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Body Mass Index and Lumbar Lordosis in Children: A Cross-Sectional Study

Ketut Ayu Padma Wati[1*], Gede Parta Kinandana[2], I Putu Gde Surya Adhitya[3]

[1]Undergraduate and Professional Physiotherapy Program, Faculty of Medicine, Udayana University
[2,3]Department of Physiotherapy, Faculty of Medicine, Udayana University

*Correspondence author at. Jl. Raya Kampus Unud, Jimbaran, South Kuta, Badung Regency, Bali 80361, Indonesia
E-mail address: ayu.padma011@student.unud.ac.id

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Abstract

Introduction: Childhood, particularly between the ages of 10 and 12, is a critical growth phase marked by significant physical changes. Body Mass Index (BMI) is a key factor in assessing nutritional status and can influence postural development. An abnormal BMI may contribute to postural disorders, including lumbar hyperlordosis, characterized by excessive curvature of the lumbar spine. This study examines the relationship between BMI and lumbar lordotic curvature in children aged 10–12 years at SD Negeri Kelurahan Panjer to aid in the early prevention of musculoskeletal disorders.
Methods: This cross-sectional study employed an observational analytic approach with purposive sampling, involving 139 children. BMI was measured using weight and height calculations, while lumbar lordotic curvature was assessed using a flexible ruler. Data were analyzed using Spearman's rho correlation test.
Results: The analysis revealed a significant association between BMI and lumbar lordotic curvature ($p = 0.002$, $p < 0.005$) with a weak correlation coefficient ($r = 0.26$).
Conclusion: Higher BMI is associated with increased lumbar lordotic curvature in children aged 10–12. However, this study has limitations, including an uneven BMI distribution among subjects and a lack of control over physical activity, sitting habits, and genetic influences. Future research should consider these factors and include a more diverse sample to obtain more comprehensive findings.

Keywords: Children, Body Mass Index, Lumbar Lordosis

Introduction

Human resources (HR) is crucial in achieving high-quality national development. The quality of human resources is influenced not only by behavioral and environmental factors but also by health aspects such as nutritional intake.[1] Monitoring and improving nutritional status should be conducted at all stages of life, starting from fetal development, infancy, early childhood, preschool years, school-age years, adolescence, adulthood, and old age.[2] Efforts to enhance children's nutritional status to support human resource development must begin early in childhood.

A child is an individual who has not yet reached adulthood or is still underage. According to Law No. 35 of 2014 on child protection, Article 1, Clause (1) states that a child is anyone under the age of 18, including those still in the womb.[3] Children aged 10–12 years are typically in elementary school when they begin exploring new environments and social settings.[4] Growth and development vary among children, and ensuring balanced progress requires meeting their essential needs, particularly nutritional requirements. In Indonesia, children face two major dietary issues: undernutrition and overnutrition.[5]

Children's nutritional status is a critical factor that demands attention. According to the 2018 Basic Health Research (Riskesdas) data, 2.4% and 6.8% of children aged 5–12 years were classified as severely underweight and underweight, respectively. Meanwhile, 10.8% were categorized as overweight, and 9.2% were obese. These figures highlight Indonesian children's nutritional challenges, which require intervention and improvement.[6] Abnormal nutritional status, whether underweight or overweight, can hinder a child's growth and development. Nutritional status is commonly assessed through anthropometric measurements, which are widely used due to their reliability in evaluating and predicting health and nutritional issues. Additionally, anthropometry is a simple, cost-effective, and non-invasive method.[7] Among anthropometric indicators, Body Mass Index (BMI), derived from weight and height measurements, is the most frequently used tool for assessing children's nutritional status and growth.[8]

BMI is the body weight (kg) ratio to the square of height (m).[9] An underweight BMI may lead to postural instability due to inadequate nutrient intake, particularly calcium and vitamin D, essential for bone strength and density. Poor bone health can affect posture, potentially leading to postural abnormalities. Conversely, an overweight BMI exerts mechanical stress on bones due to gravitational forces, increasing the risk of fatigue and injury. Both underweight and overweight BMI can contribute to vertebral deformities.[10] These deformities may alter the spinal structure, particularly in the sagittal plane, causing deviations from normal anatomical alignment and leading to instability and increased lumbar lordosis. Lordosis refers to excessive forward curvature of the spine. However, the term also describes the normal inward curvature of the lumbar and cervical vertebrae.[11]

Lumbar lordosis most commonly occurs in the lower back and involves an exaggerated inward curve of the L1–L5 vertebrae.[11] When this curvature becomes excessively pronounced or abnormally flattened, it is classified as pathological lumbar lordosis, which may result in back pain or postural issues. Research indicates that the normal lumbar lordosis angle ranges between 20° and 40°, whereas hyperlordosis is diagnosed when the angle exceeds 40°.[12] Besides BMI, lumbar lordosis can be influenced by physical activity, sitting habits, and genetic factors. Although all age groups are susceptible to lumbar lordosis, children and adolescents are at higher risk due to rapid spinal growth and developing muscle imbalances associated with growth spurts.

An abnormal BMI, whether overweight or underweight, can affect lumbar lordotic curvature due to changes in weight distribution on the spine. Research suggests a significant correlation between obesity and increased lumbar lordotic curvature, as individuals with excess weight exhibit a posterior shift in their center of gravity to maintain stability. Conversely, underweight individuals with low BMI may have weaker spinal support muscles, making it challenging to maintain proper posture and potentially leading to an imbalanced lumbar curvature.[13]

Studies examining the relationship between BMI and lumbar lordosis in children aged 10–12 years remain limited, particularly in Indonesia. This study addresses this gap by providing specific data from the Bali region. Children within this age range were selected due to the high prevalence of musculoskeletal complaints, suggesting that this period is a critical stage for postural changes that may contribute to discomfort or pain. These issues may stem from children's lack of awareness regarding their daily activities, compounded by increased screen time due to technological advancements, which reduce their engagement in physical activities.

The study focuses on elementary school children aged 10–12 years in Kelurahan Panjer, South Denpasar. Denpasar was chosen as the study location due to its diverse BMI distribution compared to other areas in Bali, encompassing normal, underweight, and overweight categories. The city has approximately 81,777 elementary school students enrolled in public and private institutions. This population provides a suitable sample pool for the study based on predefined criteria. By narrowing the study area to Kelurahan Panjer, the findings can offer a representative overview of the local population’s characteristics.

This study uses Spearman's rho statistical test to analyze the association between BMI and lumbar lordotic curvature in children aged 10–12 years. The research hypothesis proposes a significant positive correlation: higher BMI is associated with an increased lumbar lordotic curve. This study has important implications for physiotherapy, particularly in understanding how nutritional status influences spinal posture in children. The findings may serve as a reference for healthcare professionals in designing preventive measures to reduce spinal deformities and developing appropriate intervention strategies.

Methods

This study employed an analytical observational method with a cross-sectional approach. This design was chosen as it allows for examining the relationship between BMI and lumbar lordotic curvature at a single point in time without intervention. The study was approved by the Research Ethics Committee of FK Unud under approval number 1026/UN14.2.2.VII.14/LT/2024. The research was conducted in six public elementary schools in Kelurahan Panjer, targeting children aged 10–12. Subject selection was performed using purposive sampling, wherein participants were preselected based on predetermined inclusion criteria. Participant selection began with interviews and initial screenings to ensure eligibility based on inclusion criteria while excluding those meeting the exclusion criteria. Exclusion criteria included children with at least one year of dance experience, a history of spinal surgery, or known spinal fracture pathology identified through interviews. Following the selection process, 139 children met the eligibility criteria and participated in the study.

The study variables included BMI as the independent variable, lumbar lordotic curvature as the dependent variable, and age as a control variable to minimize potential bias. Age was controlled by ensuring that all subjects were within the same range, thereby reducing variations in postural development and ensuring that differences did not significantly impact the relationship between the studied variables. Additionally, objective measurement tools were employed, and the same physiotherapy team was involved throughout the study to ensure data consistency and accuracy. To further enhance the validity of the findings, an additional strategy was implemented wherein two different researchers cross-checked the initial measurement results.

The study commenced with obtaining permission from each school through an official letter from the Physiotherapy Study Program, followed by coordination with school authorities to provide information and explain the research procedures to the participants. Before data collection, students were given informed consent forms to take home, which had to be signed by their parents to indicate agreement to participate. The study was conducted in three phases during October 2024. The first phase took place at SD Negeri 2 Panjer and SD Negeri 6 Panjer, the second phase at SD Negeri 1 Panjer and SD Negeri 5 Panjer, and the final phase at SD Negeri 3 Panjer and SD Negeri 4 Panjer.

BMI was calculated using weight measurements in kilograms (kg) obtained with a weighing scale, divided by the square of height in meters (m) measured using a microtome. The BMI results were adjusted for age and converted into Z-scores, classifying nutritional status into normal (good nutrition) and poor nutrition categories, including severely underweight, overweight, and obese. The Z-score interpretation was as follows: severe undernutrition (< -3 SD), undernutrition (thinness) (-3 SD to < -2 SD), good nutrition (-2 SD to +1 SD), overweight (+1 SD to +2 SD), and obesity (> +2 SD). In this study, BMI-for-age (BMI/U) was used to assess children's nutritional status, as it accounts for age, providing more accurate detection of nutritional issues while aligning with WHO and CDC growth standards.[14]

The degree of lumbar lordotic curvature was measured using a flexible ruler, selected for its objective assessment capabilities, continuous representation of spinal curvature, and high interclass correlation coefficient (ICC) reliability value of 0.83. Before data collection, calibration was performed on the flexible ruler, weighing scale, and microtome to ensure that measurements adhered to standard procedures and minimized errors, thus enhancing data validity. The measurement process began by marking anatomical landmarks, with Th12 as the starting point and S2 (above the coccyx) as the endpoint, ensuring the inclusion of the entire lumbar region. Participants were instructed to stand upright in a relaxed posture to maintain their natural spinal alignment. The flexible ruler was placed along the spine, conforming to the lumbar curve, and the resulting shape was traced onto plain white paper. To minimize external variables, participants' clothing was adjusted to ensure clear visibility of the spinal curvature. The measurements were conducted in a private setting with only the physiotherapy team present to maintain participant privacy and comfort. The measured curvature was analyzed using the lordosis angle formula and classified as usual (20°–40°), hyperlordosis (< 20°), or hyperlordosis (> 40°).[15]

The sample size was determined using power analysis with the G*Power software, based on a two-sided confidence level of 95% and a statistical power of 80%. An effect size of 0.28 was derived from a previous study by Taweetanalarp and Purepong (2015), which examined the relationship between BMI and lumbar lordotic curvature. Although the study was conducted in a population with different characteristics, the effect size provided a reference for estimating an adequate sample size. Based on the calculations, a minimum of 103 participants was required to ensure statistically valid results.

Collected data were analyzed using IBM SPSS Statistics 24.0. The analysis methods included univariate analysis to describe age, sex, BMI, and lumbar lordotic curvature. Additionally, using Spearman's rho correlation test, bivariate analysis was performed to examine the relationship, direction, and correlation strength between BMI and lumbar lordotic curvature. A significance level of $p < 0.05$ was used to determine statistical significance. This test was chosen because the data were not normally distributed ($p < 0.05$), as determined by the Kolmogorov-Smirnov normality test, and the data were presented in ordinal form. No missing data were observed in this study, eliminating the need for missing data management strategies such as listwise deletion or imputation.

Results

The subjects of this study were children aged 10–12 years from six public elementary schools in Panjer Village, selected using purposive sampling. One hundred thirty-nine children who met the inclusion and exclusion criteria were included as study participants. The research process is illustrated in Figure 1.

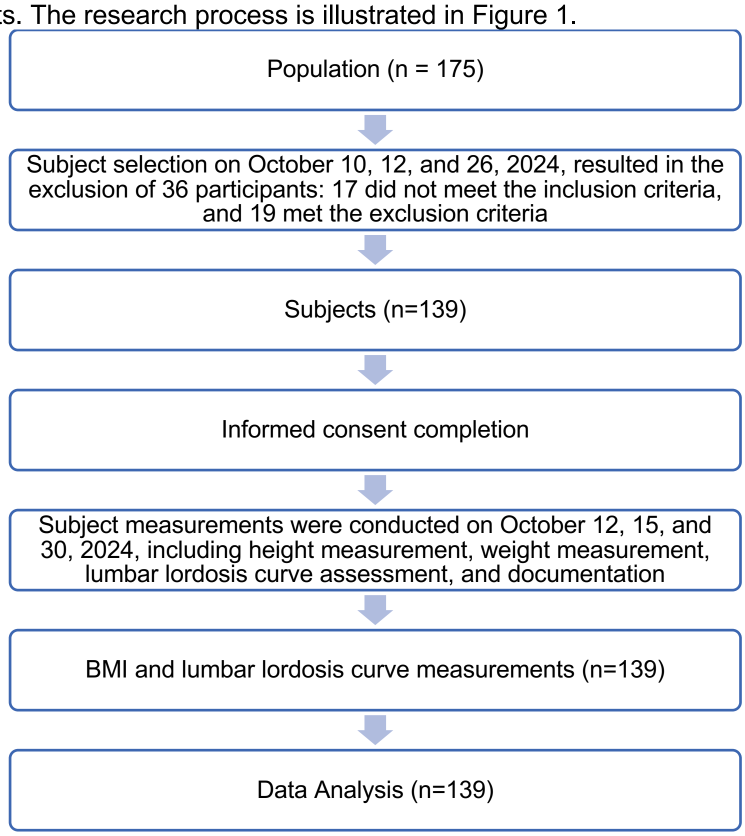

Figure 1. Study Flow Diagram

Of the total 175 children in the accessible population, 36 children were excluded from this study. Seventeen children did not meet the inclusion criteria, and 19 were excluded based on the exclusion criteria, as they were dancers with more than one year of dance experience or had spinal pathology. Thus, the final number of respondents was 139 children.

After data collection and univariate and bivariate analyses using Spearman's rho correlation, the study results are presented in the tables below. The descriptive characteristics of the study subjects are shown in Table 1.

Table 1. Frequency Distribution of Study Subject Characteristics

Variable	Frequency (n)	Percentage (%)
Gender		
Female	71	51.1
Male	68	48.9
Age		
10 years	23	16.5
11 years	74	53.2
12 years	42	30.2
BMI		
Severely underweight	0	0
Underweight	16	11.5
Normal weight	87	62.5
Overweight	13	9.4
Obese	23	16.5
Lumbar Lordosis		
Hypolordosis	2	1.4
Normal	103	74.1
Hyperlordosis	34	24.5

Based on Table 1, in this study conducted in six elementary schools in Panjer Village, the number of female subjects was higher (71 children, 51.1%). Most subjects were 11 years old (74 children, 53.2%). The most common BMI category was normal (87 children, 62.5%), and most subjects had normal lumbar lordosis (103 children, 74.1%). The cross-tabulation of BMI distribution with lumbar lordosis curvature is shown in Table 2.

Table 2. Cross-tabulation of BMI Distribution with Lumbar Lordosis Curvature

BMI Category	Lumbar Lordosis Curvature						Total	
	Hypolordosis		Normal		Hyperlordosis			
	n	%	n	%	n	%	n	%
Severely underweight	0	0	0	0	0	0	0	0
Underweight	2	12.5	11	68.75	3	18.75	16	100
Normal weight	0	0	72	82.76	15	17.24	87	100
Overweight	0	0	6	50	7	50	13	100
Obese	0	0	14	60.87	9	39.13	23	100
Total	2	1.44	103	74.1	34	24.46	139	100

According to Table 2, no subjects were classified as severely underweight. Among underweight subjects, two children (12.5%) had hyperlordosis, 11 children (68.75%) had normal lordosis, and three children (18.75%) had hyperlordosis. In the normal BMI category, no subjects had hyperlordosis, while 72 children (82.76%) had normal lordosis, and 15 children (17.24%) had hyperlordosis. Among overweight children, none had hyperlordosis, while six children (50%) had normal lordosis, and seven children (50%) had hyperlordosis. In the obese category, no children had hyperlordosis, while 14 children (60.87%) had normal lordosis, and nine children (39.13%) had hyperlordosis. This cross-tabulation provides an overview of the distribution of subjects based on BMI category and lumbar lordosis curvature. A correlation analysis was conducted to determine whether a significant relationship exists between these two variables, as shown in Table 3.

Table 3. Correlation Between BMI and Lumbar Lordosis Curvature in Female Children

Correlation Variables	Correlation Coefficient	Sig. (2-tailed)	N
BMI and Lumbar Lordosis Curvature in Female Children	0.315	0.007	71

Figure 2. Bar Chart of BMI and Lumbar Lordosis Curvature Relationship in Female Children

Table 3 and Figure 2 show Spearman's rho test results on the relationship between BMI and lumbar lordosis curvature in female children. The correlation test yielded a p-value of 0.007 ($p < 0.05$) and a correlation coefficient of 0.315 (95% CI: 0.088–0.511), indicating a statistically significant positive relationship, though the correlation strength was weak.

Table 4. Correlation Between BMI and Lumbar Lordosis Curvature in Male Children

Correlation Variables	Correlation Coefficient	Sig. (2-tailed)	N
BMI and Lumbar Lordosis Curvature in Male Children	0.272	0.025	68

Figure 3. Bar Chart of BMI and Lumbar Lordosis Curvature Relationship in Male Children

Table 4 and Figure 3 present Spearman's rho test results on the relationship between BMI and lumbar lordosis curvature in male children. The correlation test yielded a p-value of 0.025 ($p < 0.05$) and a correlation coefficient of 0.272 (95% CI: 0.036–0.479), indicating a statistically significant positive relationship, though the correlation strength was weak.

Table 5. Correlation Between BMI and Lumbar Lordosis Curvature in Children Aged 10–12 Years

Correlation Variables	Correlation Coefficient	Sig. (2-tailed)	N
BMI and Lumbar Lordosis Curvature (Total)	0.261	0.002	139

Figure 4. Bar Chart of BMI and Lumbar Lordosis Curvature Relationship in Children Aged 10–12 Years

Table 5 and Figure 4 show Spearman's rho test results on the relationship between BMI and lumbar lordosis curvature in children aged 10–12. The correlation test yielded a p-value of 0.002 ($p < 0.05$) and a correlation coefficient of 0.261 (95% CI: 0.099–0.410), indicating a statistically significant positive relationship, though the correlation strength was weak. Although the results indicate a significant relationship between BMI and lumbar lordosis, the weak correlation suggests that this relationship is not strong enough to infer a direct causal connection.

Discussion

Characteristics of Research Subjects

The research subjects were aged 10–12 years, with the majority being 11 years old (74 subjects, 53.2%). The dominance of 11-year-old subjects is because many participants were recruited from fifth-grade elementary school classes. The 10–12-year-old age range is a critical period and the early stages of puberty, often leading to postural imbalances due to changes in body structure and composition. A study conducted in Greece found that among children aged 9–15 years, the highest prevalence of musculoskeletal complaints occurred at 11. This indicates that this age represents a peak period of postural changes that can trigger pain or discomfort. [16] The gender distribution in this study was slightly dominated by female participants (71 subjects, 51.1%), while male participants accounted for 68 subjects (48.9%).

Based on BMI, four different categories were identified: normal BMI (87 subjects, 62.5%), underweight BMI (16 subjects, 11.5%), overweight BMI (13 subjects, 9.4%), and obese BMI (23 subjects, 16.5%). The predominance of subjects with normal BMI aligns with data from the Indonesian Ministry of Health (2018), which reported that 70% of children aged 5–12 years in Bali Province had a normal BMI.[6] Additionally, this could be influenced by the age of the subjects, whose metabolic systems are still efficient, allowing for optimal nutrient absorption. Another study found that 39 out of 59 fifth and sixth-grade children had a BMI within the normal range.[17]

In this study, the most frequently observed lumbar lordotic curve was the standard category (103 subjects, 74.1%), while the least frequent was the hypolordotic category (2 subjects, 1.4%). A study by Bustan and Anwar (2018) found that among elementary and middle school students, lordosis was 21.9%, with 61.9% of subjects having an abnormal BMI. [18] Additionally, postural disorders in children can also be influenced by non-ergonomic body posture and excessive school bag loads.

Relationship Between Body Mass Index and Lumbar Lordotic Curve

Non-parametric Spearman's rho analysis indicated a significant relationship between BMI and the lumbar lordotic curve ($p = 0.002$; $p < 0.005$), with a correlation coefficient of 0.261, suggesting a weak but positive correlation. This means that higher BMI values in children tend to be associated with increased lumbar lordotic curvature. These findings support the initial hypothesis that BMI and the lumbar lordotic curve have a significant positive correlation. In this study, children with normal to obese BMI had a higher proportion of hyperlordotic curves compared to underweight children. Conversely, underweight children tended more toward lumbar hyperlordosis, although at a low frequency (2 subjects).

An abnormal BMI, whether underweight or overweight, can affect weight distribution and muscle balance, leading to biomechanical changes in the spine. Malnourished children tend to have inadequate muscle mass to support optimal spinal stability, potentially leading to weakness in stabilizing muscles such as the erector spinae and multifidus. This may result in an inability to maintain normal lumbar curvature and an increased risk of hyperlordosis. On the other hand, overweight or obese children may exert excessive axial loads on the spine, increasing intra-abdominal pressure and enhancing shear and compressive forces on the lumbar facet joints. This excessive load can also cause postural muscles to work harder to maintain balance, potentially contributing to spinal curvature changes such as hyperlordosis due to an anterior shift in the body's center of mass. Poor biomechanical adaptations may also increase the risk of other postural disorders, such as kyphosis or scoliosis. [19]

Statistical analysis in this study indicated that gender did not significantly influence the relationship between BMI and lumbar curvature in children (P = 0.007 and L = 0.025). This suggests that both male and female children with abnormal BMI tend to experience alterations in their lumbar curve. These findings align with a study by Rahmawati and Sidarta, which found that obesity or excess body weight can affect lumbar lordosis regardless of gender. [13] Although no significant gender differences were found in the relationship between BMI and lumbar lordosis, correlation analysis in this study showed that the correlation strength was slightly higher in females ($r = 0.315$) than in males ($r = 0.272$). This suggests that postural changes due to increased BMI may be more pronounced in females. Possible contributing factors include differences in fat distribution, as females tend to accumulate more subcutaneous fat in the hip area, which can influence posture. Additionally, hormonal changes during puberty may affect the relationship between BMI and lumbar lordotic curvature, influencing body development and fat distribution. During puberty, increased estrogen levels lead to changes in body composition, including more significant fat accumulation in the hips and thighs and growth in connective tissues such as ligaments and tendons, which affect joint and spinal stability and flexibility.[20]

The findings of this study are consistent with previous research demonstrating a positive relationship between BMI and the lumbar lordotic curve. Taweetanalarp et al. compared upper and lower lumbar angles between respondents with normal and overweight BMI, further supporting this study's results. The study found that the standard BMI group had an average upper lumbar angle of 14.50 ± 5.90 and a lower lumbar angle of 16.10 ± 6.40. Meanwhile, the overweight group increased the upper lumbar angle to 18.80 ± 7.40 and the lower lumbar angle to 22.90 ± 7.90, with a statistically significant difference in the lower lumbar region ($p < 0.05$). Additionally, Pearson's correlation test between BMI and lower lumbar lordosis yielded a substantial value of $p = 0.03$ with $r = 0.28$, indicating that overweight individuals experience a more significant increase in lower lumbar curvature than those with normal BMI.[21]

Similarly, Onyemaechi et al. found that lumbar lordotic curvature was higher in overweight and obese individuals and had a positive relationship between lumbar lordosis angle and BMI ($p = 0.001$). A study by Wendra et al. investigating the relationship between obesity and lumbar lordosis also found a significant correlation ($p = 0.000$) with a high correlation coefficient (0.843). These findings support the current study's results, demonstrating that higher BMI is associated with an increased lumbar lordotic curve. [22]

Conversely, a study by Grabara yielded different results. In a group practicing yoga, a significant negative correlation was found between BMI and lumbar lordosis ($p = 0.003$, $r = -0.11$), indicating that higher BMI was associated with a smaller lumbar lordotic angle. This may be attributed to the Hatha Yoga interventions in the study, which focused on backward bends (straightening exercises) aimed at stretching the chest muscles and strengthening the back extensors. Hatha Yoga also emphasizes reducing hip anteversion and strengthening the abdominal muscles, which can decrease lumbar lordosis. Postural education was also provided as part of the intervention. Grabara's findings suggest that in overweight participants, regular yoga practice can influence anterior-posterior vertebral curvature and promote correct posture.[23] These differences highlight the potential role of physical activity and postural interventions in modulating the relationship between BMI and lumbar lordosis.

Other factors must also be considered in this study, such as the uneven distribution of BMI categories, where normal BMI subjects were predominant, and no severely underweight subjects were found. This may limit the study's ability to capture the relationship among children with extreme BMI values fully. Additionally, the lack of control over physical activity levels, sitting habits, and genetic predispositions may introduce confounding variables in the relationship between BMI and lumbar curvature. Future studies should address these limitations for a more comprehensive understanding.

The study subjects, exclusively students from SD Negeri Kelurahan Panjer, may not represent children in other regions with different characteristics. Variations in school environments, activity patterns, and cultural factors across areas could influence the study results. However, this study provides an initial representation for healthcare practitioners, educators, and parents, highlighting that children with abnormal BMI—either underweight or overweight—are at higher risk of developing postural disorders such as lumbar hyperlordosis and hyperlordosis.

Therefore, early intervention is necessary through proper posture education, physical exercise programs to improve balance and muscle strength, and maintaining an ideal body weight. In physiotherapy, these findings can serve as a basis for designing specific rehabilitation programs tailored to children's postural conditions. For instance, children with a low BMI at risk of hyperlordosis may benefit from core-strengthening exercises such as the plank, bird-dog, and bridging to enhance lumbar stability. Meanwhile, children with a high BMI, who are more prone to hyperlordosis, could benefit from posterior muscle strengthening exercises like glute bridge, dead bug, and pelvic stabilization exercises to reduce excessive pressure on the lumbar area.

Additionally, these findings can support promotive and preventive programs aimed at reducing the risk of lower back pain due to postural disorders that develop from an early age. This can be achieved through school posture awareness campaigns and parental guidance on proper sitting habits. For schools, the study results can help design an ergonomic learning environment, including using furniture that matches children's height, limiting school bag weight to prevent spinal strain, and balancing study and rest periods to avoid postural fatigue.

With a multidisciplinary approach involving physiotherapists, educators, and parents, early intervention through exercise-based programs and education can be effectively implemented to maintain children's postural health and prevent musculoskeletal disorders in the future.

Conclusion

The relationship between BMI and lumbar lordosis curvature is positive but weak, indicating that although an increase in BMI tends to accompany an increase in lumbar lordosis curvature, this relationship is not strong enough to be considered the sole influencing factor. Therefore, it is essential to consider other contributing factors such as physical activity, sitting habits, and genetic predisposition. Further research should account for these factors and include a more diverse sample to obtain more comprehensive results.

The practical implications of this study highlight the importance of maintaining an ideal nutritional status as part of efforts to support proper posture, particularly in maintaining a standard lumbar lordosis curve. Early intervention through a healthy lifestyle, including regular exercise, a nutritious diet, and adequate rest, can help prevent postural disorders and support optimal postural development. A multidisciplinary approach is also necessary for prevention efforts, including posture education in schools, monitoring school bag weight, and implementing physical exercises that enhance postural stability. Therefore, healthcare professionals and educators should actively develop early prevention programs to raise awareness and promote good postural habits among children.

Author Contribution

Ketut Ayu Padma Wati: Conceptualization, methodology, data collection, data analysis, and manuscript drafting.
Gede Parta Kinandana: Supervision, guidance on research design, and critical review of the manuscript.
I Putu Gde Surya Adhitya: Supervision, validation, and manuscript editing.

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Conflict of Interest Statement

The authors declare that there are no conflicts of interest related to this study.

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Ethics Statement

This study was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki. Ethical approval was obtained from the Research Ethics Committee of the Faculty of Medicine, Universitas Udayana (Approval No. 1026/UN14.2.2.VII.14/LT/2024). All participants provided informed consent prior to data collection.

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