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Small But Healthy: An Adaptive Response in Baduy Children

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ABSTRACT

Life history explains natural selection, resulting in phenotypic plasticity that can be studied through the growth pattern (growth rate and body size). The Baduy People, one of the indigenous peoples in Indonesia, exhibit prolonged growth, a slow growth rate, a low peak growth spurt, and small adult size as an adaptation to challenging biocultural conditions. The life history trade-offs of the Baduy People are demonstrated by ontogenetic allometry, which synchronizes between skeletal growth and future reproduction. The study aims to characterize the growth of Baduy children aged 0-5 years with more precise 'tracking' of developmental plasticity. We collected anthropometric data (body height-BH, body weight-BW, head circumference-HC, body mass index-BMI) using a cross-sectional method from 118 girls and 97 boys aged 0-5 years across 24 Baduy Luar hamlets. Data were analyzed with Generalized Additive Models for Location, Scale, and Shape (GAMLSS) in R version 4.2.1. Nutritional statuses were categorized based on the BMI z-score. The growth pattern showed a decline in growth rate after birth until 2 or 3 years, but the body size increased yearly. The body size (BH and BW) of Baduy children is lower than the Indonesian National Synthetic Growth Charts (INSGC), but most of them have a good nutritional status (>80%). This finding is consistent with the "small but healthy" hypothesis: a small body is an advantageous evolutionary strategy for energy efficiency and maximizing growth potential in challenging biocultural conditions.

1. Introduction

Children's growth is often associated with stunting, as seen from the body's height being below standard. In addition, some studies show that genetic, nutritional (chronic undernutrition), economic, and environmental conditions affect stunting. However, based on research by Scheffler and Hermanussen (2022), stunting is a natural condition of human height. It has frequently been observed in people with low incomes and in affluent and well-nourished social strata over the last 10,000 years. Viewed from an evolutionary life history perspective, every organism is under selective pressure to allocate energy and resources obtained from the environment and consumed towards growth, maintenance, reproduction, and raising offspring to be self-sufficient and avoid death/survival (Wells *et al.* 2017; Little 2020; Bogin 2021). Two key concepts of life history theory are trade-offs (energy allocation) and reaction norms (biological traits). Trade-offs refer to the allocation of energy or costs incurred in life strategies. Reaction norms describe the spectrum of phenotypes produced by one genotype in various environmental conditions, along with the allocation of energy or expenses incurred. Human adaptation to biology and cultural (biocultural) conditions contributed not only to body size but also to all uniquely human attributes (Wells *et al.* 2017; Bogin 2021), such as growth pattern and completion variations,

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the timing of sexual maturity and reproduction, and other phenotypic plasticity (Walker *et al.* 2006; Bogin 2021). Thus, life history is an excellent framework to integrate information about selective pressures to achieve optimal body size through growth pattern variation among populations.

Some populations in Southeast Asia and South America who have small body sizes are categorized as Pygmies (adult male height <150 cm; Perry and Dominy 2009) or Pygmoids (adult male height between 150 and 160 cm; Richards 2006). The small body size showed a life history trade-off between extended growth and early reproduction due to high mortality rates (Migliano *et al.* 2007). In hunter-gatherer populations, the small body size is also characteristic of these populations (Perry and Dominy 2009), which is an adaptation to disease, malnutrition, hot or humid rain forests, and efficient foraging (Walker *et al.* 2006). In traditional or small-scale societies, energy allocation is generally used more for survival than reproduction, resulting in smaller body sizes. The "small but healthy" hypothesis also explains the general idea that selection for small body size is a favorable evolutionary strategy when successfully handling limited physical resources and as a form of energy efficiency in metabolism (Pelto and Pelto 1989; Little 2020; Scheffler and Hermanussen 2022).

In a previous study, the growth of Baduy People (aged 4 to 30 years) was characterized by prolonged growth, a slow growth rate, a low peak growth spurt, and small adult size (slow life history strategy). Based on their body height, the Baduy People belong to the Pygmoid (adult height: 161.4 cm for males and 149.4 cm for females) and have similarities with other indigenous populations or small-scale societies worldwide (Rohmatullayaly *et al.* 2017). On the other hand, the ontogenetic allometry mechanism in the growth of Baduy girls generally results in smaller and shorter body sizes and delayed sexual maturity. The life history trade-offs of Baduy People are shown by energy allocation to synchronize between skeletal growth and future reproduction as an adaptation response to biocultural conditions such as limited food resources and variation, isolated hamlets in the hilly area (slope of 49.1%), and cultural subsistence/swidden farming practices which required more physical activity (Ichwandi and Shinohara 2007; Rohmatullayaly *et al.* 2018). Engaging in excessive activities during growth phases is believed to expend more energy, leading to decreased available energy for growth, similar to what occurs in various subsistence or hunter-gatherer societies worldwide (Kramer and Greaves 2011). Slower maturation and reduced growth rate are responses to the environment that are interpreted as adaptations (Cameron and Schell 2022). Besides, trade-offs in life-history traits result in the developmental plasticity of body and brain size (Bogin 2021). At an early age, slow and prolonged somatic growth (skeletal growth and other organs) allows more energy to be allocated to the rapid growth of the brain (Kuzawa *et al.* 2014). Thus, bone growth, especially in the skull, is prioritized over fat (Bogin 2021). The study aims to characterize the growth of Baduy children aged 0-5 years. This information can provide a more precise 'tracking' of developmental plasticity and show the adaptation response in the life history of Baduy People towards their biocultural conditions.

2. Materials and Methods

2.1. Time and Location

The research was conducted from November 2022 to May 2023 in Kanekes Village, Leuwidamar District, Lebak Regency, Banten Province. Data analysis was performed at the Biosystematics and Molecular Laboratory, Department of Biology, Universitas Padjadjaran. This research has been registered with the Research Ethics Commission of Universitas Padjadjaran under Number 191/UN6.KEP/EC/2022.

2.2. Subject

The research subjects are Baduy children aged 0-5 years who live in Kanekes Village with original residence status known from birthplace and parent's information from two generations up (father, mother, grandfather, and grandmother). Before data collection, the parents or guardians of prospective subjects were informed about the purpose of the research. Suppose the prospective subject's parents or guardians agreed and were willing to participate in the study. They were directed to sign or give a thumbprint on the available informed consent. Furthermore, the parents or guardians of the subject were guided to fill out the provided questionnaire. If the parents or guardians of the subject could not read and write, the interviewer filled out the questionnaire for them.

2.3. Data Collection

The data collection used the cross-sectional method. Subjects were measured or observed at a certain age or in several specific age ranges and measurements. This approach is based on the cross-sectional analysis of a particular age group, sex, or population (Malina *et al.* 2004). Data were collected door to door by visiting each subject's house in 28 hamlets out of 65 hamlets in Baduy Luar in Kanekes Village, starting from the closest hamlets to the Kanekes Village office. However, the total number of subjects obtained in the study was 118 girls and 97 boys from 24 Baduy Luar hamlets.

2.4. Birth Date and Age Class

The birth date was obtained by asking directly, but most Baduy People give birth with the help of a *paraji* (shaman), so they need a record of the date of birth. However, some Baduy People give birth with the help of midwives, so the birth records (certificates from midwives) can verify the date of birth. If the subjects had no birth record, they were asked their age and when they were born. This information was cross-checked based on events or ceremonies in the traditional calendar, such as naming a seven-day-old child (*peureuhan*). If the date of birth was unknown, a conversion was performed according to the procedure by Rohmatullayaly *et al.* (2017). Subjects' ages were then grouped into age classes ranging from 0 to 5 years, with one-year intervals.

2.5. Anthropometric Measurement

Growth patterns of children aged 0 to 5 years were calculated based on four anthropometric dimensions, namely body length or body height (BH), body weight (BW), head circumference (HC), and body mass index (BMI). Body weight (BW) was measured by placing the baby on a digital baby scale Onemed Type 712 for ages 0 to 1 years in a lying position and using a digital scale Omron Type HBF-214 for ages 2 to 5 years in a standing position. Body length (BH) were measured using a digital infant scale Onemed Type 712 for ages 0 to 1 year. For ages 2 to 5 years, body height (BH) was measured using a SECA stadiometer Type 213. Measurements were taken with the subject standing upright and relaxed, looking straight ahead, and both heels and knees straightened. Head circumference (HC) was measured at the most significant part above the eyebrows and above the ears using a tape measure Onemed Waist Ruler OD 235.

2.6. Nutritional Status

Nutritional status is assessed based on the value of the body mass index-BMI (WHO 2016). As a global WHO recommendation, BMI is a feasible assessment of nutritional status that correlates with lifestyle, eating habits, health problems, and body mass measurements and allows comparison between children based on age, sex, and ethnicity. The BMI category standards for children use the nutritional status categories for children aged 0-5 in the Regulation of the Minister of Health of the Republic of Indonesia Number 2 of 2020 (Table 1; Permenkes 2020).

$$\text{Body mass index (BMI)} = \frac{\text{body weight (kg)}}{(\text{body height})^2\ (\text{m}^2)}$$

2.7. Data Analysis

The anthropometric measurements were analyzed using the Generalized Additive Models for Location, Scale, and Shape (GAMLSS) method (Rigby and Stasinopolous 2007). The GAMLSS package in R allows for fitting growth curves using a Box Cox Power Exponential (BCPE) distribution and for smoothing degrees of freedom to be determined stepwise. The BCPE model has four parameters: l (median), r (coefficient of variation), m (the Box-Cox transformation power), and s (parameter related to kurtosis) manner (Rigby and Stasinopoulos 2004). The GAMLSS method was used to display the distribution of anthropometric dimensions displayed as curves in 9 percentiles (3, 5, 10, 25, 50, 75, 90, 95, and 97). The curve refers to the standard curve with percentiles 3 to 97 recommended by WHO to assess a child's physical growth and nutritional status (Kuczmarski *et al.* 2002). In the GAMLSS analysis, the data obtained are normalized so that the mean value received equals the median value (50th percentile). Furthermore, the annual body size growth rate was calculated as the annual increase from the 50th percentile and visualized as a

Table 1. Nutritional status categories and thresholds based on body mass index-for-age (0-5 years)

Nutritional status categories	Cut-off (z-score)
Severely wasted	< - 3 SD
Wasted	- 3 SD to < - 2 SD
Normal	- 2 SD to + 1 SD
Possible risk of overweight	> + 1 SD to + 2 SD
Overweight	> + 2 SD to + 3 SD
Obese	> + 3 SD

curve. The growth rate/velocity pattern demonstrated trade-offs and developmental plasticity in life history.

Median body height (BH), body weight (BW), and body mass index (BMI) values were also compared with the Indonesian National Synthetic Growth Charts (INSGC) and plotted on a curve (Pulungan *et al.* 2018). The Indonesian National Synthetic Growth Charts (INSGC) curve is more appropriate for Indonesian children's growth and has been tested on a population of children in Bandung (Novina *et al.* 2020). The z-score of children's Body Mass Index (BMI) was categorized based on Indonesian children's anthropometric standards (Table 1; Permenkes 2020) and visualized in tabular form. All data analyses were performed using R version 4.2.1 for Mac.

3. Results

The growth pattern of Baduy children aged 0-5 years (118 girls and 97 boys), which includes body length or body height (BH), body weight (BW), head circumference (HC), and body mass index (BMI), is presented in Figure 1 to 4. The 50th percentile shows the median physical growth of Baduy children aged 0-5. Children's body size increases year by year as they

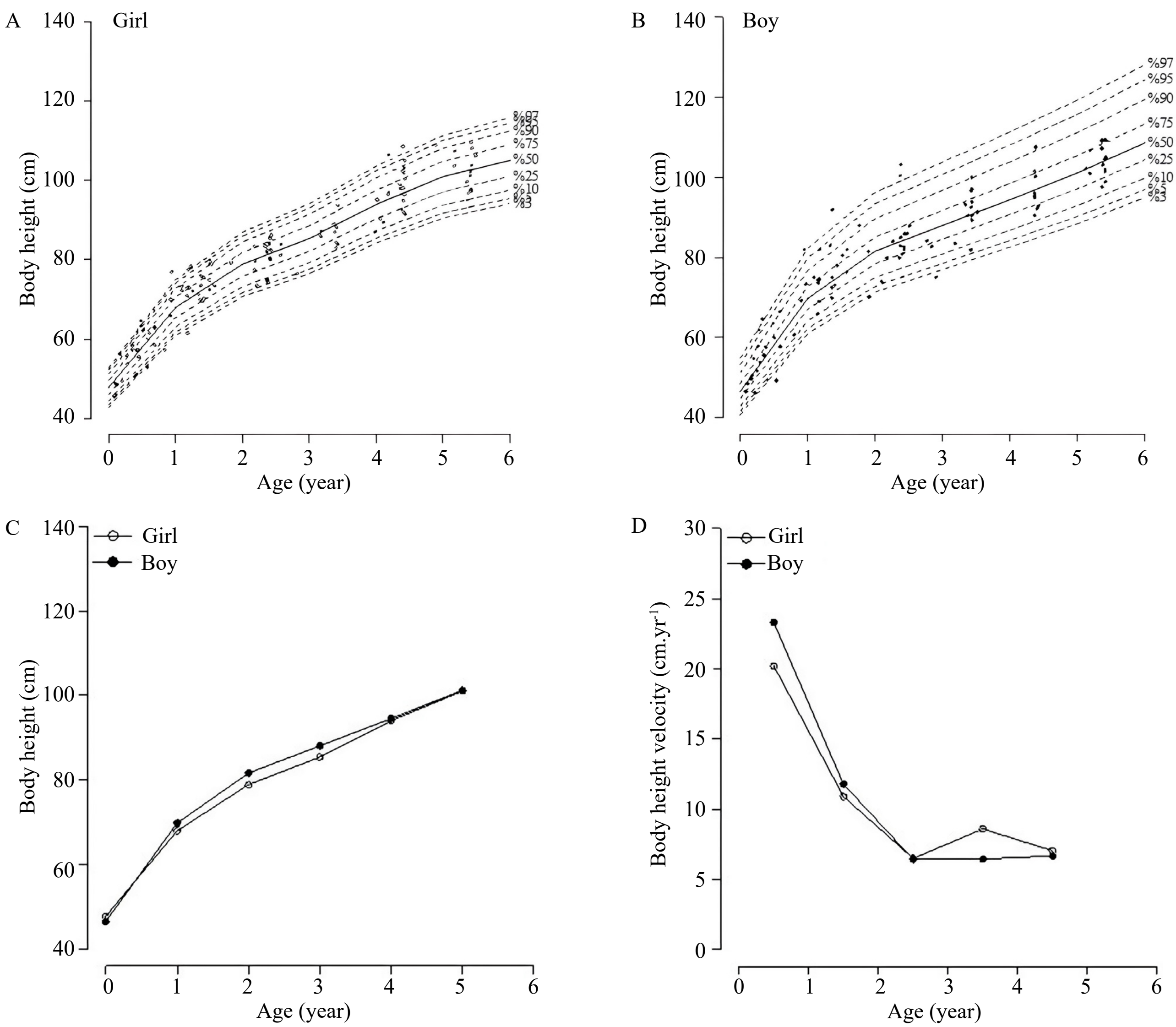

Figure 1. Growth pattern of body height aged 0-5 years (solid line is median). (A) Girls, (B) Boys, (C) Growth pattern from median, and (D) Growth velocity

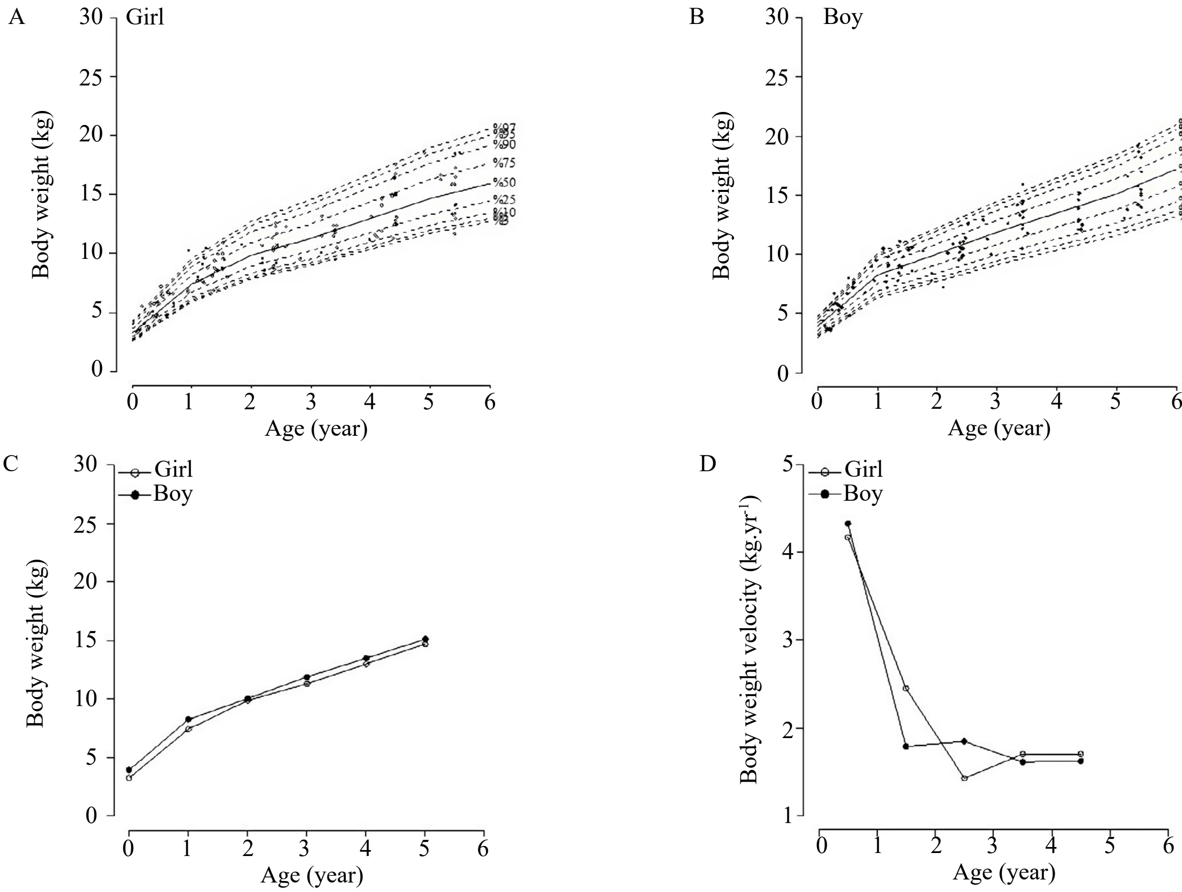

Figure 2. Growth pattern of body weight aged 0-5 years (solid line is median). (A) Girls, (B) Boys, (C) Growth pattern from median, and (D) Growth velocity

age. In general, the growth rate decreases after the birth phase and rises again at 2 or 3 years of age in both sexes.

3.1. Body Height

Figure 1 shows the growth pattern of body height (BH) in girls and boys. At age 0, boys (46.5 cm) were slightly shorter than girls (47.8 cm). However, as age increased, the BH of boys (101.2 cm at age 5) was similar to that of girls (101.0 cm at age 5). The growth velocity of girls and boys has a similar decline in the 0-3 age range but with a difference in the growth rate (20.2 to 6.5 cm/year for girls and 23.3 to 6.4 cm/year for boys). Then, at the age of 3-4 years, the growth rate in girls increased (8.6 cm/year) and decreased again at the age of 4-5 years (7.0 cm/year), while in boys, the growth rate was stable at the age of 3-5 years (6.5 to 6.7 cm/year).

3.2. Body Weight

The growth pattern of body weight (BW) is similar to the body height (BH), which shows a continuous increase each year (Figure 2). The BW is nearly the same for both sexes from 0-5 years, with the BW of girls slightly lower than boys. It starts at 3.3 kg and 3.9 kg at age 0 and reaches 14.7 kg and 15.1 kg at age 5 for girls and boys, respectively. The growth velocity of BW shows a different pattern between girls and boys. In girls, the growth rate decreases at age 0-3 years (4.2 to 1.4 kg/year), increases at age 3-4 years (1.7 kg/year), and tends to stabilize at age 4-5 years. However, the growth rate of boys decreases at age 0-2 years (4.3 kg/year to 1.8 kg/year), slightly fluctuates at age 2-3 years (1.9 kg/year), and tends to stabilize at age 3-5 years (1.6 kg/year).

3.3. Head Circumference

The growth pattern of head circumference (HC) in girls and boys is presented in Figure 3. The head circumference of girls (34.7 cm age 0 years to 48.0 cm age 5 years) is smaller than that of boys (38.6 cm age 0 years to 48.9 cm age 5 years). This also makes the growth rate of head circumference of girls and boys different, where the growth rate in girls decreased in

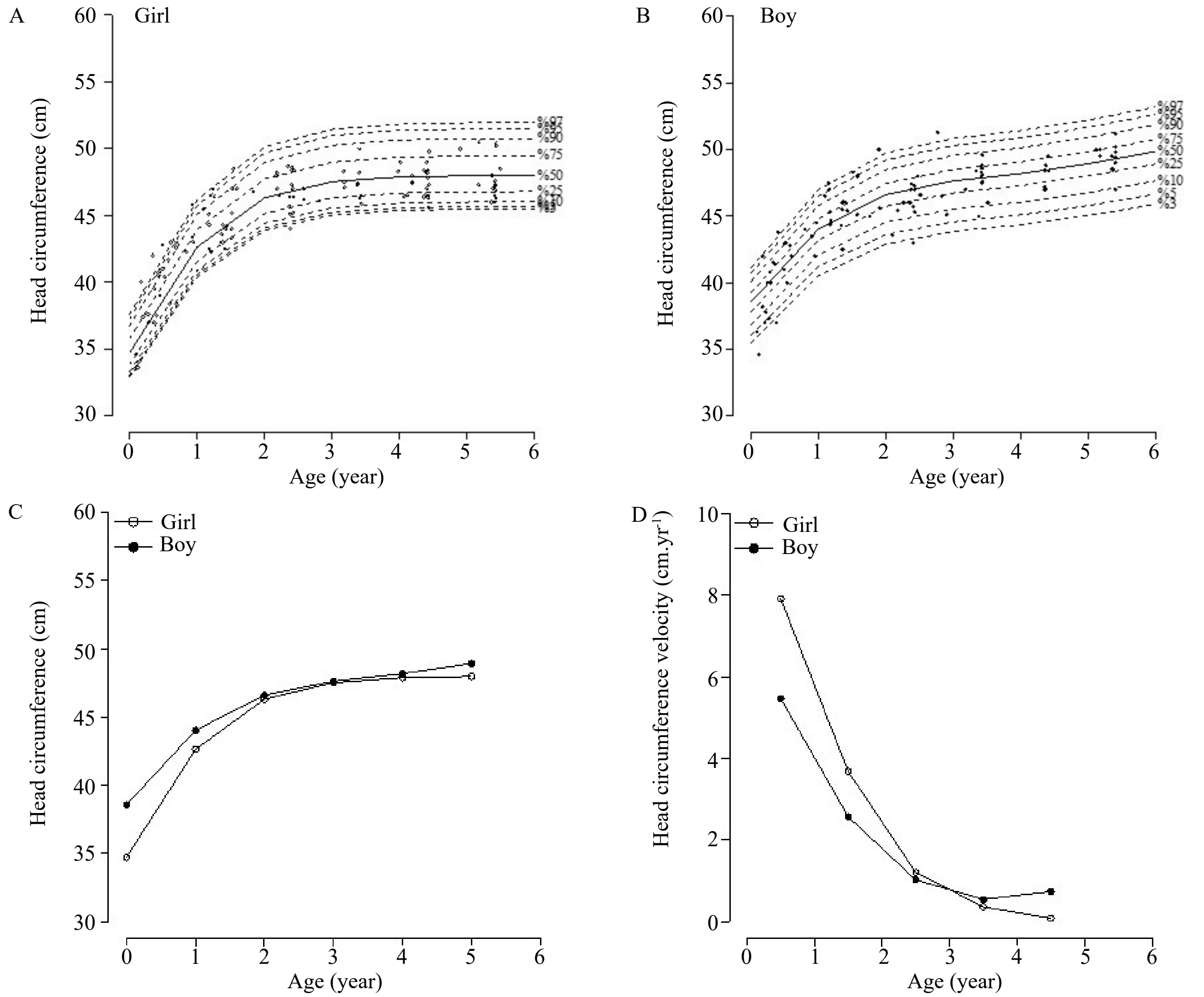

Figure 3. Growth pattern of head circumference aged 0-5 years (solid line is median). (A) Girls, (B) Boys, (C) Growth pattern from media, and (D) Growth velocity

the age range of 0-5 years (7.9 to 0.1 cm/year), while the decrease in growth rate in boys occurred in the age range of 0-4 years (5.5 to 0.6 cm/year) and then increased at the age of 5 years (0.7 cm/year).

3.4. Body Mass Index

We also calculated body mass index (BMI) in Baduy girls and boys. The growth pattern of BMI is presented in Figure 4, which shows that at 0-1 years, girls (15.9 $kg.m^2$ to 16.1 $kg.m^2$) were lower than boys (19.1 $kg.m^2$ to 17.3 $kg.m^2$). However, at the age of 2-5 years, the BMI of girls was greater than that of boys. The growth velocity of BMI also shows a different pattern between girls and boys. The BMI growth rate in girls decreased at 0-4 years (0.3 to -0.8 $kg.m^{-2}$/year) and increased at 4-5 years (-0.03 $kg.m^{-2}$/year). However, the growth rate in boys fluctuated with the maximum growth rate at the age range of 2-3 years (0.07 $kg.m^2$/year).

3.5. Baduy vs. Indonesian Curve

A comparison of body height (BH), body weight (BW), and body mass index (BMI) for Baduy children with the Indonesian National Synthetic Growth Charts (INSGC) shows that Baduy children are shorter (BH) and slimmer (BW) than Indonesian children standard for both sexes, girls and boys (Figure 5). In general, the BMI of Baduy girls is lower than the INSGC curve, except at age 2-3 years, where it is the same size. Meanwhile, the median BMI for Baduy boys aged 0-1 years is higher than the INSGC curve but becomes lower than the INSGC curve after that.

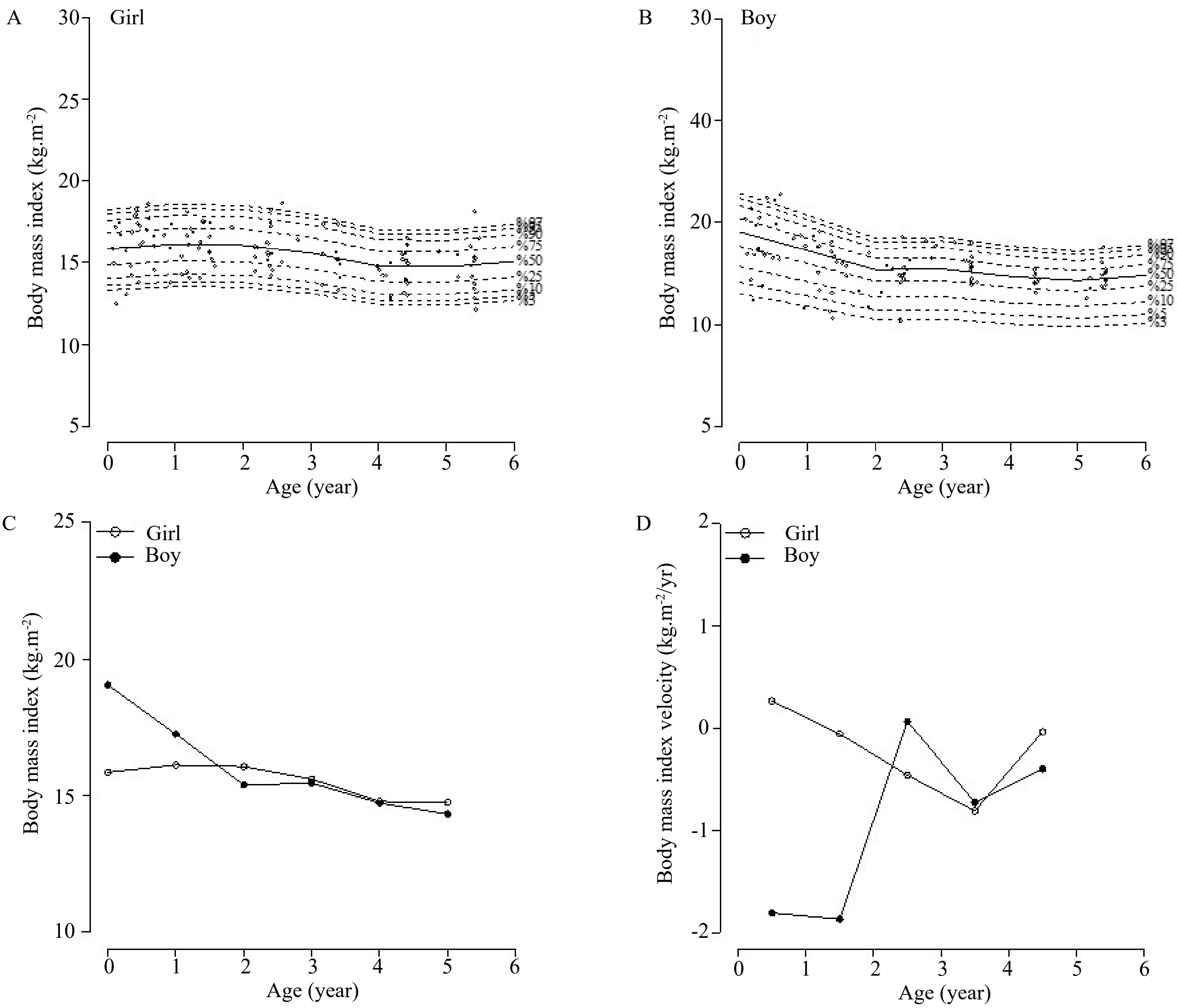

Figure 4. Growth pattern of body mass index aged 0-5 years (solid line is the 50th). (A) Girls, (B) Boys, (C) Growth pattern from 50th percentile, and (D) Growth velocity

3.6. Nutritional Status

The nutritional status of Baduy children aged 0-5 years is mostly good or normal, both in girls (82.2%) and boys (86.6%). However, compared to children with wasted nutritional status (2.5% for girls and 1.0% for boys), Baduy children are at a possible risk of being overweight, at 15.3% for girls and 12.4% for boys (Table 2).

4. Discussion

The growth of children under five years old is a rapid period of physical and cognitive development (Butchon and Liabsuetrakul 2017). Our result shows that Baduy children's body size generally increases yearly according to age, with a decreasing growth rate after birth until 2 or 3 years (Figures 1 to 4). The growth rate of BH increases after age 3 years in both sexes, girls and boys. However, the growth rate of BW increases after one year in boys and is followed by girls after age 2 years. The infancy phase (0-3 years) is generally characterized by a steep decrease in growth rate, which is the fastest-changing growth rate and lasts until childhood (3-7 years) due to most energy (40-85 percent) being allocated to brain growth, where the brain grows faster than other organs at an early age (Bogin 1999; Kuzawa *et al.* 2014; Bogin 2021).

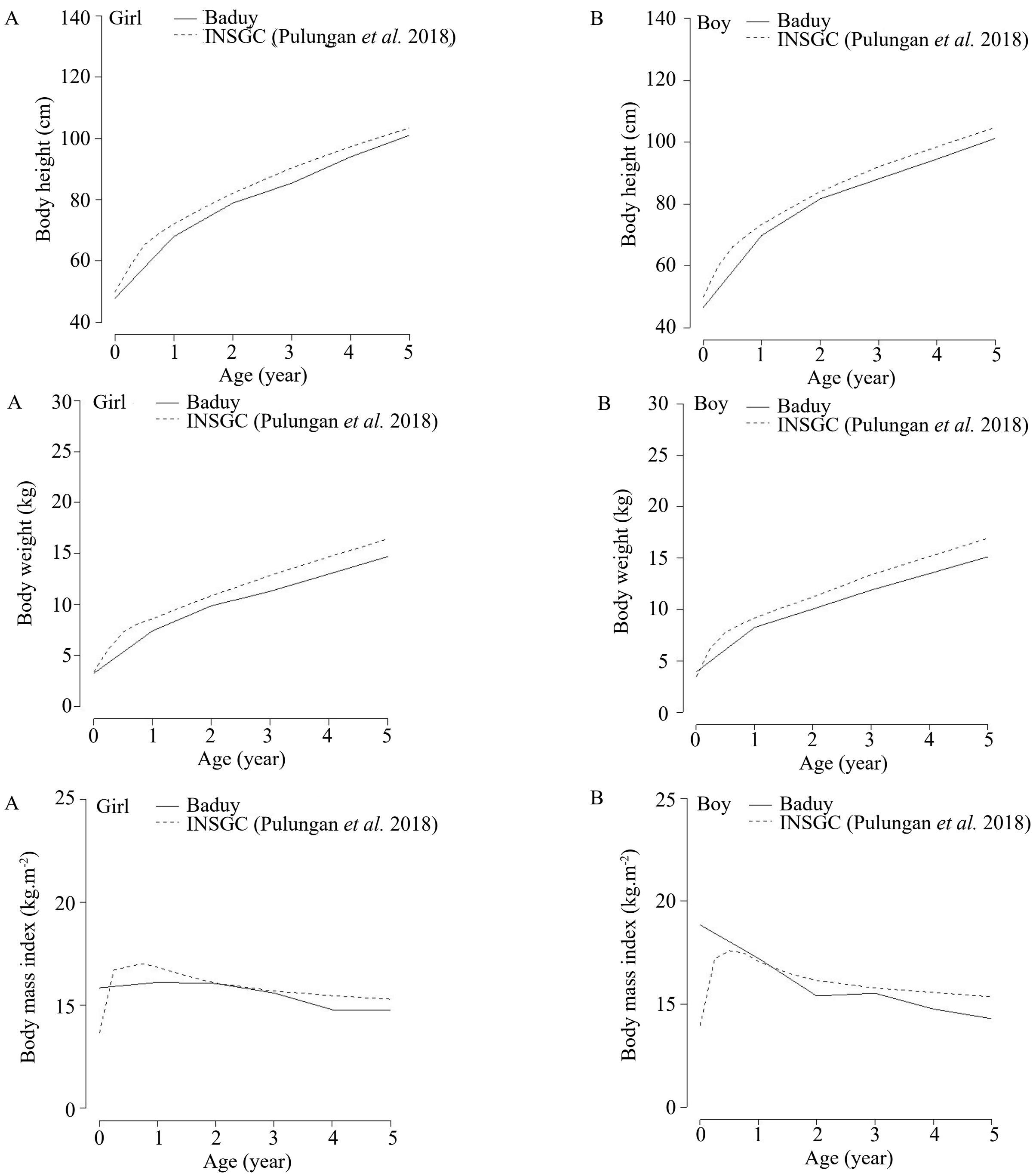

Figure 5. Comparison of median values of body height, body weight, and body mass index for Baduy children aged 0-5 years and the Indonesian National Synthetic Growth Charts (INSGC). (A) Girls and (B) Boys

The characterization of growth changes in brain size can be predicted through head circumference (HC) measurements (Bergerat *et al.* 2021). According to Sindhu *et al.* (2019), brain growth occurs in the first two years of life, and its volume will continue to increase until adolescence. Our result shows that the growth pattern of HC in Baduy children is different between girls and boys. The growth of HC in Baduy girls increases and tends to stabilize after 3 years, while for Baduy boys, it continues to grow until age 5 years. The slowing down of the growth rate is one of the signs of the end of the infancy phase into the childhood phase (Bogin 2021). Energy will be divided between growth and maintenance in infancy and is allocated to efforts in indirect activities, such as starting to walk, eating alone, and collecting and sharing some of these foods in childhood (Reiches

Table 2. Nutritional status of Baduy children (0-5 years) based on body mass index z-score

Category	Girls		Boys	
	Number of individual	Percentage (%)	Number of individual	Percentage (%)
Severely wasted	0	0.0	0	0.0
Wasted	3	2.5	1	1.0
Normal	97	82.2	84	86.6
Possible risk of overweight	16	13.6	7	7.2
Overweight	2	1.7	5	5.2
Obese	0	0.0	0	0.0
Total	118	100	97	100

et al. 2009). In addition, the decrease in the growth rate of BH is more rapid than of HC and BW, indicating the trade-offs (energy allocation) between bone (BH), brain growth (HC), and body weight (BW) (Figure 1D, Figure 2D, and Figure 3D). Bone growth, especially in the skull, is favored over fat and maintained against short- to medium-term variations in the energetic state (Bogin 1999; Bogin 2021; Stulp and Barrett 2014). For example, the trade-offs show that energy needs are prioritized for bone growth before fat storage due to competitive energy demand in the Savanna Pumé population (Kramer *et al.* 2021).

The growth pattern in Baduy children results in shorter and slimmer body sizes (BH differences: 2.0-4.0 cm; BW differences: 0.1-2.0 kg) than the Indonesian National Synthetic Growth Charts (INSGC) (Figure 5). Our results are consistent with previous studies; Baduy People have a lower height and weight compared to the Indonesian population and are more like the Pygmoid population as adults (Rohmatullayaly *et al.* 2017), who live in isolated environmental conditions with high physical activity and limited resource access. In general, the BMI of Baduy children was lower than INSGC, without a prior increase in early postnatal growth. This condition is similar to that of children in Timor-Leste, who live in unfavorable environments, such as high infectious disease transmission rates and poor nutrition (Spencer *et al.* 2017).

Based on their consumption patterns, most Baduy children consume breastmilk until the age of 2 years and start being fed at 6 months in the form of baby porridge, but some children have been given food (bananas) since the age of one week. For older children (aged 1-5 years), children usually eat the same food as their parents. In their daily lives, Baduy People generally consume rice, salted fish, and local vegetables and fruit available in nature (Rohmatullayaly *et al.* 2017). Apart from consumption patterns such as nutritional intake, other biocultural factors such as lifestyle (high physical activity) and socio-economic levels differ across various communities. In our observation, most Baduy children are already walking, especially those aged 3-5, doing physical activities outside their house, such as playing. Some children even start going to the *huma*/swidden rice field, located on steep hills, with their parents by walking, which requires more energy. In allocating energy, individuals' energy is pooled from the environment and food intake and energy recovered during alternative expenditures (activity). Activity affects energy availability, and expenditure is an important means of accounting for metabolic input and output (Kramer and Ellison 2010). Cultural values influencing behavior may evolve by sacrificing genetic fitness, so behaviors that develop in society may not necessarily benefit health (Wells *et al.* 2017).

Although Baduy children have a smaller body size than Indonesian standards (INSGC), most have normal or good nutritional status based on BMI categorization (Table 2). This condition conformed to is the "small but healthy" hypothesis (Pelto and Pelto 1989), which explains that small body size is a form of adaptation and a favorable evolutionary strategy when a population successfully handles limited natural resources. On the other hand, small body size is an advantage to dissipating body heat in the tropics, reducing food energy requirements, and easing mobility in the forest (Little 2020; Scheffler and Hermanussen 2022). The interaction between biological and cultural (biocultural) aspects influences environmental pressure on human growth (Stearns 2000; Bogin and Silva 2003) and is known to cause selective pressures on body size (Little 2020). The biocultural environment also influences the well-being of the current generation of humans and affects the next generation (Bogin *et al.* 2007).

Based on a biocultural perspective, cultural processes are based on the biological needs of the human life cycle, such as growth. In contrast, biological processes are limited, organized, and developed by cultures, such as religious beliefs and ideologies (Carrol *et al.* 2017). In traditional societies, energy allocation is generally used more for survival, thus causing a smaller body size, which aims to achieve growth balance (Little 2020). Our results show that Baduy children's small body size does not mean unhealthy conditions or undernutrition. This evidence is in accordance with the "small but healthy" hypothesis as an adaptation mechanism in the form of a life strategy presented by a trade-off (energy allocation) in growth patterns of body size. Viewed from an evolutionary perspective, this condition suggests that an adaptation mechanism of the availability and allocation of energy for growth efficiency, maintenance, and activity in unfavorable environments causes the uniqueness of Baduy's life history trait. We find overwhelming evidence that life history is an excellent framework for better understanding the complex regulation of human growth, which eventually leads to phenotypic variation.

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