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Physical Development of Children Before and After Surgical Correction of Congenital Heart Disease and Factors Associated with Impaired Growth

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ABSTRACT: Objective. To assess the physical development of children from their first clinical presentation to surgery and during the 12 months following surgical correction of congenital heart disease (CHD), and to identify factors associated with changes in physical development.

Materials and Methods. A total of 128 children were examined, of whom 83 underwent surgery. Seventy-eight children had at least one postoperative anthropometric assessment. Weight, height, and body mass index were assessed using WHO z-scores at first clinical presentation, surgery (T0) and at 3, 6, 9, and 12 months thereafter. Preoperative changes, clinical categories, physical-development patterns, category transitions, and associated factors were also evaluated.

Results. From the first clinical presentation to surgery, WAZ decreased from -0.75 to -0.88 SD ($p < 0.001$), and BAZ decreased from -0.03 to -0.13 SD ($p = 0.018$), whereas HAZ did not change significantly (-1.19 and -1.23 SD; $p = 0.267$). At 12 months after surgery, the adjusted changes were $+0.259$ SD for WAZ (95% CI 0.208–0.310; $p < 0.001$), $+0.337$ SD for BAZ (95% CI 0.255–0.419; $p < 0.001$), and $+0.054$ SD for HAZ (95% CI 0.005–0.102); the overall time effect for HAZ was not statistically significant ($p = 0.142$). Underweight decreased from 9.1% to 2.6% ($p = 0.063$), stunting remained present in 22.4%, and overweight/obesity increased from 4.0% to 14.7% ($p = 0.008$). A longer

waiting time to surgery was associated with smaller annual increases in WAZ ($\beta = -0.097$ SD/year; $p = 0.015$) and BAZ ($\beta = -0.144$ SD/year; $p = 0.021$).

Conclusion. During the first postoperative year, WAZ and BAZ improved substantially faster than HAZ, with the largest changes occurring during the second half of the year. Postoperative follow-up should include simultaneous monitoring of WAZ, HAZ, and BAZ and consideration of the time to surgical correction.

INTRODUCTION

Nutritional status disorders are among the most common extracardiac manifestations of congenital heart disease (CHD) in children. The main causes of these disorders may include increased energy expenditure, rapid fatigue during feeding, reduced food intake, chronic hypoxemia, tachypnea, heart failure, pulmonary hypertension, infectious diseases, and socioeconomic factors [1–4]. According to a meta-analysis of 39 studies, before surgery underweight was found in 27.4% of children, stunting in 24.4%, and wasting in 24.8% [3]. These disorders are often associated with longer mechanical ventilation, longer hospitalization, and a higher risk of postoperative complications [5–7].

After elimination of pathological hemodynamics, conditions are created for improved nutrition and growth. However, recovery of body weight and height does not occur synchronously. Body weight may increase already within the first months after surgery, whereas linear growth depends on a longer recovery of nutrition, bone tissue, and endocrine regulation. Therefore, stunting may persist even after successful correction of the defect [1, 2, 4, 8].

Physical development is influenced not only by the type and severity of CHD. Age at surgery, time from detection of the defect to correction, birth weight, pulmonary hypertension, frequent infections, and feeding pattern may also be important. In foreign studies, late diagnosis, prolonged waiting time for surgery, low birth weight, and severe CHD were associated with underweight and stunting [25–28].

After surgery, the spectrum of disorders may change. In some children, the weight deficit decreases, but overweight may simultaneously be observed. This is possible when weight recovers faster than height: with a stable or low HAZ, the BAZ value becomes higher even with a desirable weight gain. In addition, after successful surgery children sometimes continue to observe an excessively cautious regimen, although their clinical condition already allows expansion of physical activity [19–24].

WHO indices allow assessment of different aspects of physical development. WAZ reflects weight relative to age, HAZ reflects height relative to age, and BAZ reflects body mass index relative to age [13, 14]. Joint assessment of these three indicators helps to understand the basis of the change in physical development: whether the child is truly catching up with peers in height or predominantly gaining weight.

The aim of the study was to assess the physical development of children with CHD from their first clinical presentation to surgery and during the first year after surgical treatment, and to identify factors associated with impairment of physical development.

MATERIALS AND METHODS

The study included 128 children with an established diagnosis of congenital heart disease (CHD). Of these, 83 children underwent surgery. Seventy-eight children had at least one postoperative anthropometric assessment; five operated children lacked complete postoperative anthropometric data. The examination at the time of surgery was taken as the baseline point T0. Follow-up examinations were performed at 3, 6, 9, and 12 months. Weight and height were measured at each stage. Body mass index was calculated according to WHO standards (Anthro/AnthroPlus). WHO 2006 standards were used for children under 5 years, and WHO 2007 standards for children aged 5–19 years [13, 14]. WAZ, HAZ, and BAZ were calculated. Underweight was defined as $WAZ < -2$ SD, stunting as $HAZ < -2$ SD, and wasting (BAZ deficit) as $BAZ < -2$ SD. Overweight and obesity were defined according to WHO age-specific thresholds: under 5 years — $BAZ > +2$ and $> +3$ SD; at 5–19 years — $BAZ > +1$ and $> +2$ SD. The preoperative analysis included all operated children with paired data at first presentation and at T0, regardless of the availability of subsequent follow-up.

In addition, changes from first presentation to T0 and the frequency of individual WHO categories were assessed. Physical development without deviations in WAZ, HAZ, and BAZ was considered normal. The deficient type included underweight by

WAZ and/or wasting by BAZ; the growth-restricted type included stunting; the excess type included overweight or obesity. Tall stature was defined as HAZ>+2 SD. When two or more deviations were combined, a mixed type was identified.

Statistical analysis. Quantitative data are presented as mean $\pm$ standard deviation and median [Q1–Q3]; categorical data are presented as n (%). The dynamics of WAZ, HAZ, and BAZ were assessed using separate linear mixed models with a random intercept for each child. Time was treated as a categorical variable, with T0 used as the reference point. Each model included only children who had the corresponding indicator at T0 and at least one postoperative value.

Annual changes in WAZ, HAZ, and BAZ were compared within the same paired sample of children who had all three indicators available at T0 and at 12 months. The Friedman test was used, and for pairwise comparisons, the Wilcoxon test with Holm correction was applied. Changes in the frequency of underweight, stunting, wasting, and overweight were assessed using McNemar's exact test. The analysis was additionally repeated only in children with all five time points completed. Associations between clinical factors and WAZ, HAZ, and BAZ were analyzed using Spearman's correlation coefficient. To assess factors associated with annual change, separate multivariable linear regression models were built for Δ WAZ, Δ HAZ, and Δ BAZ, including baseline z-score, age at surgery, sex, time to surgery, aggregated CHD group, and breastfeeding. A p-value <0.05 was considered statistically significant.

RESULTS

Among the 78 children with postoperative anthropometric data, there were 45 girls (57.7%) and 33 boys (42.3%). The mean age at surgery was 50.0 ± 21.7 months. The most common defects were patent ductus arteriosus — 33 cases (42.3%) and ventricular septal defect — 31 (39.7%). Atrial septal defect was noted in 8 children (10.3%), tetralogy of Fallot in 4 (5.1%), and combined defects in 2 children (2.6%). The baseline characteristics of the examined children are presented in Table 1.

Table 1

Parameter	Value
Age at surgery, months	50.0 ± 21.7 ; 47.5 [34.3–64.0]
Time from CHD detection to surgery, months	17.6 ± 9.0 ; 17.5 [11.0–24.0]
Girls	45 (57.7%)
Boys	33 (42.3%)
Patent ductus arteriosus	33 (42.3%)
Ventricular septal defect	31 (39.7%)
Atrial septal defect	8 (10.3%)
Tetralogy of Fallot	4 (5.1%)
Combined CHD	2 (2.6%)
Pulmonary hypertension	3 (3.8%)
Cyanotic CHD	4 (5.1%)
History of breastfeeding	61 (78.2%)
WAZ at T0 (n=78)	-0.86 ± 0.87 ; Me -0.85 [–1.43––0.13]
Underweight, WAZ<–2 SD	8 (10.3%)
HAZ at T0 (n=76)	-1.20 ± 1.02 ; Me -1.20 [–1.90––0.43]
Stunting, HAZ<–2 SD	17 (22.4%)
BAZ at T0 (n=76)	-0.14 ± 1.17 ; Me -0.27 [–0.81––0.43]

Wasting, BAZ<-2 SD	5 (6.6%)
Overweight or obesity	3 (3.9%)

Baseline characteristics of the examined children (n=78). Note: data are presented as n (%), mean±SD and/or median [Q1–Q3]. The number of observations for WAZ, HAZ, and BAZ is presented separately.

The preoperative period was characterized by a significant decrease in WAZ — from -0.75 to -0.88 SD ($\Delta=-0.13\pm0.24$ SD; $p<0.001$) — and BAZ — from -0.03 to -0.13 SD ($\Delta=-0.10\pm0.34$ SD; $p=0.018$). At the same time, HAZ did not change significantly: -1.19 and -1.23 SD ($\Delta=-0.04\pm0.26$ SD; $p=0.267$) (Table 2).

Table 2

Indicator	n pairs	First presentation, M	T0, M	Δ M±SD	Δ Me [Q1–Q3]	p
WAZ	82	-0.75	-0.88	-0.13 ± 0.24	$-0.10 [-0.24-0.04]$	<0.001
HAZ	79	-1.19	-1.23	-0.04 ± 0.26	$-0.02 [-0.24-0.15]$	0.267
BAZ	79	-0.03	-0.13	-0.10 ± 0.34	$-0.06 [-0.36-0.13]$	0.018

Change in anthropometric indices from first presentation to surgery (T0). Note: the T0 column presents indicators in the same children who had a value at first presentation. p — Wilcoxon test.

When physical development indicators were divided into categories in paired samples at T0 and at 12 months, underweight by WAZ decreased from 7 of 77 children (9.1%) to 2 (2.6%); the overall distribution of WAZ categories changed at the borderline of statistical significance ($p=0.050$). Stunting by HAZ was noted in 17 of 76 children (22.4%) at both time points ($p=1.000$). Wasting by BAZ decreased from 5 of 75 children (6.7%) to 2 (2.7%), whereas the number of children with overweight or obesity increased from 3 (4.0%) to 11 (14.7%). The overall distribution of BAZ categories changed significantly ($p=0.011$) (Table 3).

Table 3

Index	Category	T0, n (%)	12 months, n (%)	p (Stuart–Maxwell)
WAZ	Severely reduced weight	1 (1.3%)	0 (0.0%)	0.050
	Reduced weight	6 (7.8%)	2 (2.6%)	
	Normal	70 (90.9%)	75 (97.4%)	
	Increased/high weight	0 (0.0%)	0 (0.0%)	
HAZ	Marked stunting	3 (3.9%)	3 (3.9%)	1.000
	Stunting	14 (18.4%)	14 (18.4%)	
	Normal	59 (77.6%)	59 (77.6%)	
	Tall stature	0 (0.0%)	0 (0.0%)	
BAZ	Marked wasting	0 (0.0%)	1 (1.3%)	0.011
	Wasting	5 (6.7%)	1 (1.3%)	
	Normal	67 (89.3%)	62 (82.7%)	
	Overweight	2 (2.7%)	6 (8.0%)	
	Obesity	1 (1.3%)	5 (6.7%)	

WAZ, HAZ, and BAZ categories in paired samples, T0–12 months. Note: for each index, percentages are calculated within its own paired sample: WAZ $n=77$, HAZ $n=76$, BAZ $n=75$. The “overweight risk” category was combined with normal in the BAZ analysis; the excess type included only overweight and obesity.

When WAZ, HAZ, and BAZ were assessed simultaneously in the same paired sample of 75 children, normal physical development was noted in 51 children (68.0%) at T0 and in 54 (72.0%) at 12 months. The deficient type decreased from 7 (9.3%) to 3 (4.0%), isolated stunting decreased from 12 (16.0%) to 6 (8.0%), and the excess type increased from 1 (1.3%) to 2 (2.7%). At the same time, the combination of stunting with overweight increased from 2 cases (2.7%) to 9 (12.0%) (Table 4).

Table 4

Physical development type	T0, n (%) (n=75)	12 months, n (%) (n=75)
Normal physical development	51 (68.0%)	54 (72.0%)
Deficient type	7 (9.3%)	3 (4.0%)
Stunting	12 (16.0%)	6 (8.0%)
Excess type	1 (1.3%)	2 (2.7%)
Tall stature	0 (0.0%)	0 (0.0%)
Mixed: stunting + excess type	2 (2.7%)	9 (12.0%)
Mixed: excess type + tall stature	0 (0.0%)	0 (0.0%)
Mixed: stunting + deficient type	2 (2.7%)	1 (1.3%)
Mixed: deficient type + tall stature	0 (0.0%)	0 (0.0%)

Physical development types at T0 and at 12 months. Note: physical development type was determined in the same paired sample of 75 children with simultaneously available WAZ, HAZ, and BAZ at T0 and at 12 months. Mixed type indicates a combination of two or more deviations.

In the paired sample, the proportion of children with the excess type, including its combination with stunting, increased from 3 (4.0%) to 11 (14.7%), $p=0.008$ by McNemar's exact test. The remaining main categorical changes did not reach statistical significance.

After adjustment for age at surgery, sex, and CHD group, WAZ and BAZ increased predominantly during the second half of the year, whereas changes in HAZ remained small (Table 5).

Table 5

Indicator	n	3 mo, β (95% CI)	6 mo, β (95% CI)	9 mo, β (95% CI)	12 mo, β (95% CI)	p for time
WAZ	78	−0.001 (−0.052; 0.050)	0.027 (−0.023; 0.078)	0.184 (0.133; 0.235)	0.259 (0.208; 0.310)	<0.001
HAZ	76	0.023 (−0.026; 0.072)	0.042 (−0.007; 0.091)	0.054 (0.005; 0.103)	0.056 (0.005; 0.107)	0.142
BAZ	76	−0.033 (−0.115; 0.049)	−0.023 (−0.105; 0.059)	0.219 (0.137; 0.301)	0.337 (0.255; 0.419)	<0.001

Change in WAZ, HAZ, and BAZ after surgery according to linear mixed models. Note: n indicates the number of children who had the corresponding indicator at T0 and at least one postoperative value. β reflects the change in z -score relative to T0. p for time — joint Wald test for the four time contrasts.

The change in WAZ relative to T0 was −0.001 SD at 3 months, +0.027 SD at 6 months, +0.184 SD at 9 months, and +0.259 SD at 12 months ($p<0.001$ for time). For BAZ, the changes were −0.033, −0.023, +0.219, and +0.337 SD, respectively ($p<0.001$). HAZ changed only slightly: +0.023 SD at 3 months, +0.042 SD at 6 months, +0.054 SD at 9 months, and +0.056 SD at 12 months. The overall dynamics of HAZ over time was not statistically significant ($p=0.142$) (Figure 1).

Age at surgery was not independently associated with mean WAZ, HAZ, or BAZ after adjustment for sex and CHD group ($p=0.109$, $p=0.086$, and $p=0.913$, respectively). Sex and CHD group were also not independently associated with mean index values.

Figure 1. Dynamics of WAZ, HAZ, and BAZ during the first year after surgery (relative to surgery).

In the analysis of 75 children who had WAZ, HAZ, and BAZ simultaneously available at T0 and at 12 months, the mean annual change was $+0.255 \pm 0.238$ SD for WAZ, $+0.337 \pm 0.362$ SD for BAZ, and $+0.051 \pm 0.218$ SD for HAZ. The differences between the three indicators were statistically significant (Friedman $\chi^2=33.65$; $p<0.001$). On average, the increase in WAZ was 0.205 SD greater than the increase in HAZ, and the increase in BAZ was 0.286 SD greater than the increase in HAZ; both comparisons remained significant after Holm correction ($p<0.001$). The increase in BAZ was also 0.081 SD greater than the increase in WAZ ($p=0.031$; Table 6).

Table 6

Change	n	M $\pm$ SD, SD	Me [Q1–Q3], SD	Range, SD
Δ WAZ	75	0.255 ± 0.238	0.280 [0.100–0.455]	–0.40...0.73
Δ HAZ	75	0.051 ± 0.218	0.040 [–0.110–0.180]	–0.36...0.75
Δ BAZ	75	0.337 ± 0.362	0.330 [0.090–0.630]	–0.52...1.14

Change in WAZ, HAZ, and BAZ between T0 and 12 months in the same children. Note: overall comparison — Friedman test, $p<0.001$. Pairwise comparisons with Holm correction: Δ WAZ vs Δ HAZ — $p<0.001$; Δ BAZ vs Δ HAZ — $p<0.001$; Δ WAZ vs Δ BAZ — $p=0.031$.

Among the main physical development categories, underweight decreased from 7 of 77 children (9.1%) to 2 (2.6%; $p=0.063$), stunting persisted in 17 of 76 children (22.4%; $p=1.000$), and wasting decreased from 5 of 75 (6.7%) to 2 (2.7%; $p=0.250$). In contrast, overweight or obesity increased from 3 of 75 children (4.0%) to 11 (14.7%; $p=0.008$; Table 7).

Table 7

Category	n pairs	T0	12 mo	Yes→No	No→Yes	p
Underweight (WAZ <-2 SD)	77	7 (9.1%)	2 (2.6%)	5	0	0.063
Stunting (HAZ <-2 SD)	76	17 (22.4%)	17 (22.4%)	0	0	1.000
Wasting (BAZ <-2 SD)	75	5 (6.7%)	2 (2.7%)	3	0	0.250
Overweight/obesity	75	3 (4.0%)	11 (14.7%)	0	8	0.008

Change in main physical development categories between T0 and 12 months. Note: p — McNemar's exact test.

When examining factors associated with physical development, simple correlations between time to surgery and WAZ and HAZ at T0 and at 12 months were not statistically significant. In the multivariable model, each additional year of waiting for surgery was associated with a smaller increase in WAZ of 0.097 SD (95% CI -0.175 ... -0.020 ; $p=0.015$; $n=77$) and in BAZ of 0.144 SD (95% CI -0.266 ... -0.023 ; $p=0.021$; $n=75$). The adjusted R^2 of the models was 0.041 for Δ WAZ and 0.071 for Δ BAZ. Age at surgery, sex, CHD group, breastfeeding, and baseline z-score showed no independent statistically significant associations with annual changes (Table 8).

Table 8

Factor	PD indicator	Method	Effect	p
Time to surgery	Δ WAZ	Multivariable regression	$\beta=-0.097$ SD/year (95% CI -0.175 ... -0.020); $n=77$; $R^2=0.041$	0.015
Time to surgery	Δ BAZ	Multivariable regression	$\beta=-0.144$ SD/year (95% CI -0.266 ... -0.023); $n=75$; $R^2=0.071$	0.021

Statistically significant factors of annual change in physical development. Note: baseline z-score, age at surgery, sex, CHD group, and breastfeeding were also included in each model; for these factors, $p > 0.05$.

Verification of the results using other methods gave a similar picture. Among children with all five time points completed, the dynamics were significant for WAZ ($n=77$; $p < 0.001$) and BAZ ($n=75$; $p < 0.001$), but not for HAZ ($n=76$; $p = 0.326$). In a direct comparison of T0 and 12 months, WAZ increased by 0.257 SD (95% CI 0.203–0.311; $p < 0.001$), BAZ increased by 0.337 SD (95% CI 0.254–0.420; $p < 0.001$), and HAZ increased by 0.054 SD (95% CI 0.004–0.103; $p = 0.055$).

DISCUSSION

Considering the above, it can be noted that WAZ decreased by 0.13 SD and BAZ by 0.10 SD, whereas HAZ did not change significantly. After surgery, the picture became more favorable: over 12 months, WAZ increased by 0.259 SD, BAZ by 0.337 SD, and HAZ by only 0.054 SD. This was confirmed by a direct comparison in the same 75 children: Δ WAZ was +0.255 SD, Δ BAZ was +0.337 SD, and Δ HAZ was +0.051 SD ($p < 0.001$). Thus, weight indicators improved faster than the linear growth indicator. After surgery, energy expenditure on breathing and cardiac work decreases, feeding becomes easier for the child, and appetite improves. This is reflected more quickly in body weight and BMI, whereas linear growth requires a longer recovery period [2, 4, 8].

The five observation points allowed identification of when changes began. At 3 and 6 months, WAZ was practically unchanged from T0 (−0.001 and +0.027 SD), then increased to +0.184 SD at 9 months and +0.259 SD at one year. BAZ also did not change significantly in the first 6 months (−0.033 and −0.023 SD), but then increased to +0.219 and +0.337 SD. For HAZ, changes remained small at all time points — from +0.023 to +0.056 SD. Consequently, the most pronounced improvement in weight indicators occurred during the second half of the first postoperative year.

The association with time to surgery appeared only after adjustment for other factors. In simple correlation analysis, time to surgery was not associated with WAZ or HAZ at T0 or at one year. However, in the multivariable model, each additional year of waiting was associated with a smaller annual increase in WAZ of 0.097 SD and in BAZ of 0.144 SD.

Breastfeeding, baseline z-score, age at surgery, sex, and aggregated CHD group were not independently associated with annual changes in WAZ, HAZ, or BAZ. Birth weight and Apgar score also showed no statistically significant correlations with BAZ or HAZ.

Analysis of physical development types in the same paired sample of 75 children showed that normal physical development was noted in 51 children (68.0%) at T0 and in 54 (72.0%) at one year. The deficient type decreased from 9.3% to 4.0%, and isolated stunting decreased from 16.0% to 8.0%. At the same time, the combination of stunting with overweight increased from 2.7% to 12.0%. These data show why a single weight indicator is insufficient to characterize physical development.

BAZ categories changed in two directions. Wasting decreased from 6.7% to 2.7%, but overweight and obesity increased from 4.0% to 14.7%. With HAZ almost unchanged, the increase in BAZ can be partly explained by weight increasing faster than height. Therefore, a high BAZ in this situation requires simultaneous assessment of growth trajectory, diet, and physical activity. Nevertheless, foreign data confirm that excess weight in children with CHD is a genuine problem. In a study of 172 children after surgery, 29% had overweight or obesity, and higher habitual physical activity was associated with lower BMI [21]. In a cohort of 316 children, overweight was found in 26.9%, with about half of the children being irregularly active or sedentary [22].

It is possible that the increase in BAZ was caused by a cautious regimen after surgery. It should also be considered that children who had overweight and obesity remained in the same group after surgical treatment, which may reflect the children's lifestyle. A possibly sedentary lifestyle and high-calorie diet may have persisted after surgery. Accelerometry studies show that only a small proportion of children with CHD meet the recommendation of at least 60 minutes of moderate to vigorous activity per day [23]. The American Heart Association states that most children after successful CHD correction do not need extensive restrictions on daily activity [20]. Therefore, after improvement of the condition, it is necessary not only to adjust nutrition but also to gradually expand safe physical activity.

CONCLUSION

From the first clinical presentation to surgery, WAZ and BAZ decreased, while HAZ did not change significantly. During the first year after surgery, WAZ increased by 0.259 SD, BAZ by 0.337 SD, and HAZ by only 0.054 SD. The frequency of

underweight decreased from 9.1% to 2.6%, stunting persisted in 22.4% of children, and overweight and obesity increased from 4.0% to 14.7%. A longer waiting time for surgery was associated with a smaller increase in WAZ and BAZ. Postoperative follow-up should include simultaneous assessment of weight, height, WAZ, HAZ, and BAZ, as well as timely correction of both deficient and excess disorders. In children with weight deficit, the effectiveness of nutritional support must be monitored, but after normalization of weight it is important to prevent its excessive increase. With low HAZ, longer follow-up of growth and a search for additional causes of the delay are required. When BAZ increases, growth trajectory, diet, and physical activity should be assessed simultaneously.

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