Echocardiographic nomograms and Z-scores for term Indian neonates

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ABSTRACT

Background : **The availability of nomograms is crucial for the correct interpretation of pediatric and neonatal echocardiograms. Echocardiographic Z-score applications/websites use Western nomograms as reference, which may not be an appropriate standard for gauging Indian neonates. Currently available Indian pediatric nomograms either have not included neonates or have not been specifically designed for neonates. This gross underrepresentation of neonates renders available nomograms unreliable for use as standards for comparison.**

Objectives : **The objective of this study was to collect normative data for the measurement of various cardiac structures using M-Mode and two-dimensional (2D) echo in healthy Indian neonates and to derive Z-scores for each measured parameter.**

Methods : **Echocardiograms were performed on healthy term neonates (within first 5 days of life). Birth weight and length were recorded, and body surface area was calculated using Haycock's formula. Twenty M-mode and 2D-echo parameters were measured (including left ventricular dimensions, atrioventricular valves, and semilunar valves' annuli sizes, pulmonary artery and branches, aortic root, and arch).**

Results : **We studied 142 neonates (73 males) with a mean age of 1.83 ± 1.12 days and mean birth weight of 2.89 ± 0.39 Kg. Regression equations with linear, logarithmic, exponential and square root models were tested to select the best model of fit for the relationship between birth weight and each echocardiographic parameter. Scatter plots and nomogram charts with Z-scores were prepared for each echocardiographic parameter.**

Conclusions : **Our study provides nomograms with Z-scores for term Indian neonates weighing between 2 kg and 4 kg at birth, within first 5 days of life, for a set of echocardiographic parameters that are frequently used in clinical practice. This nomogram has poor predictability for babies at extremes of birth weight. There is a need for further indigenous studies to include neonates at extremes of weight, both term, and preterm.**

Keywords : Echocardiography, Indian, neonates, pediatric echo, Z score

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INTRODUCTION

The availability of nomograms is crucial for the correct interpretation of pediatric echocardiograms. As a neonate's heart adapts to postnatal hemodynamics, relative sizes and flows across cardiac chambers change. It is, therefore, more challenging to diagnose abnormalities in this age group in comparison to a pediatric or an adult heart. Since the right ventricle is usually larger than the left ventricle (LV) at birth, it is not possible to use it as a reference to compare LV dimensions against it, as is done in adults. In the absence of age and body surface area (BSA) indexed normal reference values for LV, pathologies may go undetected. Nomograms are thus mandatory for reliable assessment of dimensions of cardiac chambers, valves, and great vessels, more so in the neonatal population.

At present, there are limited echocardiographic nomograms for Indian neonates. While performing neonatal echocardiograms, Z-score applications or websites are usually used to calculate the deviation of an echocardiographic measurement from the reference value.[1,2] While this practice may suit western countries, it might give wrong results, if done in India and other Asian countries as the reference nomograms included in these calculators are derived from Western data. Given the large variations in dimensions of cardiac structures (as is true for other organs as well) among different races, nomograms from the western population may not be suitable tools to gauge Indian neonates. The Indian population, in itself, is quite diverse, and ideally ethnicity-specific reference nomograms should be available. In addition, most echocardiographic studies have provided data for the pediatric population as a whole, including all children from birth to 18 years of age. Among them, the number of neonates included is either unspecified or is very less, translating into a gross under-representation of neonates.[3] We have summarized all the available studies in Appendix 1. Relatively more data are needed for neonates, considering their unique hemodynamics and the need for making early and accurate decisions regarding management if an abnormality is present.

Heterogeneity of results while applying different nomograms to an individual newborn is a cause for concern that advocates for the development of ethnicity specific nomograms. For example, for the same child, Z-score for mitral valve annulus (MVA) may range from – 1.63 to – 4.84 when different reference values are used.[4] Furthermore, most of the studies have provided nomograms for LV and valvular dimensions in neonates, while data on pulmonary arteries and aorta are limited.[4,5]

In view of the aforementioned limitations, there is a clear need for indigenous data on the echocardiographic parameters of the Indian neonatal population. This prospective study provides data for Indian neonatal echocardiographic nomograms along with Z-scores. Z-scores represent how many standard deviations (SDs) a value is higher or lower from the population mean and is considered the best method for assessing a value in a normally distributed population.[6]

METHODS

This was a cross-sectional observational study. We included consecutively born term neonates (within first 5 days of life). All children had APGAR score >7 at 1 min and at 5 min. The following neonates were excluded:

1. Any congenital heart disease (except patent foramen ovale or small patent ductus arteriosus <2.5 mm within 1st 5 days of life)
2. Any illness that required admission
3. Suspected genetic syndromes, chromosomal abnormalities, inborn errors of metabolism
4. Congenital heart disease detected antenatally by fetal echocardiogram
5. Antenatally/postnatally diagnosed to have diseases of other organ systems that required continued hospitalization/surgery in the immediate newborn period
6. Respiratory distress that required respiratory support in any form, including supplemental oxygen in the immediate newborn period, transient tachypnea of newborn
7. Early onset sepsis
8. Babies of mothers who had premature rupture of membranes/meconium-stained liquor.

Sample size calculation

Assuming a normal distribution of the variables and estimating the population SD at 1.7 mm (among all the echocardiographic parameters, aortic annulus size had a min SD of 1.7 mm) as seen on average in previous literature,[7] 124 subjects will be required to provide a 95% confidence interval with a margin of error of 0.3. Assuming that not all the echocardiographic studies would contain complete information, a higher subject number would be required. Assuming 10% of studies will have incomplete measurements, a total of 137 subjects was calculated.

Sampling technique: Consecutive inclusion

After obtaining informed consent, weight and length were measured. BSA was calculated using Haycock's formula.[8] – $BSA = 0.024265 \times \text{height (cm)}^{0.3964} \times \text{weight (kg)}^{0.5378}$. ECG-gated echocardiograms were performed using S8-3 probe of EPIQ 7G (Philips Medical System, Andover, MA) echocardiography machine in the Department of Cardiology. Loops were acquired by a qualified pediatric cardiologist and stored in digital imaging and communications in medicine format. Echocardiographic measurements were done offline as per the recommendations by Lopez *et al.*[9] Standard apical four chamber (A4C), parasternal long axis (PLAX), short axis, and suprasternal views were used to make all measurements. Neonates found to be having any congenital heart disease (except patent foramen ovale and small patent ductus arteriosus <2.5 mm) were excluded. Any study with an incomplete dataset was excluded from the analysis. No sedation was used before echocardiography. Mothers were encouraged to breastfeed their babies before the examination. Most babies were examined in the postfed state while they were tranquil or sleeping. Dextrose water was used to pacify babies who were crying. Our center does not practice swaddling newborns/use of pacifiers/nonnutritive sucking for echo examination, although these methods are being successfully used in other centers.

The following M-Mode parameters were recorded-
1. Interventricular septum dimension in diastole
2. LV internal dimension in diastole
3. Left ventricle posterior wall dimension in diastole
4. Interventricular septum dimension in systole
5. LV internal dimension in systole
6. LV posterior wall dimension in systole.

Following two-dimensional (2D)-echo parameters were recorded:
1. Aortic valve annulus (AVA)
2. Sinus of valsalva dimension
3. Sino-tubular junction dimension
4. Ascending aorta dimension (AscAo)
5. Pulmonary valve annulus
6. Main pulmonary artery dimension (MPA)
7. Right pulmonary artery dimension
8. Left pulmonary artery dimension
9. Mitral valve annulus (PLAX view)
10. Mitral valve annulus in apical 4-chamber view
11. Tricuspid valve annulus in 4-chamber view (TVA)
12. Aortic arch proximal
13. Aortic arch distal
14. Aortic arch isthmus.

Ethics

The study was approved by the Institute ethics committee. Informed consent was obtained from either of the parents of each baby enrolled in the study.

Statistics

The mean and SD of all echocardiographic parameters were measured. Using IBM SPSS Statistics for Windows, Version 19 (IBM Corp, Armonk, N.Y., USA), regression equations with linear, logarithmic, exponential, and square root models were tested to examine the relationship between birth weight and each of the echocardiographic variables. The models with the highest R^2 value for each echocardiographic variable were selected. Using STATA software "(Stata Statistical Software. College Station, TX: StataCorp), birth weight-adjusted nomogram charts (with Z-scores) were prepared for each echocardiographic parameter using the model with the best fit.

RESULTS

We assessed the echocardiograms of 142 neonates (73 were male). All echocardiographic examinations were done within the first 5 days of life. Data on average age, birth weight, length, and BSA is provided in Table 1. The mean values and SD for the 20 assessed echocardiographic parameters are provided in Table 2. Figures 1-4 show scatter plots for TVA, AVA, MPA, and AscAo as per birth weight. Scatter plots for the other echocardiographic parameters are provided in Appendix 2.

Using regression equations, various models (linear, logarithmic, exponential, and square root) were

Table 1: Basic characteristics of the entire cohort (*n*=142)

Character	Value
Age (in days) mean +/- SD	1.83±1.12
Number of male babies *n*(%)	73 (51.4)
Number of female babies *n*(%)	69 (48.6)
Weight (kg) mean +/-SD	2.8±0.39
Length (cm) mean +/-SD	49.47±1.97
BSA (m^2) mean +/-SD	0.20±0.02

BSA: Body surface area, SD: Standard deviation

Table 2: Echocardiographic parameters of the entire cohort (*n*=142)

Parameter (mm)	Mean±SD	Minimum	Maximum
TV annulus	10.93±1.24	8.4	14.5
MV annulus (A4C)	9.14±1.08	6.9	12.4
MV annulus (PLAX)	9.78±1.37	6.6	13.5
IVS in diastole	3.75±0.78	2	5.7
LVID in diastole	15.97±2.36	10.1	26.2
LVPW in diastole	3.06±0.60	1.7	5
IVS in systole	5.46±0.99	3.1	7.8
LVID in systole	10.47±2.13	5.4	19.3
LVPW in systole	4.63±0.84	2.4	7.5
PV annulus	6.80±0.96	4.7	9.3
Main PA	8.02±1.30	4.8	12.3
Right PA	4.45±0.63	3.2	6.4
Left PA	4.72±0.80	3.2	7.8
AV annulus	6.30±0.72	4.7	8.4
Aortic root	9.16±0.83	7.5	10.9
Sino-tubular junction	7.02±0.76	5.3	9
Ascending aorta	7.86±1.02	3.9	9.8
Aortic arch proximal	6.99±0.78	5.2	8.7
Aortic arch distal	5.98±0.79	4.2	7.9
Aortic arch isthmus	4.44±0.65	3.1	6.3

SD: Standard deviation, TV: Tricuspid valve, MV: Mitral valve, 4CV: 4-chamber view, PLAX: Parasternal long axis, IVS: Interventricular septum, LVID: Left ventricle internal dimension, LVPW: Left ventricle posterior wall, PV: Pulmonary valve, PA: Pulmonary artery, AV: Aortic valve

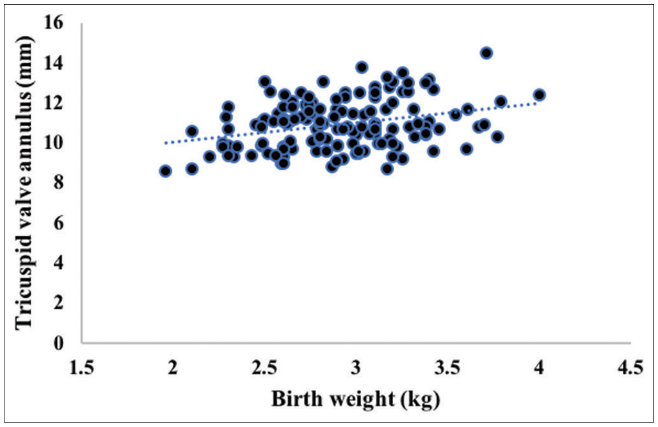

Figure 1: Scatter plot showing distribution of TVA dimensions as per birth weight. TVA: Tricuspid valve annulus

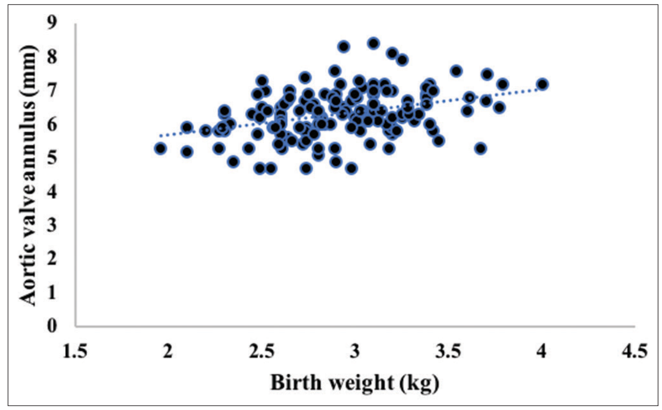

Figure 2: Scatter plot showing distribution of AVA dimensions as per birth weight. AVA : Aortic valve annulus

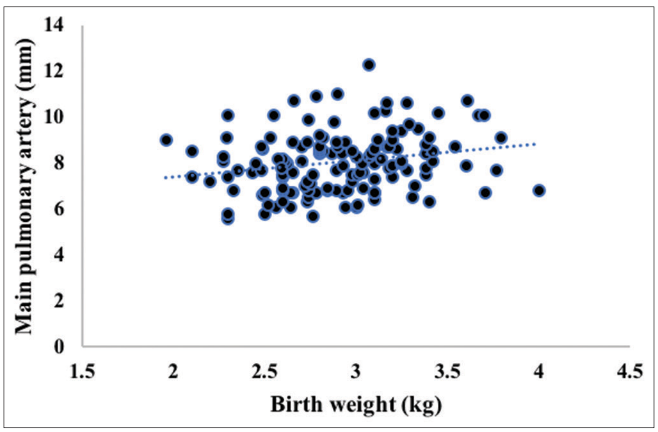

Figure 3: Scatter plot showing distribution of MPA dimensions as per birth weight. MPA: Main pulmonary artery

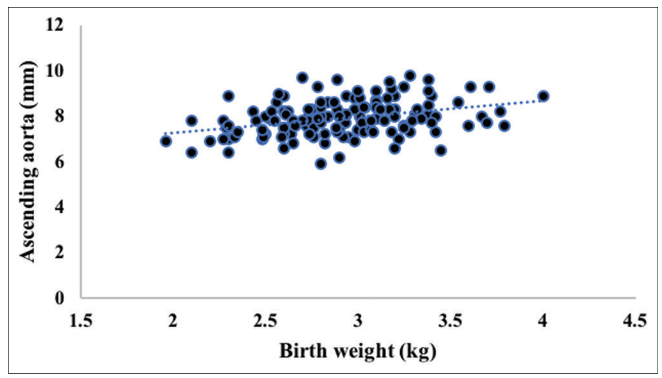

Figure 4: Scatter plot showing distribution of AscAo dimensions as per birth weight. AscAo: Ascending aorta dimension

created to predict the echocardiographic parameters by birth weight. Models with best fit (max R^2 values) have been provided in Table 3. Prediction charts for TVA, AVA, MPA, and AscAo as per birth weight are shown in Figures 5-8. Prediction charts for all parameters are available in Appendix 3.

DISCUSSION

We included 142 neonates within first 5 days of life. The mean age was 1.83 ± 1.12 days. We assessed 20 variables that are considered most important for a routine echocardiographic examination. Echocardiographic measurements in neonates with congenital heart disease are critical for decision-making regarding the need for and timing of surgery/interventional therapy.

The study by Trivedi *et al.* included 132 neonates and assessed most echocardiographic parameters relevant for decision-making in pediatric cardiology practice.[10] Z-scores for children from the newborn period to 16 years of age correlated with BSA were provided. Details regarding the newborn subset including the number of term versus preterm babies in the cohort of 132, number of small for gestational age (SGA) versus appropriate for gestational age versus large for gestational age (LGA) babies, average age in mean days of life when the echocardiography examination was performed were not elaborated upon. Jain *et al.* did echocardiograms for 50 neonates on day 1 and day 2 of life and measured right ventricular parameters.[11] The study by Tacy *et al.* was the earliest to provide reference values for valvular annuli for 70 neonates, including both preterms and terms.[12] Many newborns had very low birth weight. Solinger *et al.* provided cardiac chamber dimensions at a time when 2D echocardiography had not come into vogue.[13] They had included 240 neonates within 1st week of life. In addition, there have been a few pediatric echocardiographic studies designed for establishing nomograms across a wide age group, that also incorporated adequate focus on neonates.[7,14]

Most of the echocardiographic measurements correlate with body weight and BSA. As birth weight has more variability in comparison to BSA in the newborn period and since length measurement is prone to error in neonates,[11] birth weight is preferred over BSA for indexing echocardiographic measurements. The weight of neonates in our study ranged from 1.96 to 4.0 kg, and

Table 3: Best models for prediction of the measured echocardiographic parameters

Parameter	Intercept	*B*	SE-β	MSE	KS test statistic	*P*	R^2	Model of fit
TV annulus	7.58	3.31	0.88	1.48	0.075	0.185	0.125	Model: y=a + bln (x)
MV annulus (A4C)	6.49	2.6	0.77	1.13	0.064	0.2	0.103	Model: y=a + bln (x)
MV annulus (PLAX)	2.02	0.26	0.1	0.017	0.045	0.2	0.068	Model: ln (y)=a+bln (x)
IVS in diastole	0.96	0.32	0.15	0.044	0.069	0.2	0.043	Model: ln (y)=a+bln (x)
LVID in diastole	2.53	0.21	0.11	0.023	0.083	0.086	0.036	Model: ln (y)=a+bln (x)
LVPW in diastole	0.53	0.19	0.05	0.04	0.066	0.2	0.129	Model: ln (y)=a+bx
IVS in systole	2.36	1.83	0.82	0.9	0.061	0.2	0.049	Model: y=a + b sqrt (x)
LVID in systole	2.25	0.07	0.15	0.043	0.091	0.039	0.002	Model: ln (y)=a+bln (x)
LVPW in systole	2.98	0.57	0.22	0.78	0.087	0.058	0.061	Model: y=a + bx
PV annulus	1.57	0.35	0.1	0.018	0.076	0.168	0.116	Model: ln (y)=a+bln (x)
Main PA	2.37	0.28	0.19	0.051	0.05	0.2	0.021	Model: sqrt (y)=a+b sqrt (x)
Right PA	1.43	0.08	0.1	0.02	0.077	0.15	0.006	Model: ln (y)=a+bln (x)
Left PA	1.47	0.1	0.12	0.027	0.054	0.2	0.007	Model: ln (y)=a+bln (x)
AV annulus	4.27	1.99	0.45	0.39	0.057	0.2	0.166	Model: y=a + bln (x)
Aortic root	7.31	1.84	0.55	0.57	0.06	0.2	0.103	Model: y=a + bln (x)
Sino-tubular junction	5.19	1.68	0.54	0.55	0.051	0.2	0.091	Model: y=a + bln (x)
Ascending aorta	1.72	0.33	0.06	0.008	0.05	0.2	0.216	Model: ln (y)=a+bln (x)
Aortic arch proximal	6.67	0.5	0.49	0.45	0.056	0.2	0.011	Model: y=a + bln (x)
Aortic arch distal	1.74	0.07	0.09	0.014	0.059	0.2	0.007	Model: ln (y)=a+bln (x)
Aortic arch isthmus	3.78	0.76	0.46	0.41	0.041	0.2	0.026	Model: y=a + bln (x)

TV: Tricuspid valve, MV: Mitral valve, A4C-Apical 4 chamber view, PLAX: Parasternal long axis, IVS: Interventricular septum, LVID: Left ventricle internal dimension, LVPW: Left ventricle posterior wall, PV: Pulmonary valve, PA: Pulmonary artery, AV: Aortic valve, SE: Standard error, KS: Kolmogorov–Smirnov, MSE: Mean squared error

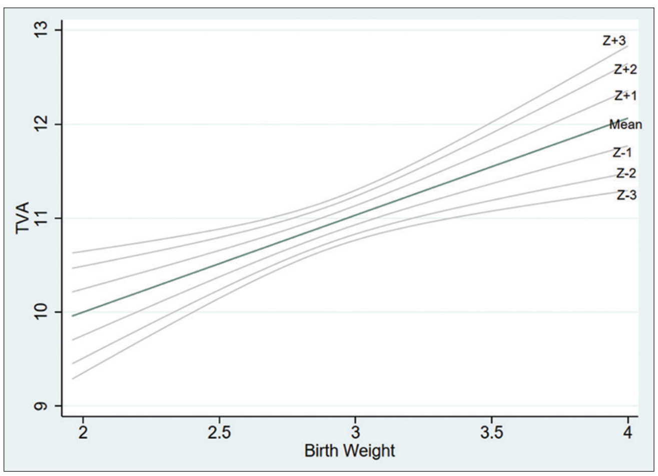

Figure 5: Prediction chart for TVA using weight. TVA: Tricuspid valve annulus

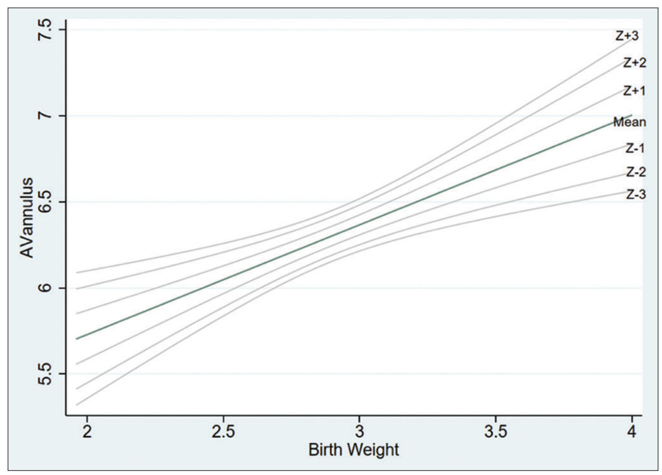

Figure 6: Prediction chart for AVA using weight. AVA: Aortic valve annulus

BSA ranged from 0.16 to 0.24 m^2. This narrow range led to a homogenous study cohort which was also the result of including exclusively term newborns within the first 5 days of life. The SD for weight for our neonates was only 0.39 kg. This led to weak statistical correlations between echocardiographic parameters and birth weight. The regression analysis showed that birth weight had low predictability for echocardiographic parameters in our study. Maximum predictability was found for AscAo (21.6%). However, in our study, the variability of echocardiographic parameters in relation to BSA (as shown in scatterplots) was comparable to the study by Trivedi *et al.*[10] Although Cantinotti *et al.*[7] have shown that BSA can be a suitable standard for young infants too, in a cohort like ours with minimal variation of BSA, weight was a more suitable standard. Since neonates are under-represented in most pediatric nomograms, reliability of those for providing the answers in neonates is questionable, signifying the need for prospectively designed studies for establishing neonatal nomograms. Although the pediatric heart network database[14] demonstrated the generalizability of their nomogram to children of various races and ethnic backgrounds residing in North America, whether it holds true universally is to be tested, more so since evidence revealing significant differences on comparing an Indian pediatric echocardiographic nomogram[15] against Western literature is available.[16] When left ventricular and left atrial chamber dimensions in older children and adolescents assessed by established nomograms [including American, European, African and Asian (Indian and Japanese)] were compared, significant differences were identified.[16] Unless validated by large-scale studies in Asian and African

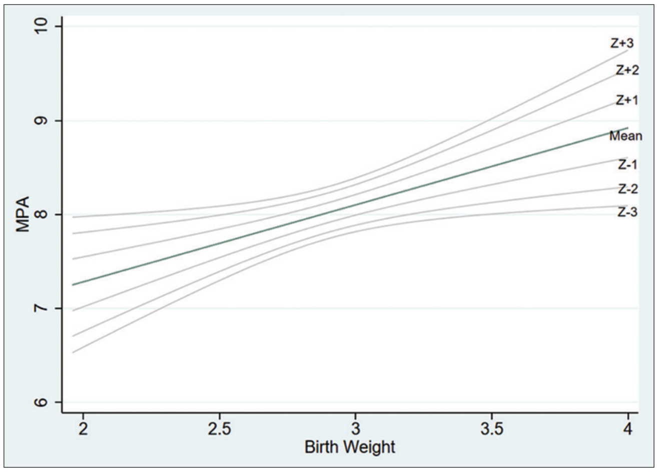

Figure 7: Prediction chart for MPA using weight. MPA: Main pulmonary artery

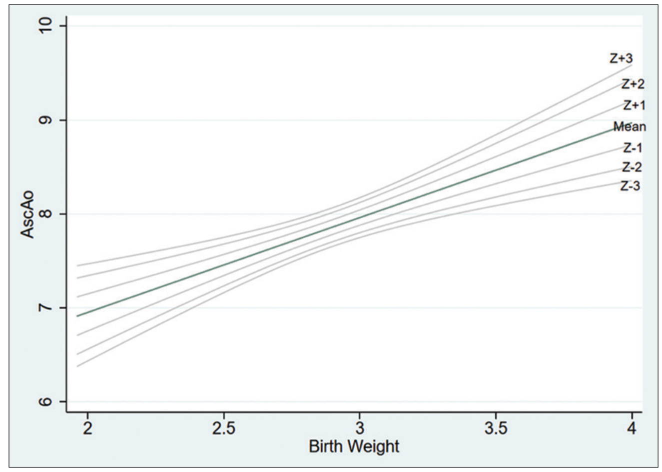

Figure 8: Prediction chart AscAo for using weight. AscAo: Ascending aorta dimension

populations, the practice of applying Western literature to children from these countries might lead to erroneous conclusions and decisions. Whether race plays an insignificant role in determining cardiac dimensions needs to be studied in children, especially since evidence to the contrary is available in adults.[17] It may be interesting to note that left ventricular volumes and dimensions were significantly lower in Asians in comparison to Europeans[17] in adults, similar to what was revealed by the analysis of Majonga *et al.*[16] in children.

There is a need to sample more neonates with extremes of birth weight like pre-terms and large for gestational age babies to give accurate weight adjusted models. In recent years, studies have been done to provide Z-scores exclusively for preterms, which is an encouraging trend. Abushaban *et al.* have given reference values for LV dimensions,[18] cardiac annuli,[19] and LV mass[20] while Dijkema *et al.* have provided reference values for aortic arch dimensions[21] in preterm neonates. The reference data provided by our study can be reliably used for term Indian neonates within 2–4 kg of birth weight.

Limitations

This study includes a dataset specific for term Indian neonates within 2–4 kg of birth weight. However, due to the narrow range of birth weights included, the birth weight-based models have low predictability for echocardiographic dimensions for very low or very high birth weight neonates. Therefore, the reference data may not be applicable to SGA or LGA neonates.

CONCLUSIONS

Nomograms for a wide variety of parameters measured during the routine echocardiographic examination that are necessary for critical decision-making at/soon after birth have been provided. These nomograms apply to Indian neonates weighing between 2 kg and 4 kg at birth, within the first 5 days of life. These nomograms have poor predictability for babies at extremes of weight. There is a need for further indigenous studies to include neonates at extremes of weight, both term and preterm.

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Conflicts of interest

There are no conflicts of interest.

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APPENDIXES

Appendix 1: Studies on echocardiographic nomograms for pediatric population (some include neonates)

Year	Author	Location	*n*	Age group	Echocardiographic parameters
1973	Solinger *et al.*[1]	USA	240	Neonates	4 chambers A mode and M mode
1984	Snider *et al.*[2]	USA	110	<18 years	AV, PV
1985	King *et al.*[3]	USA	103	<15 years	MV, TV
1988	Hanséus *et al.*[4]	Sweden	120	<16 years	4 chambers, great vessels, IVC
1995	Tacy *et al.*[5]	USA	70	Neonates <10 days	MV, AV, TV, PV
1998	Skelton *et al.*[6]	UK	79	Preterm <34 weeks	LA, LV, aortic root, Vmax all 4 valves
1999	Daubeney *et al.*[7]	UK, Australia	125	<18 years	TV, RV, PA, MV, aortic root
2000	Kampmann *et al.*[8]	Germany	2036	<18 years	M-mode: LV and RV, LA, PV, AV
2001	Eidem *et al.*[9]	USA	325	<18 years	TDI MV lateral and medial, TV lateral
2005	Zilberman *et al.*[10]	USA	748	<18 years	MV, AV, TV, PV
2006	Warren *et al.*[11]	Canada	88	<18 years with bicuspid AV	Ascending aorta (in isolated bicuspid aortic valve)
2006	Overbeek *et al.*[12]	Netherlands	587	<18 years	M-mode: LV
2008	Foster *et al.*[13]	Canada	239	<21 years	M-mode: LV mass
2008	Pettersen *et al.*[14]	USA	782	<18 years	Aortic root, arch, PV, PA, MV, TV, LA
2009	Koestenberger *et al.*[15]	Austria	640	<18 years	TAPSE
2009	Neilan *et al.*[16]	USA	4109	<18 years	LA
2010	Gautier *et al.*[17]	France	353	<18 years	Aortic root, ascending aorta
2011	Dallaire and Dahdah [18]	Canada	1033	Children	Coronaries
2011	Lytrivi *et al.*[19]	Greece	100	<3 years	LVEDV
2012	Bhatla *et al.*[20]	USA	300	<18 years	Left atrial volume
2012	Koestenberger *et al.*[21]	Austria	860	<18 years	TAPSV
2014	Campens *et al.*[22]	Belgium	133	<15 years	Aortic root, ascending aorta
2015	Dallaire *et al.*[23]	Canada	1422	<18 years	Proximal aorta
2014	Jain *et al.*[24]	Canada	50	Term newborns, day 1, 2	RV dimensions and function, TV, LV, TDI, TAPSE, strain
2014	Cantinotti *et al.*[25]	Italy	1091	<17 years	LA, LV, RA, RV diameters and areas
2014	Cantinotti *et al.*[26]	Italy	445	<2.5 years	AV, aortic root, arch, IVC, PV, PA, MV, TV, LV, LVEF
2014	Abushaban *et al.*[27]	Kuwait	268	Preterms	LV dimensions
2015	Hussain *et al.*[28]	UK	50	18 days-18 years	Coronaries
2015	Dallaire *et al.*[29]	Canada	233	1-18 years	PW Doppler MV, LVOT; MPI; color TDI
2015	Fibbi *et al.*[30]	Italy	369	<17 years	LV TDI
2017	Cantinotti *et al.*[31]	Italy	1151	<17 years	AV, aortic root, arch, IVC, PV, PA, MV, TV
2016	Kobayashi *et al.*[32]	Japan	3851	<18 years	Coronaries
2016	Abushaban *et al.*[33]	Kuwait	268	Preterms	Valvular annuli
2017	Dijkema *et al.*[34]	Netherlands	385	Preterm <32 weeks	Aortic arch
2017	Gokhroo *et al.*[35]	Ajmer, Mohali India	746	4-15 years	Aortic root, ascending aorta, MV, TV, LA, RA, RV, LV dimensions
2017	Lopez *et al.*[36]	USA	3566	<18 years	PV, PA, Aortic root, ascending aorta, arch, MV, TV, coronaries, LV dimensions, area
2017	Majonga *et al.*[37]	Zimbabwe	282	6–16 years	M Mode-LA, LV, RV, TAPSE
2018	Rajagopal *et al.*[38]	USA	300	<18 years (50 were<1 year)	RA area by 2D and 3D echo
2017	Choudhry *et al.*[39]	USA	503	Preterm <2 kg	M mode LV
2018	Van Ark *et al.*[40]	Netherlands	376	Preterm <32 weeks <2 kg	AV, PV, MV, TV
2019	Krysztofiak *et al.*[41]	Poland	791	5-18 years	LV mass
2020	Abushaban *et al.*[42]	Kuwait	268	Preterm<36 weeks	LV mass and index
2018	Trivedi *et al.*[43]	MH, India	596	<16 years (132 neonates)	MV, TV, PV, PA, aortic root, arch, M-mode: LV

AV: Aortic valve, PV: Pulmonary valve, MV: Mitral valve, TV: Tricuspid valve, IVC: Inferior vena cava, LA: Left atrium, LV: Left ventricle, LVEDV: LV end diastolic volume, RA: Right atrium, RV: Right ventricle, PA: Pulmonary artery, TAPSE: Tricuspid annular peak systolic excursion, TAPSV: Tricuspid annular peak systolic velocity, TDI: Tissue Doppler imaging, PW: Pulse wave, LVEF: LV ejection fraction

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Appendix 2: Scatter plots for all echocardiographic parameters

Figure 1: Scatterplot birth weight versus tricuspid valve annulus

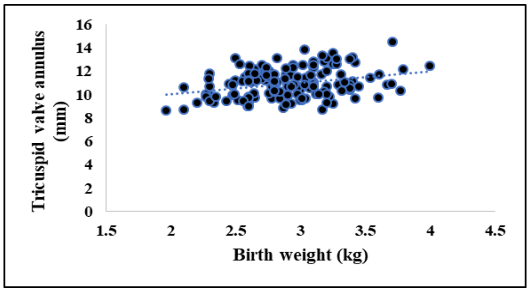


Figure 2: Scatterplot birth weight versus mitral valve annulus (4-chamber view)

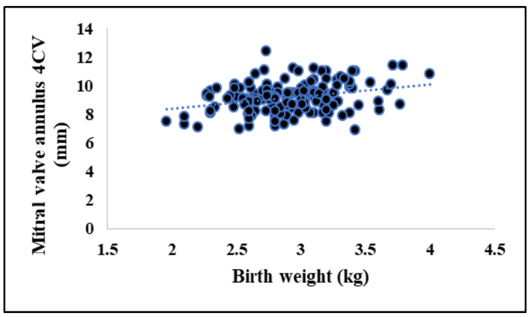


Figure 3: Scatterplot birth weight versus mitral valve annulus (PLAX view)

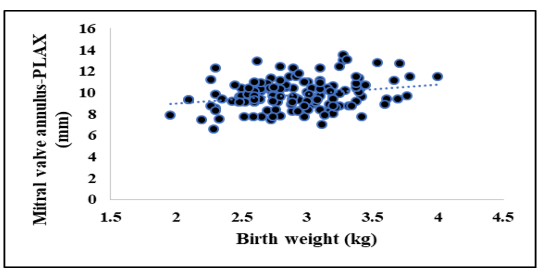


Figure 4: Scatterplot birth weight versus interventricular septum in diastole

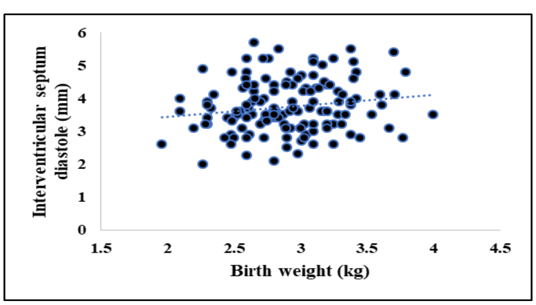


Figure 5: Scatterplot birth weight versus left ventricle internal diameter in diastole

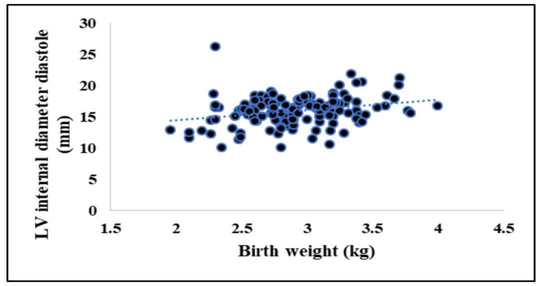


Figure 6: Scatterplot birth weight versus left ventricle posterior wall in diastole

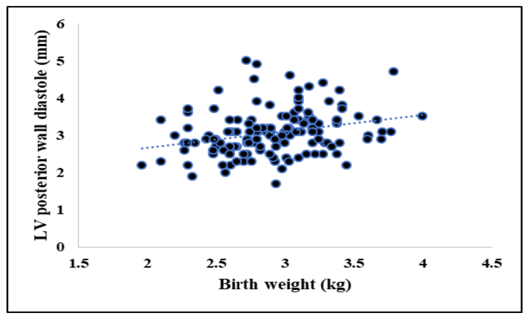


Figure 7: Scatterplot birth weight versus interventricular septum in systole

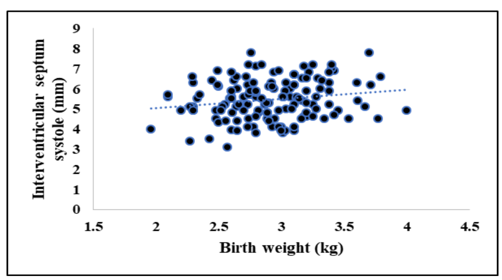


Figure 8: Scatterplot birth weight versus left ventricle internal diameter in systole

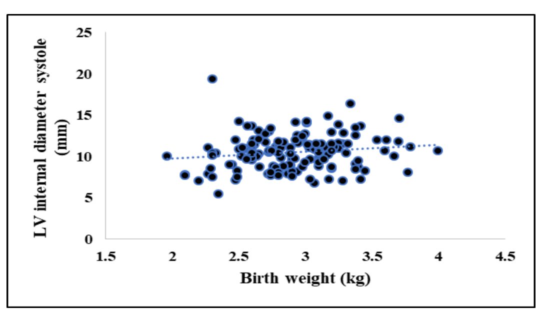


Figure 9: Scatterplot birth weight versus left ventricle posterior wall in systole

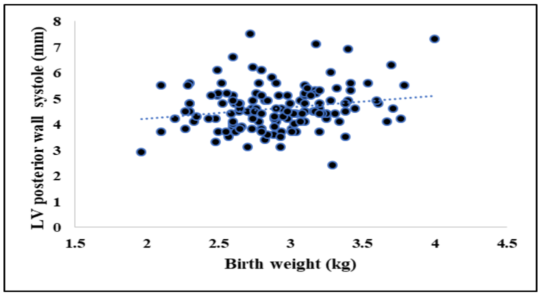


Figure 10: Scatterplot birth weight versus pulmonary valve annulus

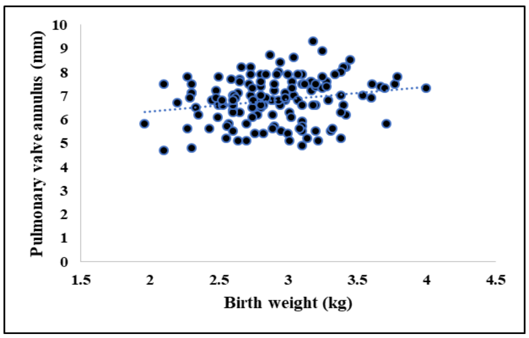


Figure 11: Scatterplot birth weight versus main pulmonary artery

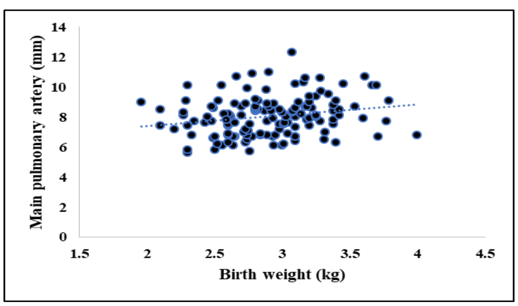


Figure 12: Scatterplot birth weight versus right pulmonary artery

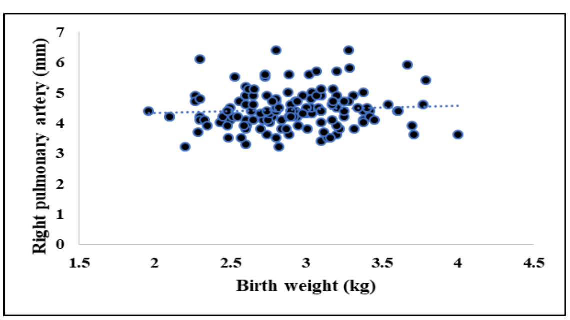


Figure 13: Scatterplot birth weight versus left pulmonary artery

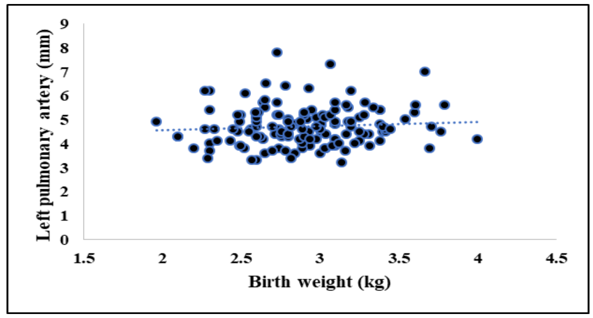


Figure 14: Scatterplot birth weight versus aortic valve annulus

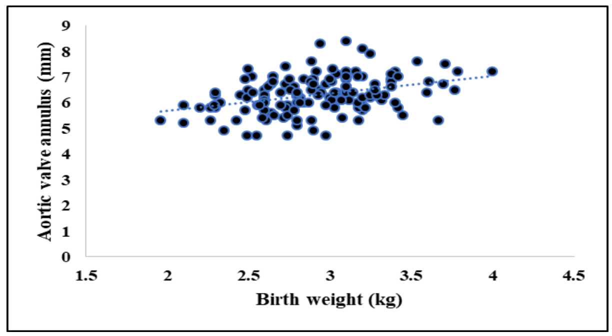


Figure 15: Scatterplot birth weight versus aortic root

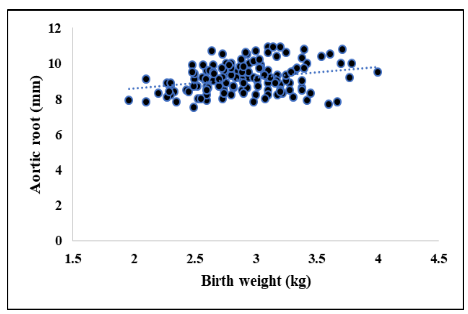


Figure 16: Scatterplot birth weight versus Sino-tubular junction

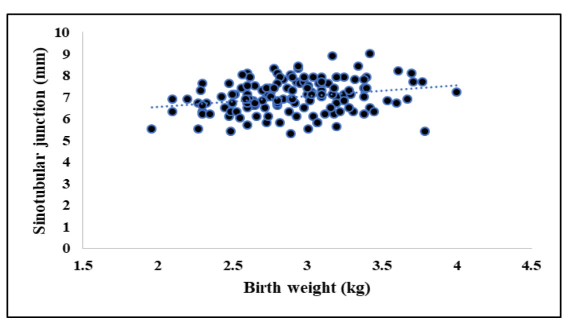


Figure 17: Scatterplot birth weight versus ascending aorta

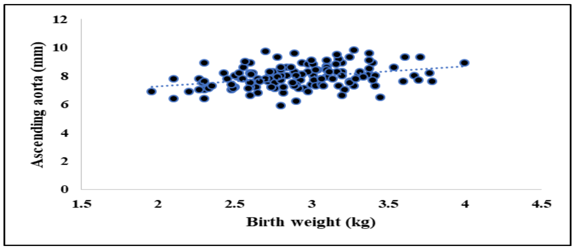


Figure 18: Scatterplot birth weight versus proximal aortic arch

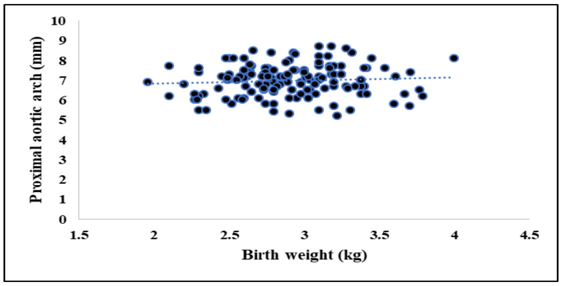


Figure 19: Scatterplot birth weight versus distal aortic arch

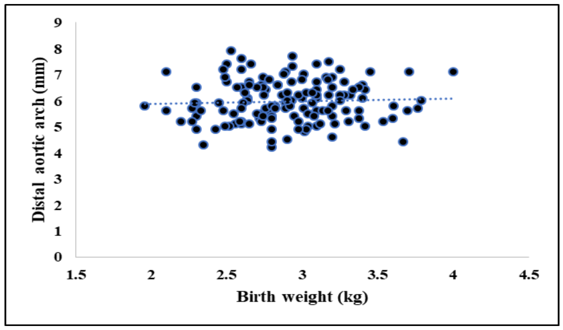
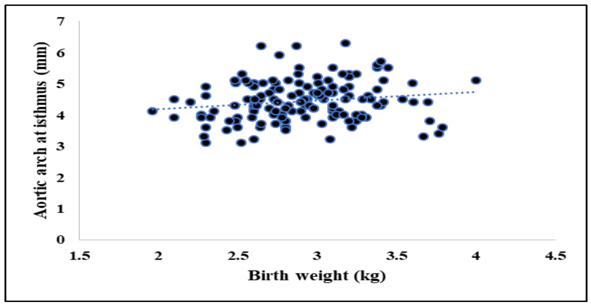


Figure 20: Scatterplot birth weight versus aortic arch at isthmus



Appendix 3: Prediction charts for all echocardiographic parameters were prepared, shown from Figures 21 to 40

Figure 21: Prediction chart for tricuspid valve annulus using weight

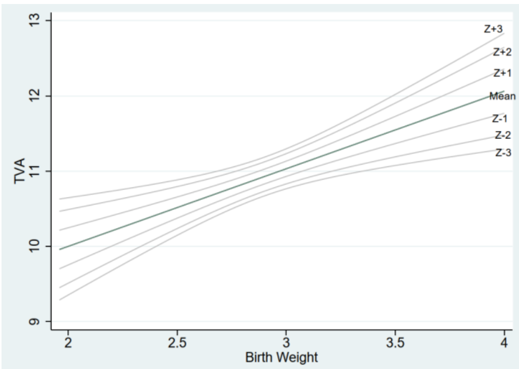


Figure 22: Prediction chart for mitral valve annulus (4-chamber view) using weight

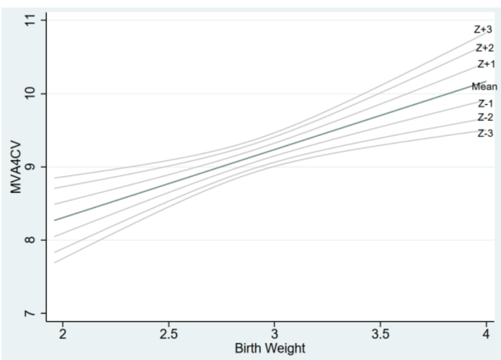


Figure 23: Prediction chart for mitral valve annulus (PLAX view) using weight

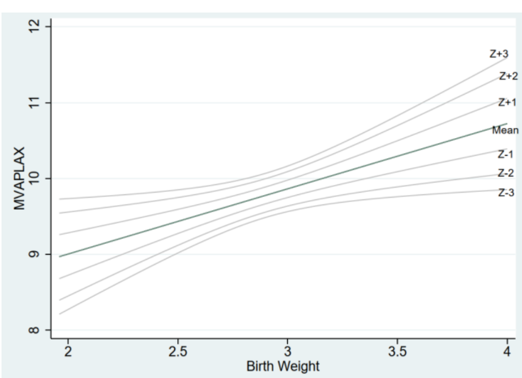


Figure 24: Prediction chart for interventricular septum in diastole using weight

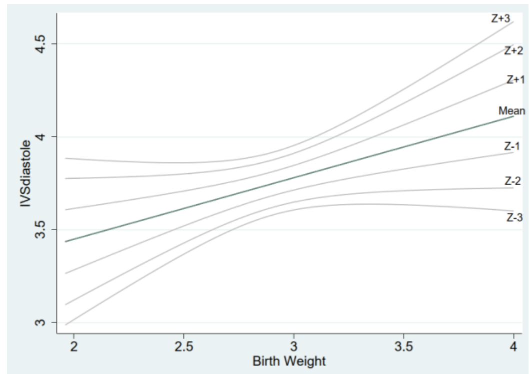


Figure 25: Prediction chart for left ventricle internal diameter in diastole using weight

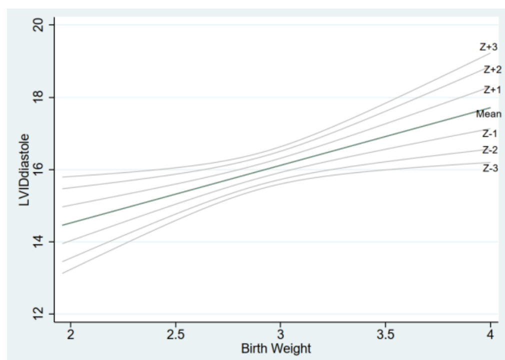


Figure 26: Prediction chart for left ventricle posterior wall in diastole using weight

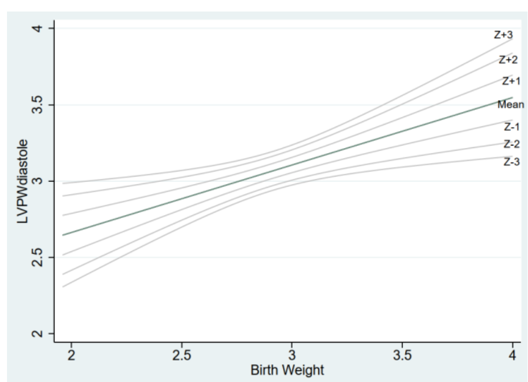


Figure 27: Prediction chart for interventricular septum in systole using weight

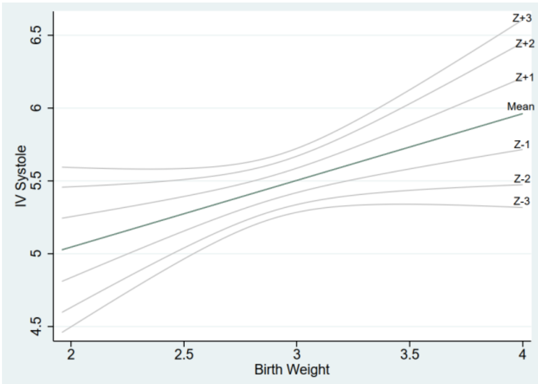


Figure 28: Prediction chart for left ventricle internal diameter in systole using weight

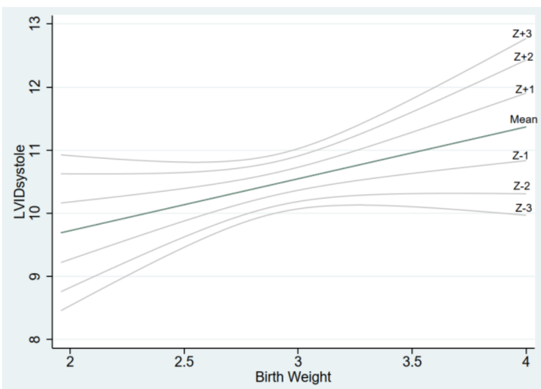


Figure 29: Prediction chart for left ventricle posterior wall in systole using weight

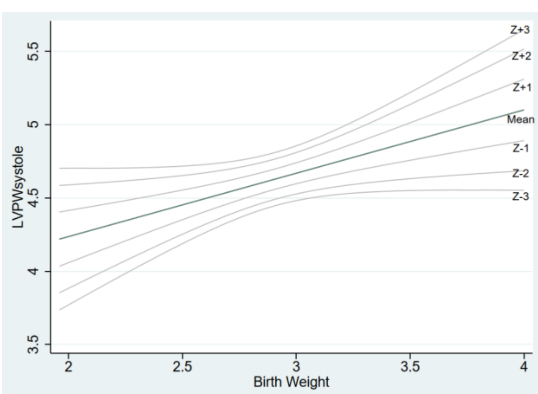


Figure 30: Prediction chart for pulmonary valve annulus using weight

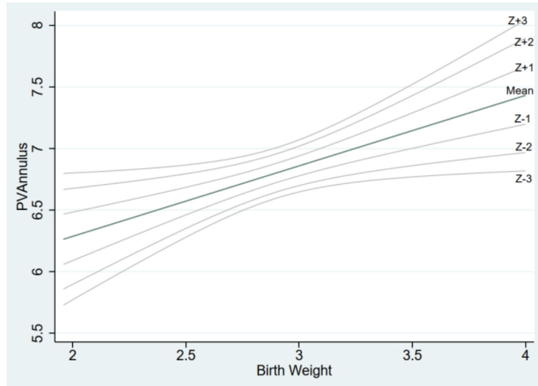


Figure 31: Prediction chart for main pulmonary artery using weight

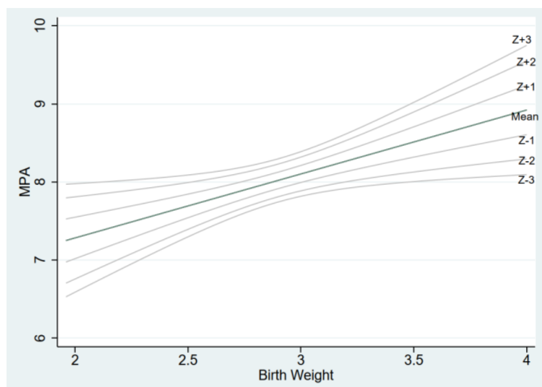


Figure 32: Prediction chart for right pulmonary artery using weight

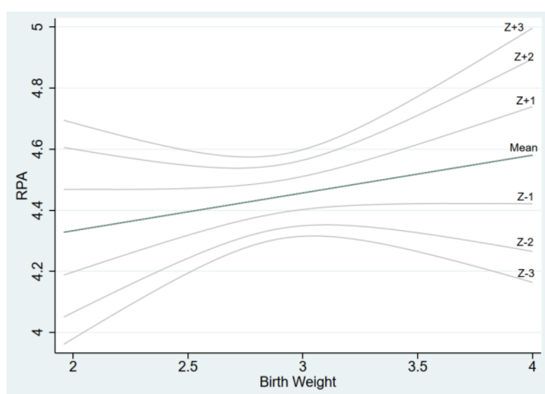


Figure 33: Prediction chart for left pulmonary artery using weight

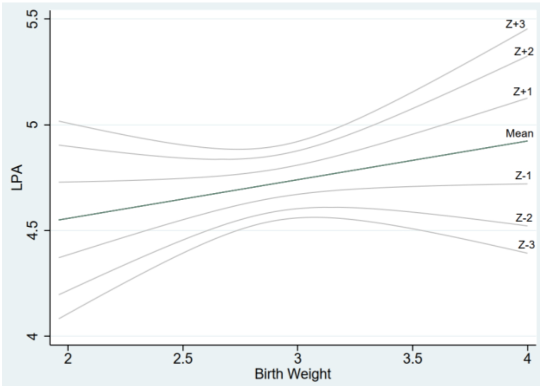


Figure 34: Prediction chart for aortic valve annulus using weight

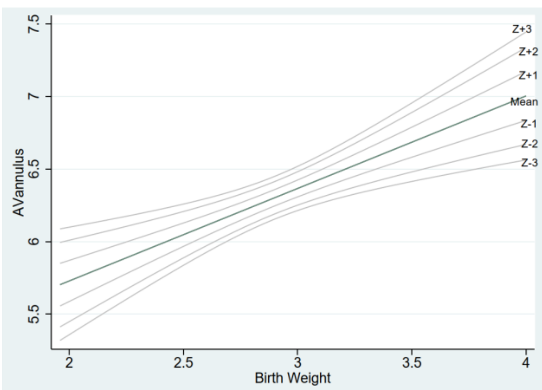


Figure 35: Prediction chart for aortic root using weight

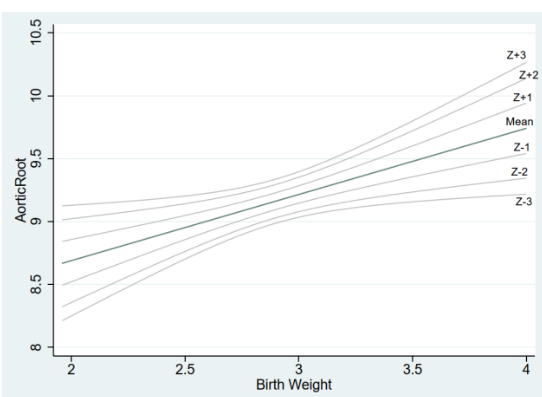


Figure 36: Prediction chart for Sino-tubular junction using weight

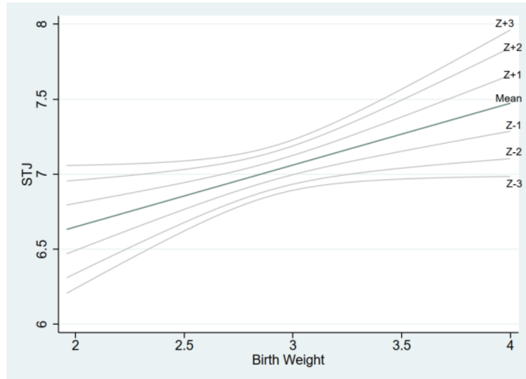


Figure 37: Prediction chart for ascending aorta using weight

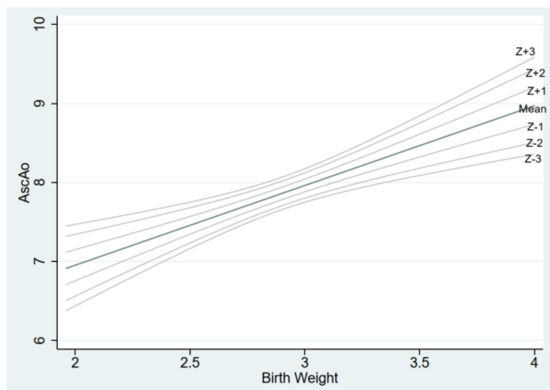


Figure 38: Prediction chart for proximal aortic arch using weight

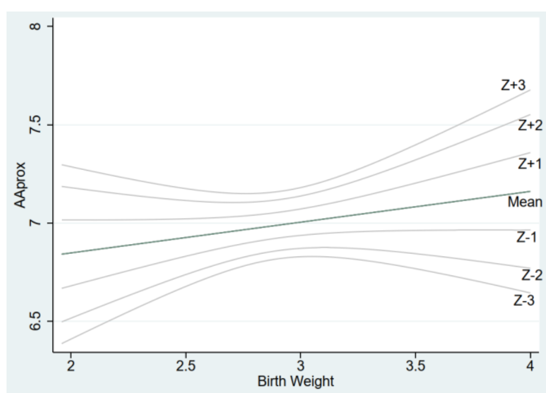


Figure 39: Prediction chart for distal aortic arch using weight

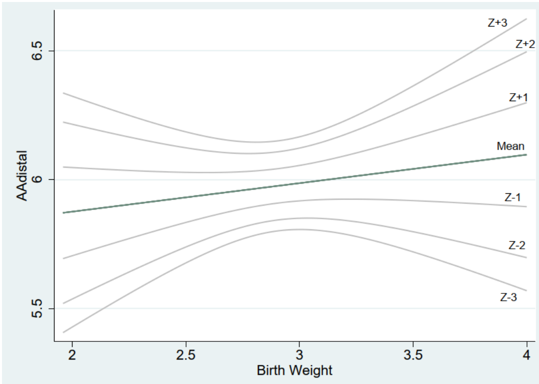


Figure 40: Prediction chart for aortic arch at isthmus using weight