Differences in body surface area development among adolescents of 26 ethnic minorities

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Abstract: To examine differences in body surface area (BSA) development among adolescents from 26 ethnic minorities, stature and body-mass data for each sex were extracted from the 2010 Chinese National Survey on Students' Constitution and Health. BSA was calculated with the Stevenson and DuBois equations. Thirty-six parameters—three indicators (stature, body mass, and BSA) across twelve age groups (7–18 years)—were subjected to factor analysis with varimax orthogonal rotation, converting the means of these parameters into factor scores. Using these factor scores, Q-type cluster analysis (Ward's method) was conducted, grouping the 26 ethnic samples by sex, and Cub models were fitted to the BSA growth curves of the resulting clusters. Results showed that the three indicators effectively summarized inter-group developmental differences. Male samples formed four clusters and female samples five, which could be labeled as high-, intermediate-, and low-development groups, with significant between-group variation. BSA development was both similar and dissimilar across ethnicities.

Keywords: ethnic minorities, adolescents, body surface area, growth and development

1. Introduction

China is a multi-ethnic country. Differences in regional customs and lifestyles generate distinct constitutional characteristics among residents of different geographical areas. Although several studies have reported on body surface area (BSA) in Chinese ethnic-minority adolescents [1–2], multivariate analyses of BSA remain scarce. BSA is closely linked to basal metabolic rate, pulmonary ventilation, cardiac output, glomerular filtration rate and other key physiological indices [3–4], and also correlates with morphological, functional and fitness indicators that reflect constitutional robustness [5–6]. Consequently, BSA has important applications in clinical practice, athletic training and physical education [1]. Since Bergmann and Rubner first conceptualised human BSA in 1848, numerous prediction equations have been proposed, including those of DuBois [7], Stevenson [8–9], Zhao Song-shan [10–11] and Hu Yong-mei [12–13]; however, selection of the most appropriate formula is still debated [1–2,12,14]. Using an osculating-value approach, Gao Guo-zhu et al. concluded that the Stevenson and DuBois equations are the most suitable for male and female adolescents [15]. Based on the 2010 National Survey on Students' Constitution and Health, the present study conducts a multivariate analysis of BSA in 26 ethnic minorities and constructs ethnicity-specific BSA growth curves, providing a scientific basis for developing tailored nutritional assessment standards.

2. Materials and Methods

2.1. Subjects

The study population comprised 7–18-year-old adolescents from 26 ethnic minorities: Mongol, Hui, Qiang, Lisu, Bouyei, Uygur, Salar, Kyrgyz, Naxi, Dong, Korean, Miao, Tu, Yao, Hani, Wa, Shui, Tujia, Kazakh, Yi, Dai, Zhuang, Dongxiang, Bai, Tibetan and Li. Each age-sex group included 66–308 individuals. Height and body-mass data were obtained from the 2010 Chinese National Survey on Students' Constitution and Health [16].

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2.2. Methods

2.2.1. Data processing

Body surface area (BSA) for each sex was calculated using the Stevenson and DuBois formulas:Male: BSA = 0.0061 × height + 0.0128 × body mass – 0.01529 Female: BSA = 70.49 × body mass^0.425 × height^0.725.

2.2.2. Statistical analysis

Based on the developmental characteristics of BSA, 36 parameters (three indicators—height, body mass and BSA—across 12 age groups from 7 to 18 years) were selected. Using SPSS 18.0, factor analysis with varimax orthogonal rotation was performed on these 36 parameters, converting the mean values into factor scores. These factor scores were then used for Q-type cluster analysis (Ward's method) to classify the 26 ethnic samples for each sex. Cub models were fitted to the BSA growth curves of the resulting clusters.

3. Results

3.1. Growth trends in height, body mass and BSA among 26 ethnic minorities

Mean height, body mass and BSA of the 26 ethnic groups increased with age (Table 1). Over the 12 years from 7 to 18 years: Boys' height rose from 120.25 cm to 167.31 cm—a 1.39-fold increase of 47.06 cm, averaging 3.92 cm per year (growth was uneven). Body mass increased from 22.53 kg to 56.90 kg—a 2.53-fold gain of 34.37 kg, averaging 2.86 kg per year (also uneven).

Girls' height increased from 119.22 cm to 155.60 cm—a 1.31-fold gain of 36.38 cm, averaging 3.03 cm per year. Body mass rose from 21.42 kg to 49.74 kg—a 2.32-fold increase of 28.32 kg, averaging 2.36 kg per year. Boys' BSA grew from 0.869 m² at age 7 to 1.596 m² at age 18 (total gain 0.727 m², mean annual increment 0.061 m²). Girls' BSA increased from 0.830 m² to 1.440 m² (gain 0.610 m², mean annual increment 0.051 m²). Growth phases were clearly delineated: Boys: steady growth (7–12 y, +0.065 m²/year), rapid growth (13–14 y, +0.101 m²/year), then slower growth after 16 y. Girls: steady growth (7–9 y, +0.065 m²/year), rapid growth (10–14 y, +0.100 m²/year), then slower growth after 15 y. A "double-crossover" phenomenon in BSA was observed: boys' BSA exceeded girls' up to 11 y, girls surpassed boys between 11–13.6 y, and after 13.6 y boys again exceeded girls with an increasing margin (Table 1, Figure 1).

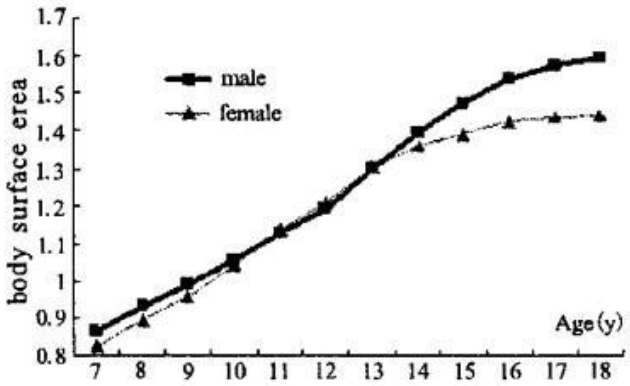

Figure 1 Growth trend of body surface area among adolescents of 26 ethnic minorities

3.2. Factor analysis of stature, body mass, and body surface area in 26 ethnic groups

The results are presented in Table 2. For the 36 male parameters, three factors were extracted, accounting for 92.01 % of the total variance; for the 36 female parameters, four factors were extracted, with a cumulative contribution of 94.46 %. These factors effectively summarize the between-group differences embedded in the 36 parameters. Factor structures differ slightly between sexes: among males, the main divergences lie in stature and in body mass at ages 8 and 13–15 years, whereas among females, the principal differences occur in stature and body mass from ages 13 to 18 years.

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3.3. Cluster analysis of stature, body mass and body surface area in 26 ethnic groups

Table 1 Growth trends in stature, body mass and body surface area of adolescents from 26 ethnic minorities (mean ± SD)

Sex	Male			Female		
Age	Height (cm)	Body mass	Body surface area	Height (cm)	Body mass	Body surface area
7	120.25±3.43	22.53±2.04	0.869±0.046	119.22±3.29	21.42±1.81	0.830±0.048
8	125.49±3.53	25.08±2.10	0.934±0.048	124.50±3.74	23.89±2.21	0.897±0.053
9	129.89±3.75	27.41±2.57	0.990±0.055	129.32±3.82	26.28±2.45	0.959±0.057
10	134.69±3.97	30.19±2.99	1.055±0.062	135.30±4.01	29.58±2.97	1.043±0.065
11	139.94±4.44	33.55±3.79	1.130±0.073	141.23±4.40	33.81±3.38	1.139±0.073
12	144.38±4.88	36.29±4.12	1.192±0.073	145.44±4.72	36.99±3.74	1.209±0.078
13	151.33±5.16	41.27±4.15	1.299±0.081	150.10±3.78	41.66±3.43	1.301±0.066
14	157.39±4.59	45.85±3.69	1.394±0.074	152.66±3.35	44.96±3.09	1.360±0.057
15	161.82±4.48	49.91±3.69	1.473±0.071	153.67±3.23	46.92±2.96	1.392±0.054
16	165.15±3.65	53.38±3.37	1.538±0.062	155.02±3.36	48.74±2.63	1.424±0.050
17	166.69±3.43	55.47±3.16	1.574±0.059	155.27±2.92	49.56±2.68	1.436±0.048
18	167.31±3.29	56.90±3.03	1.596±0.057	155.60±2.83	49.74±2.60	1.440±0.046

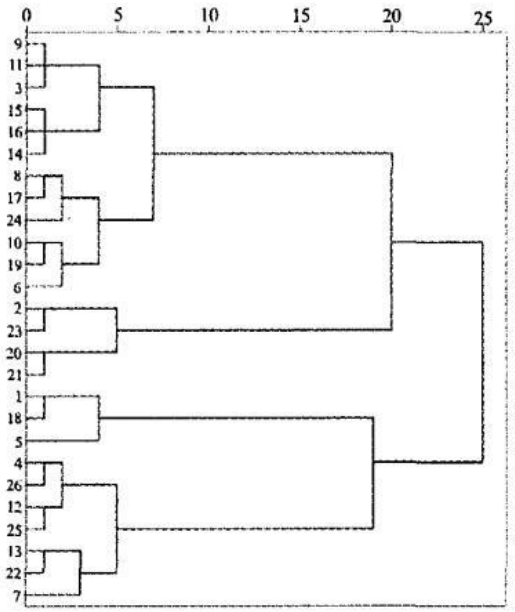

Figure 2 Dendrogram of cluster analysis for the male group

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Labels 1–26 denote Mongol, Hui, Uygur, Zhuang, Korean, Tujia, Li, Yao, Qiang, Miao, Bouyei, Dong, Bai, Dai, Hani, Lisu, Wa, Naxi, Tu, Salar, Kyrgyz, Tibetan, Kazakh, Shui, Yi, and Dongxiang, respectively.

Using factor scores of stature, body mass and body surface area, inter-group distances were computed with squared Euclidean distance and Ward's method was applied for clustering. The dendrograms (Figures 2 and 3) show that the male samples formed four clusters and the female samples five. Male clusters. Class I: Qiang, Bouyei, Uygur, Hani, Lisu, Dai, Yao, Wa, Shui, Miao, Tu, Tujia. Class II: Hui, Kazakh, Salar, Kyrgyz. Class III: Mongol, Naxi, Korean. Class IV: Zhuang, Dongxiang, Dong, Yi, Bai, Tibetan, Li. Female clusters. Class I: Lisu, Yi, Uygur, Wa, Shui, Bouyei, Dong, Tujia, Hani, Qiang, Tu/Class II: Hui, Tibetan, Kyrgyz, Salar. Class III: Mongol, Korean, Kazakh. Class IV: Zhuang, Dai, Li, Naxi, Bai. Class V: Yao, Miao, Dongxiang

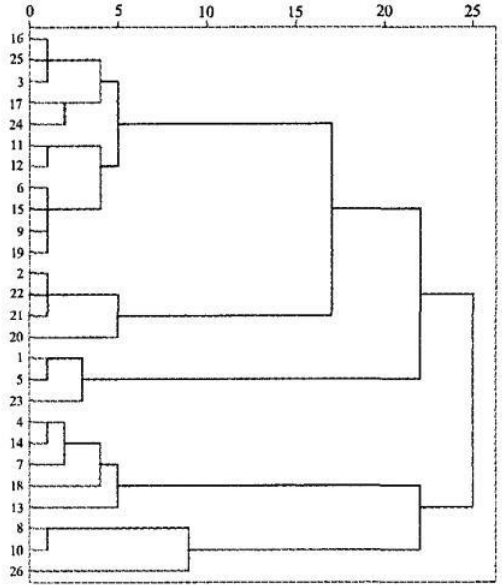

Figure 3 Dendrogram of cluster analysis for the female group

Labels 1–26 correspond to Mongol, Hui, Uygur, Zhuang, Korean, Tujia, Li, Yao, Qiang, Miao, Bouyei, Dong, Bai, Dai, Hani, Lisu, Wa, Naxi, Tu, Salar, Kyrgyz, Tibetan, Kazakh, Shui, Yi, and Dongxiang, respectively. Kyrgyz and Salar; Class III comprises Mongol, Korean, and Kazakh; Class IV includes Zhuang, Dai, Li, Naxi, and Bai; and Class V comprises Yao, Miao, and Dongxiang.

Comparisons of mean BSA between the male and female clusters are presented in Tables 1, 3, and 4. Among males, Class III was significantly higher than Class II; paired t-tests showed significant differences between every pair of the four classes ($P < 0.05$). Independent-sample t-tests indicated that the difference between Classes II and IV was concentrated in the 16–18-year age group ($P < 0.05$).

Among females, Class III was significantly higher than Class II. Paired t-tests revealed no significant differences between Classes I and V or between Classes II and IV ($P > 0.05$), whereas all other pairwise comparisons were significant ($P < 0.05$).

Table 2 Factor analysis of the 36 indicators for males and females

Sex	Male				Female			
Indicator	Age	Factor 1	Factor 2	Factor 3	Factor 1	Factor 2	Factor 3	Factor 4
Height (cm)	7		0.655		0.766			
	8		0.674		0.755			
	9			0.618	0.662			
	10			0.565	0.714			
	11		0.666		0.667			

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	12		0.570		0.620			
	13		0.781			0.665		
	14		0.743			0.841		
	15			0.695		0.799		
	16			0.731		0.851		
	17			0.755		0.803		
	18			0.772		0.812		
Body mass	7	0.696			0.709			
	8		0.644		0.806			
	9	0.712			0.760			
	10	0.765			0.768			
	11	0.749			0.776			
	12	0.727			0.706			
	13		0.829					0.730
	14		0.795					0.645
	15		0.652					0.635
	16	0.814					0.782	
	17	0.878					0.896	
	18	0.853					0.897	
Body surface area	7		0.619		0.754			
	8		0.671		0.805			
	9	0.648			0.739			
	10	0.699			0.767			
	11	0.673			0.751			
	12	0.671			0.691			
	13		0.828					0.698
	14		0.793					0.563
	15		0.647					0.579
	16	0.719					0.667	
	17	0.792					0.769	
	18	0.758					0.790	
Eigenvalue		12.974	12.380	7.770	12.310	8.453	7.906	5.338
Contribution rate		36.04%	34.39%	21.58%	34.19%	23.48%	21.96%	14.83%
Cumulative contribution rate		92.01%	94.46%					

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Table 3 Comparison of indicators among the four male classes (mean ± SD)

	Age	Class I	Class II	Class III	Class IV
Body surface area	7	0.839±0.024	0.903±0.046	0.950±0.016	0.867±0.025
	8	0.901±0.035	0.964±0.049	1.008±0.015	0.940±0.019
	9	0.957±0.038	1.030±0.062	1.077±0.016	0.988±0.029
	10	1.022±0.045	1.096±0.069	1.155±0.017	1.046±0.034
	11	1.095±0.058	1.156±0.071	1.264±0.031	1.118±0.036
	12	1.152±0.066	1.237±0.071	1.335±0.038	1.176±0.035
	13	1.242±0.045	1.305±0.092	1.435±0.066	1.333±0.047
	14	1.341±0.039	1.413±0.065	1.517±0.055	1.423±0.047
	15	1.430±0.047	1.501±0.073	1.593±0.051	1.479±0.049
	16	1.507±0.047	1.587±0.052	1.637±0.043	1.520±0.038
	17	1.546±0.032	1.644±0.049	1.663±0.032	1.544±0.035
	18	1.569±0.041	1.660±0.048	1.672±0.022	1.574±0.035

Table 4 Comparison of indicators among the five female classes (mean ± SD)

	Age	Class I	Class II	Class III	Class IV	Class V
Body surface area	7	0.894±0.025	0.936±0.031	1.001±0.014	0.925±0.028	0.924±0.018
	8	0.952±0.034	0.986±0.034	1.075±0.001	0.999±0.034	0.988±0.037
	9	1.009±0.038	1.059±0.024	1.141±0.011	1.048±0.039	1.040±0.032
	10	1.087±0.040	1.115±0.045	1.242±0.026	1.131±0.039	1.102±0.022
	11	1.170±0.055	1.202±0.038	1.325±0.021	1.244±0.042	1.176±0.039
	12	1.233±0.051	1.276±0.047	1.409±0.017	1.297±0.044	1.235±0.076
	13	1.337±0.035	1.365±0.062	1.485±0.012	1.368±0.037	1.288±0.018
	14	1.393±0.037	1.434±0.048	1.517±0.006	1.420±0.035	1.361±0.028
	15	1.424±0.036	1.473±0.038	1.541±0.009	1.443±0.038	1.396±0.030
	16	1.455±0.031	1.518±0.018	1.563±0.011	1.461±0.038	1.439±0.039
	17	1.471±0.031	1.524±0.026	1.575±0.022	1.462±0.033	1.461±0.032
	18	1.480±0.030	1.527±0.023	1.571±0.034	1.463±0.030	1.464±0.034

3.4. Fitting of body surface area growth curves

To further explore differences in BSA development among the 26 ethnic groups, a Cub model was employed to fit polynomial curves for each male and female cluster (Table 5). All fitted regression coefficients exceeded 0.98, indicating excellent model performance.

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Table 5 Composition of polynomial curves fitted to body surface area for each male and female class

Age	Type	Fitted equation	Coefficient of fitted regression
Male	Class I	$-0.0000042X^3+0.0739X+0.3030$	0.991
	Class II	$0.00029X^2+0.0669X+0.4062$	0.993
	Class III	$-0.000075X^3+0.1097X+0.1689$	0.991
	Class	$-0.000043X^3+0.0915X+0.2099$	0.980
Female	Class I	$-0.000092X^3+0.1036X+0.1683$	0.9908
	Class II	$-0.000085X^3+0.1013X+0.2210$	0.9897
	Class III	$-0.00014X^3+0.1236X+0.1592$	0.9948
	Class IV	$0.00013X^3+0.1158X-+0.1322$	0.9920
	Class V	$0.000064X^3+0.0841X-+0.3421$	0.9958

Polynomial curves for body-surface-area (BSA) development were constructed from the fitted models for each male and female class (Figures 3 and 4). Figures 3 and 4 show the following rank order of BSA magnitudes: for males, Class III > Class II > Class IV > Class I; for females, Class III > Class II > Class IV > Class I > Class V. Combining these findings with the cluster analysis, the BSA development of both sexes can be divided into three groups: High-development group: mainly Class III for males and Class III for females. Intermediate-development group: mainly Classes II and IV for both sexes. Low-development group: mainly Class I for males and Classes I and V for females.

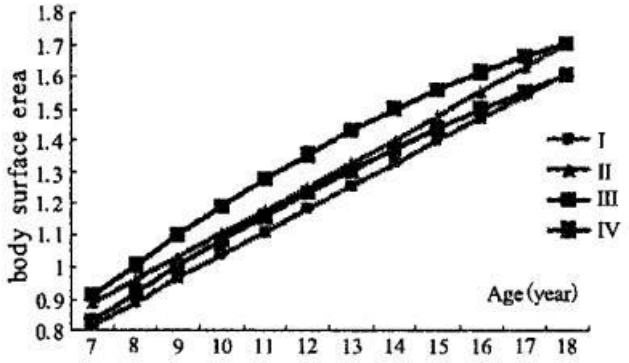

Figure 4 Schematic diagram of body-surface-area growth curves for the four male classes

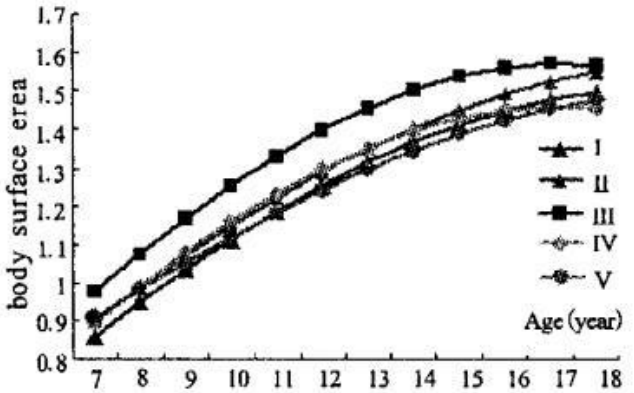

Figure 5 Schematic diagram of body-surface-area growth curves for the five female classes

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4. Discussion

Because of the irregularity of human morphology, direct measurement of body surface area (BSA) is difficult; therefore, regression equations using stature and body mass as predictors are commonly employed. However, the accuracy of existing BSA formulas is debated owing to differences in sample size and calculation errors [1–2, 12, 14]. Consequently, BSA alone is insufficient for assessing the nutritional status of a population; stature and body mass of the same age must also be incorporated to fully reflect growth and development levels.

This study shows that BSA increases with age in all 26 ethnic groups. As height and body mass rise throughout adolescence, BSA increases correspondingly—a trend consistent with age-related changes in most morphological and physiological indices of children and adolescents [17]. The "double-crossover" phenomenon observed in BSA between sexes reflects the general pattern of adolescent growth, attributable to girls entering the second growth spurt earlier than boys [18].

Factor analysis revealed slight sex differences in factor structure; these disparities may be linked to living environment, economic status, nutrition and other factors among adolescents of different ethnicities. The high cumulative contribution rates (>90 %) for both sexes indicate that the 36 parameters effectively capture inter-group variation in developmental level, maturation timing and body type, and can therefore be used for cluster delineation via factor scores.

Cluster analysis demonstrated significant differences among the male and female clusters, likely related to geographic location, living conditions, economic status, genetics and nutrition.

Growth-curve analysis and modelling are primary tools for studying adolescent growth patterns; they establish a model describing how a given growth indicator changes over time and thus reflect developmental trends. In this study, Cub models fitted to BSA growth curves yielded regression coefficients above 0.98, indicating excellent fit and permitting reliable evaluation of BSA development in the 26 ethnic minorities.

Together, cluster analysis and polynomial curves show that BSA development in both sexes can be classified into high-, intermediate- and low-development groups. The high-development group consists primarily of Mongol, Naxi and Korean boys and Mongol, Korean and Kazakh girls. These are mostly northern ethnic groups from Northeast China and Xinjiang that rely on animal husbandry and dairy-meat diets; improved nutrition is likely the main driver of their advanced physical development [19].

The intermediate group includes, among boys, Hui, Hani, Salar, Kyrgyz, Zhuang, Dongxiang, Dong, Yi, Bai, Tibetan and Li, and among girls, Hui, Tibetan, Kyrgyz, Salar, Zhuang, Dai, Li, Naxi and Bai. Most inhabit the ethnic corridor stretching from southern Gansu through the northwestern Sichuan plateau to southern Yunnan—a major migration zone where environmental changes during migration may influence growth [19].

The low-development group comprises, among boys, Qiang, Bouyei, Uygur, Kazakh, Lisu, Dai, Yao, Wa, Shui, Miao, Tu and Tujia, and among girls, Lisu, Yi, Uygur, Wa, Shui, Bouyei, Dong, Tujia, Hani, Qiang, Tu, Yao, Miao and Dongxiang. These groups are concentrated in the Yunnan–Guizhou region, where poor transportation and lagging economic development partly explain the lower physical development of adolescents [19].

Overall, BSA development among adolescents of the 26 ethnic minorities shows both similarities and differences, forming a north-to-south gradient: northern ethnic groups (Northeast and Xinjiang) rank highest, those in the ethnic corridor are intermediate, and southern groups (Yunnan–Guizhou) rank lowest—a pattern consistent with previous research [19–20].

5. Conclusion

In summary, using the 2010 National Survey on Students' Constitution and Health, this study conducted a multi-indicator, cross-sectional and longitudinal comparison of body surface area among 7–18-year-old adolescents from 26 ethnic minorities. It confirms that stature, body mass and BSA together can effectively portray developmental differences across ethnic groups. Cluster and curve-fitting analyses delineate a clear north-to-south gradient of "high–middle–low" development, underscoring the joint influence of genetic background, geographic environment and socioeconomic conditions on inter-ethnic constitutional variation. The findings provide quantitative evidence for establishing ethnicity- and sex-specific nutritional

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assessment and intervention standards, and they call for intensified nutritional improvement and health-promotion efforts among adolescents in remote southwestern regions to narrow the developmental gap between groups.

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