applying the control proportion (P_2) and odds ratio (OR) values from Fitria & Puspita[20], which yielded a minimum sample size of 171 per group. The case-to-control ratio was 1:1, resulting in a total sample

of 342 respondents (171 cases and 171 controls) drawn from the 3,038 girls in the sampling frame. The selected girls were then located and interviewed at their schools. All 342 selected girls were included in the analysis and had complete data for all variables, so no respondent was excluded for missing data.

Fe tablet consumption quality was defined as categorical, based on a checklist covering (i) the regularity of Fe tablet intake, namely one tablet weekly and one tablet daily during menstruation, following the national standard, and (ii) co-ingestion with vitamin C. We dichotomized the score at the sample mean (poor if score ≥ mean; good if score < mean). We measured sleep quality using the Pittsburgh Sleep Quality Index (PSQI), in its Indonesian version, a self-reported questionnaire of 19 items that yields seven component scores (subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleeping medication, and daytime dysfunction), each scored 0–3 and summed to a global score of 0–21. We dichotomized sleep quality at the established cut-off of 5 (poor if global score > 5; good if global score ≤ 5). In the original validation, the PSQI had an internal consistency (Cronbach's α) of 0.83 across its seven components and a test–retest reliability of 0.85, and a global score above 5 distinguished poor from good sleepers with a sensitivity of 89.6% and a specificity of 86.5%. We categorized BMI as at risk if Z-score < −2 SD and not at risk if Z-score ≥ −2 SD. We categorized MUAC as at risk if < 23.5 cm and not at risk if ≥ 23.5 cm, the threshold commonly applied in Indonesian programs for women of reproductive age. We categorized family income as below (< UMR) or at/above (≥ UMR) the regional minimum wage based on parental monthly income.

This study's dependent variable was anemia, while the independent variables included Fe tablet consumption quality, sleep quality, body mass index (BMI), mid-upper arm circumference (MUAC), and family income. Anemia was defined as a hemoglobin level below 12 g/dl among adolescent girls, based on Community Health Center reports, and measured as yes/no. Fe tablet consumption quality was measured using a checklist assessing regularity (once a week and once daily during menstruation), along with vitamin C intake, on an ordinal scale (poor if score ≥ mean; good if score < mean). We measured sleep quality using a checklist assessing freshness upon waking, sleep depth, and an ideal sleep duration of ≥ 8 hours/day, on an ordinal scale (poor if score > 5; good if score ≤ 5). BMI was categorized as at risk if < 18.5 and not at risk if ≥ 18.5. We categorized MUAC as at risk if < 23.5 cm and not at risk if ≥ 23.5 cm. We categorized family income as below (< UMR) or at/above (≥ UMR) the regional minimum wage based on parental monthly income.

Primary data were collected in June–July 2026 through structured interviews lasting 30–45 minutes using a questionnaire covering Fe tablet consumption and sleep quality, conducted through school visits. Before data collection, researchers explained the study's purpose and benefits to respondents, who then signed an informed consent form. The researchers obtained secondary data

on anemia incidence, including hemoglobin values, from the Community Health Centers. The researchers processed the collected data through editing, coding, scoring, and tabulating. The data were then analyzed using IBM SPSS Statistics version 25 in stages: univariate analysis (frequency distribution), bivariate analysis using the Chi-Square test to assess the association between each independent variable and anemia, and multivariate analysis using multiple logistic regression with the Backward Stepwise (Wald) method, in which all five variables were entered in the first step, to obtain the final model and to assess model fit (Hosmer-Lemeshow test), model strength (Nagelkerke R Square), and classification accuracy.

We set statistical significance at $p < 0.05$. We also quantified the sensitivity of the adjusted associations to unmeasured confounding using E-values, treating the AORs as approximate risk ratios because anemia prevalence in the source population is about 11–13%. To aid public-health interpretation, we also estimated the approximate attributable fraction for each factor from the adjusted odds ratio and the proportion of cases exposed, using Miettinen's formula: attributable fraction = (proportion of cases exposed) × (AOR − 1)/AOR. Ethical approval was obtained from the Health Research Ethics Committee of Sekolah Tinggi Ilmu Kesehatan (STIKES) Majapahit (ethical clearance No. 173/EC-SM/2026). Consent procedures are described below.

This study has several limitations: it did not assess important factors such as dietary iron intake, menstrual blood loss, infection status, and breakfast habits, which may lead to residual confounding. The absence of iron biomarkers prevents the differentiation between iron-deficiency anemia and other types of anemia. Hemoglobin data were obtained from routine health records, while self-reported exposures are susceptible to both recall and reporting biases. We did not include age in the analysis as a potential confounder. The 1:1 case-control ratio limits the interpretation of predicted probabilities and classification accuracy at the population level. Furthermore, the model has not undergone external validation or ROC analysis. Finally, the sensitivity analysis was limited to E-values, and the study's scope, restricted to a single regency, limits the findings' generalizability.

RESULTS

This study included 342 respondents, equally divided between the anemia and non-anemia groups (171 respondents, 50.0% in each). Most respondents had a family income ≥ the regional minimum wage (53.8%), a not-at-risk BMI status (60.2%), and a not-at-risk MUAC status (67.5%). Regarding Fe tablet consumption quality, 53.2% of respondents were in the poor category, whereas for sleep quality, most respondents (75.4%) had good sleep quality. Table 1 presents the complete frequency distribution of the study variables. Dietary iron intake, menstrual history, and age were not included in the analysis and are therefore not reported.

Table 1. Frequency Distribution of Study Variables

Variable	Category	n	%
Family income	< regional minimum wage	158	46.2
	≥ regional minimum wage	184	53.8
BMI	At risk	136	39.8
	Not at risk	206	60.2
MUAC	At risk	111	32.5
	Not at risk	231	67.5
Fe tablet consumption quality	Poor	182	53.2
	Good	160	46.8
Sleep quality	Poor	84	24.6
	Good	258	75.4
Anemia status	Anemia	171	50.0
	Non-anemia	171	50.0

Chi-Square test results showed that four of the five independent variables were significantly associated with anemia: family income (p = 0.001; OR = 2.041; 95% CI: 1.325–3.144), BMI (p < 0.001; OR = 3.361; 95% CI: 2.130–5.303), Fe tablet consumption quality (p = 0.030; OR = 1.603; 95% CI: 1.045–2.459), and sleep quality (p < 0.001; OR = 8.629; 95% CI: 4.540–16.400), whereas MUAC showed no significant association (p = 0.729; OR = 1.083; 95% CI: 0.689–1.704, crossing the value of 1). The highest OR in the bivariate analysis was found for sleep quality, indicating that respondents with poor sleep quality had 8.629 times the odds of experiencing anemia compared with those with good sleep quality. Table 2 presents the complete results.

Table 2. Association between Independent Variables and Anemia (Bivariate Analysis)

Variable	Category	Anemia n (%)	Non-anemia n (%)	OR (95% CI)	p
Family income	< regional minimum wage	94 (59.5)	64 (40.5)	2.041 (1.325–3.144)	0.001
	≥ regional minimum wage	77 (41.8)	107 (58.2)	Reference	-
BMI	At risk	92 (67.6)	44 (32.4)	3.361 (2.130–5.303)	<0.001
	Not at risk	79 (38.3)	127 (61.7)	Reference	-
MUAC	At risk	57 (51.4)	54 (48.6)	1.083 (0.689–1.704)	0.729
	Not at risk	114 (49.4)	117 (50.6)	Reference	-
Fe tablet consumption	Poor	101 (55.5)	81 (44.5)	1.603 (1.045–2.459)	0.030
	Good	70 (43.8)	90 (56.3)	Reference	-
Sleep quality	Poor	71 (84.5)	13 (15.5)	8.629 (4.540–16.400)	<0.001
	Good	100 (38.8)	158 (61.2)	Reference	-

We performed multivariate analysis using multiple logistic regression with the Backward Stepwise (Wald) method. In the first step, all five variables were entered into the model; the MUAC variable had a p-value of 0.516 and was therefore removed in the second step. The final model included four variables: family income, BMI, Fe tablet consumption quality, and sleep quality, all of which remained statistically significant (Table 3). Based on the magnitude of the adjusted odds ratio (AOR), poor sleep quality showed the strongest association with anemia (AOR = 7.463; 95% CI:

3.817–14.706; p < 0.001), followed by at-risk BMI (AOR = 3.460; 95% CI: 2.083–5.747; p < 0.001), family income below the regional minimum wage (AOR = 2.004; 95% CI: 1.206–3.333; p = 0.007), and poor Fe tablet consumption quality (AOR = 1.866; 95% CI: 1.121–3.106; p = 0.016).

Table 3. Multiple Logistic Regression Results – Final Model

Variable	B	SE	Wald	p	AOR Anemia (95% CI)
Family income					
< regional minimum wage	-0.695	0.259	7.210	0.007	2.004 (1.206–3.333)
BMI					
At-risk	-1.240	0.258	23.051	<0.001	3.460 (2.083–5.747)
Fe tablet consumption					
Poor	-0.623	0.260	5.752	0.016	1.866 (1.121–3.106)
sleep quality					
Poor	-2.010	0.343	34.368	<0.001	7.463 (3.817–14.706)
Constant	1.553	0.274	32.158	<0.001	-

Exploratory attributable fractions for anemia were calculated, under the assumptions of causal associations and that adjusted odds ratios (AORs) approximate risk ratios. The resulting estimates were 38.3% for at-risk BMI, 36.0% for poor sleep quality, 27.5% for low family income, and 27.4% for poor Fe tablet consumption quality. These estimates are not mutually exclusive and therefore cannot be summed. As AORs may overestimate risk ratios, especially for common outcomes, these results do not imply causal effects or the number of preventable cases. Additionally, reverse causality may influence sleep quality. The case-control study design precluded estimation of population anemia prevalence.

To assess sensitivity to unmeasured confounding, we calculated E-values, treating the AORs as approximate risk ratios. The E-values for the point estimates were 14.4 for sleep quality, 6.4 for BMI, 3.4 for family income, and 3.1 for Fe tablet consumption quality; for the confidence limits closest to 1, they were 7.1, 3.6, 1.7, and 1.5, respectively. An unmeasured confounder would therefore have to be associated with both sleep quality and anemia by a risk ratio of at least 14.4 to explain away the sleep association, which is unlikely for any single confounder, whereas the income and Fe tablet associations could be explained by a confounder of moderate strength such as dietary iron intake. E-values do not address reverse causation, selection, or measurement error. Hosmer-Lemeshow test (p = 0.660) shows good model fit. Nagelkerke R^2 is 0.311, which is a fairly modest level of explanatory power. Overall classification accuracy is 69.0%, with 64.3% of anemia cases (110/171) and 73.7% of non-anemia cases (126/171) correctly classified (Table 4). Again, these figures come from the fixed 1:1 case/control sampling and may not reflect performance in the general population. The model has not been externally validated.

Table 4. Fit and Predictive Ability of the Final Model

Indicator	Result	Interpretation
Omnibus Test of Model Coefficients	$\chi^2 = 90.683$; df = 4; p < 0.001	The full predictor model is significant

Indicator	Result	Interpretation
-2 Log Likelihood	383.430	Deviance measure of the final model
Cox & Snell R Square	0.233	Pseudo-R^2
Nagelkerke R Square	0.311	Model explains ± 31.1% of outcome variation
Hosmer-Lemeshow Test	$\chi^2 = 5.890$; df = 8; p = 0.660	p > 0.05; adequate goodness of fit
Overall classification accuracy	69.0%	Anemia 64.3%; non-anemia 73.7%

Based on the final model, the equation predicting the probability of anemia among adolescent girls is formulated as follows:

$$Z = -1.553 + 0.695X_1 + 1.240X_2 + 0.623X_3 + 2.010X_4 \quad (1)$$

$$P(anemia\ among\ adolescent\ girls) = \frac{1}{1 + e^z} \quad (2)$$

X_1 represents family income, X_2 BMI, X_3 Fe tablet consumption quality, and X_4 sleep quality, with 1 indicating the at-risk category and 0 the reference category. All coefficients were positive, indicating higher odds of anemia in the at-risk groups. Poor sleep quality had the largest coefficient (B = 2.010; AOR = 7.46), indicating the strongest adjusted association with anemia.

DISCUSSION

In this case-control study of senior high school girls in Mojokerto Regency, poor sleep quality, at-risk BMI, family income below the regional minimum wage, and poor Fe tablet consumption quality were each independently associated with anemia, whereas MUAC was not. Because we did not measure dietary iron intake, menstrual characteristics, or iron biomarkers, these findings describe associations with anemia (hemoglobin < 12 g/dL) rather than iron-deficiency anemia, and unmeasured nutritional factors may confound them. With this in mind, we interpret the associations below, starting with socioeconomic and nutritional factors and ending with sleep.

Family income

Family income below the regional minimum wage was associated with higher odds of anemia, in line with a cross-sectional study of adolescent girls in rural public schools in Pune, India, where anemia was more common among girls from families with low income, lower socioeconomic class, and no bank account[18]. A similar gradient was reported among school-going adolescents aged 10–17 years in Zanzibar, Tanzania, where those in the highest household wealth quintile had about 30% lower adjusted odds of anemia than those in the lowest quintile[23], and the odds of anemia fell as monthly family income rose in Azad Jammu and Kashmir, Pakistan[24]. Limited income may restrict household access to animal-source protein and heme iron, which is more bioavailable than plant-based iron, as well as to health services and nutrition education. Still, because dietary intake was not measured here, this pathway remains an interpretation. The income measure itself (parental monthly

income dichotomized at the regional minimum wage, ignoring household size) is also only a coarse proxy for household economic status.

Nutritional status: BMI and MUAC

Nutritional status showed a similar pattern for BMI. Girls with an at-risk BMI had 3.460 times the adjusted odds of anemia, directionally consistent with a meta-analysis of 15 cross-sectional studies including 9,654 adolescent girls from six countries, in which underweight girls had higher odds of anemia than girls with normal BMI (pooled aOR = 1.91; 95% CI: 1.63–2.25)[17]. The larger estimate here may reflect population differences, unmeasured confounding such as dietary intake, or the definition of low BMI. This study applied the adult cut-off of 18.5, whereas BMI-for-age z-scores are the standard for adolescents. Low BMI is a marker of inadequate energy and protein intake, which often co-occurs with inadequate iron intake and can deplete iron reserves; however, the direction of the BMI–anemia association is not uniform across populations[16], so BMI is best treated as one of several screening indicators and not as a sole determinant.

In contrast, MUAC was not associated with anemia in this study ($p = 0.729$; $p = 0.516$ in the multivariate analysis) and was removed from the final model. A scoping review of anthropometric indices in adolescent girls identified BMI and MUAC as possible initial screening indicators for anemia risk. However, it noted that few studies exist and that the relationship is inconsistent across populations[16]. MUAC reflects a combination of muscle mass and subcutaneous fat in the upper arm, which varies with individual adolescent growth rates[16], and it primarily indicates energy–protein status rather than iron status. In addition, the adult threshold of 23.5 cm may misclassify growing adolescents, biasing the association toward the null. In this population, anemia therefore appeared to be more closely associated with behavioral factors and BMI-based nutritional status than with upper arm circumference. However, this comparison is limited by the measurement issues noted above.

Fe tablet consumption quality

Poor Fe tablet consumption quality was associated with higher odds of anemia, consistent with earlier research among adolescent girls in Mojokerto showing that irregular Fe tablet consumption increased anemia risk[13] and with a study in Bekasi Regency that linked consumption-related behavioral factors to anemia[25]. A role for vitamin C is biologically plausible: ascorbic acid enhances the absorption of non-heme iron, whereas phytates and polyphenols reduce it, and a dietary intervention study among young women found that iron combined with vitamin C improved iron status[14]. Because that study was an intervention in a different population, it supports plausibility rather than corroborating our observational association directly.

Fe tablet consumption quality was assessed based on regularity and vitamin C co-ingestion, making it difficult to identify which behavior contributed most to the association. Furthermore, the poor and good categories did not reflect adherence to the recommended intake of at least 52 tablets per

year. Therefore, these findings should be interpreted as associations with consumption quality rather than adherence to the recommended intake[10], and the contrast between the two categories may be small, which may partly explain why the association was weaker than for sleep quality. Among adolescent girls, irregular Fe tablet consumption is frequently influenced by side effects such as nausea, inadequate knowledge regarding the benefits of Fe tablets, and insufficient support from family and the school environment in encouraging adherence to consumption schedules. These factors show the need for school-based Fe tablet supplementation programs that emphasize distribution, along with thorough education and support to encourage consistent use.

Sleep quality

Sleep quality showed the strongest association with anemia in this study. This is consistent with a longitudinal study among adolescents aged 10–19 years in Indonesia during the COVID-19 pandemic, in which poor sleep quality and depressive symptoms were associated with reduced hemoglobin concentration[19], and with a cross-sectional study of Indonesian adolescent girls in which anemia was associated with sleep quality[20]. A cross-sectional study among adolescents in Nepal similarly reported an association between poor sleep quality and several adolescent health problems, including a tendency toward excessive device use that disrupted sleep patterns[26], and a study among adolescents in China found that poor sleep quality was associated with lower physical activity and reduced life satisfaction[27]. Most of this evidence is cross-sectional, and the latter two studies concern sleep and general health rather than hemoglobin.

The association between poor sleep quality and anemia was actually stronger than the association with any of the nutritional factors. This could be a case of reverse causality though, as the fatigue associated with anemia could be the cause of poor sleep quality. There are likely a number of unmeasured factors at play here (dietary iron intake, menstrual blood loss, psychological stress etc.) which may be responsible for the association. The association with the nutritional factors may also be underestimates due to the simplicity of the measures used. The E-value is suggestive of robustness to unmeasured confounding under the risk ratio assumption, but doesn't deal with the issue of reverse causality or measurement overlap. Poor sleep may influence anemia through changes in appetite, stress hormones, dietary intake, and circadian regulation, although these mechanisms remain unclear in adolescents. Nighttime screen use, diet, and physical activity may also affect sleep quality[28,29]. However, our findings do not establish that improving sleep reduces anemia. Sleep hygiene education may complement school-based anemia prevention programs, alongside nutritional interventions, iron supplementation, and WHO-recommended health services[30]. Further prospective studies assessing dietary intake and iron status are needed to clarify this association.

CONCLUSION

This study concludes that family income, BMI, quality of Fe tablet consumption, and sleep quality significantly predict anemia among adolescent girls in Mojokerto Regency, whereas MUAC showed no significant association. Based on the adjusted odds ratios in the final logistic regression model, poor sleep quality was the most dominant predictor (AOR = 7.463), followed by at-risk BMI (AOR = 3.460), family income below the regional minimum wage (AOR = 2.004), and poor Fe tablet consumption quality (AOR = 1.866). The resulting logistic regression model fit well, explaining about 31.1% of the variation in anemia occurrence and achieving a classification accuracy of 69.0%.

Based on these findings, we recommend that anemia prevention and control programs for adolescent girls not only expand coverage and regularity of Fe tablet use, but also broaden to include education on sleep hygiene and healthy lifestyle management, given sleep quality's substantial contribution to anemia risk. School-based programs should involve parents and teachers in supporting regular Fe tablet use and limiting nighttime device use. In addition, school-based interventions should address adolescents' nutritional status (BMI) and family socioeconomic conditions to support early detection of high-risk groups for anemia. Future research should use prospective cohort or intervention designs that measure dietary iron intake and diet diversity, menstrual history, iron biomarkers (ferritin and transferrin receptor or saturation), markers of inflammation, BMI-for-age z-scores, and per-capita household income.

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