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ORIGINAL ARTICLE

Prospective Comparative Evaluation of Performance of Fetal Growth Charts in the Diagnosis of Suboptimal Fetal Growth During Third Trimester Ultrasound Examination in an Unselected South Indian Antenatal Population

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Abstract Growth standards are key tools in assigning fetal smallness. Growth charts are central to this. The availability of growth charts with varying conceptual methodology and design makes their comparison imperative to ensure wise clinical decision making. This was a prospective, descriptive and correlational study performed at two fetal medicine centers, on 1019 unselected third trimester South Indian women with singleton pregnancies. The estimated fetal weight (EFW) was calculated from one dataset per woman using the Hadlock III formula. The EFW centiles were obtained from eight prenatal growth charts: Hadlock, FMF, Spanish, INTERGROWTH, WHO, NICHD, Mikolajczyk and GROW (fully customized), and categorized to $\leq$ 5th, 5.1 to $\leq$ 10th, 10.1–89.9th and $\geq$ 90 centiles. Comparison was done with similar categories of neonatal birthweight centiles obtained from Fenton, INTERGROWTH and GROW customized neonatal standards. At EFW cut-off of $\leq$ 10th centile, the sensitivity range of the fetal growth charts were between 9.5 and 60% and the false positive rates (FPR) between 1.9 and 18.38%. Similar figures for EFW $\leq$ 5th centile, were 9.5–64.2% and 1.0–12.8%, respectively. The INTERGROWTH chart had the highest positive predictive value of 54.6–63.6%. The FMF chart had the highest sensitivity and the highest FPR. The sensitivity, at a cut-off of $\leq$ 5th centile, of Mikolajczyk (9.5–12.6%), and the GROW (14.4–18.9%) prenatal charts were closest to the incidence of uteroplacental insufficiency (7.9%) in our study. Wide variations noted in the performance of prenatal and neonatal growth charts in detecting fetal-neonatal smallness indicates the need for critical selection of growth charts and possibly additional supportive information in clinical decision making.

Keywords Fetal growth charts · Fetal growth standards · Small for gestational age · Fetal growth restriction · Third trimester fetal ultrasound · Hadlock · Intergrowth · GROW · Neonatal growth standards

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Introduction

Assessment of the normal fetal growth trajectory and the early identification of its pathological deviations, constitutes one of the cardinal objectives of prenatal care [1]. Failure to attain the endorsed growth potential in utero is known as fetal growth restriction (FGR) [2]. It affects 4–8% of pregnancies in developed countries, and 10–25% of pregnancies in developing countries of the world [3, 4]. Suboptimal fetal growth is the leading contributor to antepartum stillbirth, accounting for 30% of such cases [5]. Additionally, FGR is an important cause for neonatal morbidity due to iatrogenic prematurity, impaired neurodevelopment, cerebral palsy and death [6–8]. Besides short term consequences, FGR leads to adult sequelae as well, consisting of cardiovascular disease, stroke, hypertension, diabetes and certain cancers [9].

Most of the FGR affected pregnancies have underlying placental malperfusion [10]. Such fetuses may benefit by regular surveillance, stagewise management and timing of delivery. The key to their prompt identification is the performance of ultrasound in a standardised fashion to measure fetal biometric parameters and calculate the estimated fetal weight (EFW) [2, 11]. Once the EFW is obtained, the next pertinent step is to assess its appropriateness for gestational age. This is done by comparing it with a growth standard or reference, and currently an EFW less than the 10th centile is used as the discriminatory cut-off to label the fetus as small for gestational age (SGA) [12, 13].

The recent introduction of several growth charts makes it imperative to compare it with existing ones especially in populations with a sizable load of FGR. Our study endeavors to compare and evaluate eight published prenatal growth charts with varying conceptual designs and methodology with neonatal growth charts as standards, in their performance for the identification of sub-optimal fetal growth in the third trimester. This is expected to provide information of immense practical utility to the obstetrician, the maternal–fetal medicine specialist and the neonatologist to optimize the diagnosis of fetal and neonatal growth restriction and their evidence based management.

Materials and Methods

This was a prospective, descriptive and observational study conducted from 01 March 2018 till 30 October 2018, at two institutions, ARMC-Aegis hospital (ARMC- Asian Reproductive Medical Center), Perinthalmana and Nahas Hospital, Parappanangadi. These are tertiary care institutions with dedicated units of obstetrics, assisted reproduction, fetal medicine and neonatal care in the district of Malappuram, Kerala; a state in south India. The centers provide fetal medicine services to regular antenatal cases of the institution as well as those referred to it from other institutions at practices. The study protocol was approved by the institutional ethical committee, reference number ARMC/HRD/210/10/2018.

The study sample was constituted by the antenatal women of the above institutions recruited in a non-selective fashion. All women were of south Indian origin. The inclusion criteria were singleton pregnancies, gestational age between 28 and 40 weeks, availability of a dating scan done between 8 and 14 weeks of gestation and willing to enroll in the study. The exclusion criteria were pregnancies with known fetal chromosomal or morphological abnormalities. The women belonged to mid-to-high socio-economic class. An informed written consent was obtained from all women. A single measurement was obtained from each women in our study.

The ultrasound examinations were performed using GE Voluson E6 radiance BT18 unit, using a transabdominal curvilinear transducer with a frequency of 1–5 MHz (C1-5-D) by two fetal medicine specialists. Fetal biometry was obtained according to the guidelines of the International Society of Ultrasound in Obstetrics and Gynecology (ISUOG) [14]. The EFW of each fetus was calculated from the head circumference (HC), abdominal circumference (AC) and the femoral diaphyseal length (FL) using the Hadlock III formula: $\text{Log}_{10}\text{BW} = 1.326–0.00326 * \text{AC} * \text{FL} + 0.0107 * \text{HC} + 0.0438 * \text{AC} + 0.158 * \text{FL}$ [15].

Using eight prenatal growth charts (Table 1), the EFW centiles were obtained and were categorized into four groups for comparative purpose to $\leq$ 5.0 centile, 5.1–10th centile, 10.1–89.9th centile and $\geq$ 90th centile. The neonatal birthweight centiles were obtained from three neonatal charts (Table 1) and were similarly categorised. With the postnatal charts as the gold standard, the performance of each prenatal chart for the detection of small fetuses was evaluated using the parameters of sensitivity, specificity, positive predictive and negative predictive values. Two categories of small for gestational age fetuses were defined by an EFW $\leq$ 10th centile and $\leq$ 5th centile.

Descriptive and inferential statistical analysis was carried out in our study. Results on continuous variables are presented as mean $\pm$ standard singleton and median with interquartile range (IQR). Chi-square and Fisher Exact test was used to assess the significance of study parameters on categorical scale between two or more groups, and non-parametric setting for qualitative data analysis. Statistical software SPSS (Statistical Package for the Social Sciences Inc. Released 2009. PASW Statistics for Windows, Version 18.0. Chicago: SPSS Inc.), and R environment version 3.2.2 (R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org/.) was used for data analysis.

Results

1019 ultrasound examinations were performed from March 01, 2018 till October 30, 2018 after satisfying the criteria for inclusion and exclusion. All were South Indian women, and had singleton pregnancies which ended in live births. Only one dataset of fetal biometry was obtained from each woman in the third trimester.

The median age of the study cohort was 25 years [IQR = 22–29 years]. The maximum number of women were in the age group of 20–30 years (754/1019, 74%) and

Table 1 The Growth charts used in our study

Growth chart	Details
A. Fetal	
1. Hadlock [16]	Growth reference, constructed from a cross-sectional data of 392 women in Texas, US, published in 1991
2. INTERGROWTH 21st [17, 18]	Growth standard, highly prescriptive in nature; based on the concept that under ideal conditions of sound health, adequate nutrition, proper educational status, and with minimal environmental constraints, ethnic or genetic influences would be minimal (less than 4%). The study was conducted in eight countries across the world, with India being one of them
3. WHO [11]	Growth standard, based on the Multicenter Growth Reference Study (MGRS) that collected data from 1439 women between 2009 to 2014 across 10 countries in the world, including India. The methodology was prescriptive. The statistical technique of quantile regression was used to calculate the centiles. The study did not exclude pregnancies with maternal complications (unlike the INTERGROWTH and the NICHD studies). The WHO growth chart had the same underlying principle as the INTERGROWTH 21st i.e. under ideal conditions the growth patterns will be similar across different ethnic populations. It used country of origin as the surrogate for ethnicity. However, unlike the INTERGROWTH study, it emphasized the important differences amongst the countries
4. NICHD [19]	The Eunice Kennedy Shriver National Institute of Child Health and Human Development Fetal growth study was conducted at 12 sites across the US. It had specific criteria of inclusion. It used the statistical approach of log transformation, linear mixed model and smoothing techniques over the gestational age. The EFW was calculated with the HADLOCK III formula. It was also designed to study the ethnic/race specific differences (White, Non-Hispanic black, Hispanic and Asian-pacific islander). Unlike the INTERGROWTH study, it excluded pregnancies with abnormal fetal Karyotypes and preterm births (< 37 weeks). Similarly, unlike the WHO study, it excluded the maternal–fetal-neonatal complications. The NICHD study calculated EFW from 10 weeks, whereas the WHO and Intergrowth gave EFW from 14 weeks onwards (Intergrowth gave centiles from 22 weeks only). In our study, the Asia specific data was used
5. Mikolajczyk [20]	The Mikolajczyk chart adapted the Hadlock gestational age based growth equation, calculated the country specific mean birthweight from a 2004–2008 WHO global survey on Maternal and Perinatal health, derived a coefficient by dividing the mean birth weight at 40.5 weeks of the Hadlock growth reference, applied this coefficient across all gestational weeks to derive a reference curve specific for the country. The idea is based on the generation of individualized reference used by Gardosi et al. Further, the reference curve can be customized for increasing number of variables. In our study, India specific data was used
6. FMF UK [21]	The FMF chart is based on the concept that though the EFW and birthweight for term neonates have good correlation, for preterm births, the birthweight is considerably lower than the median EFW. The chart was constructed from a dataset of 95 579 women undergoing routine ultrasound examination. The population essentially was unselected, hence the chart was a rather than a standard chart. Non-parametric quantile regression technique was used to calculate the centiles
7. Spanish [22]	The Spanish chart was a prescriptive customized chart
8. GROW [23]	The fully customized prenatal standards from the Perinatal institute were applied to our data. This uses a software known as GROW (gestation related optimum weight) [Gestation Network; Birmingham, UK, www.gestation.net]. In this software, maternal characteristics are entered to calculate an individually adjusted weight at 40.0 weeks. This predicted weight is then combined with a standard proportionality curve to provide a GROW curve. The Hadlock EFW curve is used for this purpose. It is converted from a weight- by-gestation curve to a percent of term weight-by-gestational age curve. Full customization was used in our study
B. Neonatal	
1. Fenton [24, 25]	The Fenton's chart is one of the most common neonatal charts used across the world including India. It has the advantages of being based on more recent data on size at birth, harmonizes the preterm growth chart with the new WHO Growth Standards, smoothens the data between the preterm and WHO estimates while maintaining integrity with the data from 22 to 36 and at 50 weeks, provides sex specific growth curves, and re-scales the chart x-axis to actual age rather than completed weeks, to support growth monitoring
2. INTERGROWTH 21st [16, 17]	It is based on integrated monitoring of growth and development from pregnancy to school age by providing a single international standard. Described above
3. GROW [23]	Fully customised standard (adjusted to Indian ethnicity, weight, height and parity) from the Perinatal institute; GROW customised neonatal growth standard (GROW; gestation network; Birmingham, UK)

EFW estimated fetal weight, *FMF* Fetal Medicine Foundation, *GROW* gestation related optimum weight, *NICHD* National Institute of Child Health and Human Development, *UK* United Kingdom, *WHO* World Health Organization, *US* United Stated

least above 41 years (9/1019, 0.9%). The mean height was 155.19 ± 5.71 cm, while the mean weight of the study subjects was 55.52 ± 10.85 kg. The mean body mass index was 23.01 ± 4.35 kg/m^2. Most of the women were at a gestational age of 32–36 weeks (n = 910/1019, 89.6%).

Table 2 Distribution of the fetal EFW and the neonatal birth weights as per the prenatal charts and neonatal growth standards

Growth chart	Categories as per centiles				
	≤ 5th	5.1–10th	≤ 10th	10.1–89.9	≥ 90
A. Fetal weights (EFW)					
HADLOCK	60 (5.9%)	69 (6.8%)	129 (12.7%)	866 (85%)	24 (2.4%)
FMF	165 (16.2%)	78 (7.7%)	243 (23.8%)	682 (66.9%)	94 (9.2%)
Barcelona	81 (7.9%)	44 (4.3%)	125 (12.3%)	772 (75.8%)	121 (11.9%)
IG 21	46 (4.5%)	20 (2.0%)	66 (6.5%)	862 (84.6%)	91 (8.9%)
WHO	80 (7.9%)	69 (6.8%)	149 (14.6%)	807 (79.2%)	63 (6.2%)
NICHD	52 (5.1%)	23 (2.3%)	75 (7.4%)	782 (76.7%)	162 (15.9%)
MIKOLAJCZYK	23 (2.3%)	15 (1.5%)	38 (3.7%)	363 (35.6%)	618 (60.6%)
GROW	38 (3.7%)	20 (2.0%)	58 (5.7%)	689 (67.6%)	272 (26.7%)
B. Neonatal birth weights					
Fenton	136 (13.3%)	10.7 (10.5%)	243 (23.8%)	737 (72.3%)	39 (3.8%)
IG 21	111 (10.9%)	103 (10.1%)	214 (21%)	742 (72.8%)	63 (6.1%)
GROW	67 (6.6%)	65 (6.4%)	132 (13%)	741 (72.7%)	146 (14.3%)

EFW estimated fetal weight, *FMF* Fetal Medicine Foundation, *IG* intergrowth, *GROW* gestation related optimum weight, *NICHD* National Institute of Child Health and Human Development, *WHO* World Health Organization

At birth, 15.3% of neonates were below 2500 g at birth (WHO cut-off for low birthweight). Table 2 shows the distribution of fetuses and neonates in the aforementioned four categories of centiles. Uteroplacental insufficiency defined as an abnormal umbilical, uterine, middle cerebral artery Doppler or cerebroplacental ratio in the context of suboptimal fetal growth was noted in 80/1019 (7.9%) cases. Tables 3 and 4 shows the detailed comparison between fetal growth and neonatal growth charts in their performance for detecting suboptimal fetal growth (≤ 10th centile and ≤ 5th centiles).

Discussion

The principal objective of our study was to evaluate the performance of the prenatal growth charts to detect small fetuses in the third trimester against neonatal growth charts as a standard. It demonstrated, firstly, the considerable variability amongst the different growth charts in the prenatal diagnosis of the small fetus. Secondly, considerable variability was noted even amongst the neonatal charts in assigning a neonate as SGA. Third, as partial and full customization were introduced, the sensitivity figures attained close proximity to the incidence of pregnancies with utero-placental insufficiency and severe growth restriction (EFW ≤ 5th centile).

Our study demonstrated that when the eight prenatal growth charts were compared to the three neonatal standards in the detection of small fetuses (≤ 10th centile) in an unselected South Indian population, detection rates varied from 9.5 to 60%, while false positive rates ranged from 1.9 to 18.38%. For a cut-off ≤ 5%, the sensitivity varied between 9.5 and 64.2%, while false positive rates ranged from 1.0 to 12.8%. The substantial difference in the performance of growth charts is evident. Similar to our study, a systematic review of 83 published reference charts of fetal biometry across 32 countries by Ioannou et al. [26] revealed wide variations between the centile values reported by published studies. Poljak et al. [27], compared the performance of antenatal tools for detection of SGA, defined as less than 10th centile in a high risk British cohort of antenatal women already screened to be having small fetuses. They concluded that there was a wide variation in the diagnostic accuracy of antenatal tools for the detection of SGA fetuses including growth charts.

In our study, the FMF chart showed the highest sensitivity and the highest false positive rates for the identification of SGA fetuses. This was explained by the composition of the FMF study sample in which 80% of the women were white [21]. The FMF chart compared their median and the 10th centiles with that of the WHO and INTERGROWTH charts and found them significantly lower in the latter two charts. This was reflected in our study also as the 10th centile was similar in the WHO and INTERGROWTH charts, and was much lower than in the FMF chart. Despite being prepared from a study sample of white women, the performance figures of the Hadlock chart was more conservative than the FMF chart (Tables 3, 4). This is possibly explained by the fact that the women included in the Hadlock study were of a middle social class of the 1970s in the US with their living conditions different from their current standards [16]. The performance of the Hadlock, WHO charts and the Spanish charts was similar.

Table 3 Performance of the Prenatal growth charts in relation to the neonatal standards (≤ 10th percentile)

Prenatal Growth charts	Neonatal Growth charts	Observation correlation									
		TP	FP	FN	TN	Total	Se (%)	Sp (%)	PPV (%)	NPV (%)	FPR (%)
HADLOCK	IG 21	72	57	142	748	1019	33.6	92.9	55.8	84.1	7
	FEN	77	52	166	723	1019	31.7	93.3	59.7	81.4	6.7
	GROW	59	70	73	817	1019	44.7	92.1	45.7	91.8	18.4
FMF	IG 21	114	129	100	676	1019	53.3	83.9	46.9	87.1	16
	FEN	125	118	118	658	1019	51.4	84.8	51.4	84.8	76.8
	GROW	80	163	52	724	1019	44.7	92.1	45.7	91.8	18.38
BARCELONA	IG21	70	55	144	750	1019	32.7	93.2	56.0	83.9	6.8
	FEN	77	48	166	728	1019	31.7	93.8	61.6	81.4	6.2
	GROW	59	70	73	817	1019	44.7	92.1	45.7	91.8	7.9
IG21	IG21	40	26	170	783	1019	19.1	96.8	60.6	82.1	3.2
	FEN	42	24	201	752	1019	17.3	96.9	63.6	78.9	3.1
	GROW	36	30	96	857	1019	27.3	96.6	54.6	89.9	3.4
WHO	IG21	79	70	135	735	1019	36.9	91.3	53.1	84.5	8.7
	FEN	84	65	159	711	1019	34.6	91.6	56.4	81.7	8.3
	GROW	62	87	70	800	1019	46.9	90.2	41.6	91.1	9.8
NICHD	IG21	44	31	170	774	1019	19.3	96.1	58.3	81.9	3.85
	FEN	48	27	195	749	1019	19.8	96.5	64	79.3	3.5
	GROW	41	34	91	853	1019	31.1	96.2	54.7	90.4	3.4
MICKOLWYZK	IG21	23	15	191	790	1019	10.8	98.2	60.5	80.5	1.9
	FEN	23	15	220	761	1019	9.5	98.1	60.5	77.6	76.9
	GROW	20	18	112	869	1019	15.2	97.9	52.6	88.6	2.03
GROW	IG21	34	24	180	781	1019	15.9	97.1	58.6	81.3	2.98
	FEN	35	23	208	753	1019	14.4	97.2	60.3	79.1	3
	GROW	33	25	99	862	1019	25	97.2	56.9	89.7	2.8

FEN fenton, *FMF* Fetal Medicine Foundation, *FN* false negative, *FP* false positive, *FPR* false positive rate, *IG* intergrowth, *GROW* gestation related optimum weight, *NICHD* National Institute of Child Health and Human Development, *NPV* negative predictive value, *PPV* positive predictive value, *Se* sensitivity, *Sp* specificity, *TN* true negative, *TP* true positive, *WHO* World Health Organization

P value < 0.001 for all rows

Their sensitivity was much lower than the FMF chart. This is probably explained by the similar anthropometric dimensions of the population [28].

Even with neonatal growth charts, the detection rates varied widely. For instance, in the GROW customized neonatal standards, the frequency of small fetuses (≤ 10th centile) was 13%, compared to 23.8% in the Fenton and 21% in the Intergrowth 21 charts. For ≤ 5th centile, the corresponding figures for the three charts were 10.5%, 6.4% and 10.1% for the Fenton, GROW and the Intergrowth charts, respectively. This was explained by the heterogeneity of the study designs including the nature of the sample [12, 29].

A high detection rate would imply that fewer cases of SGA are missed, and hence all the truly small fetuses would get medical attention in the form of prenatal interventions, in utero transfer for neonatal care, timely delivery and adequate neonatal care. As shown in our study, high detection rates are also associated with high false positive rates. In clinical practice, this scenario would translate to increased rates of unnecessary surveillance, interventions, iatrogenic preterm births and wastage of precious resources. Hence, the statistical performance of the prenatal growth charts should be carefully analyzed and correlated with adverse perinatal outcomes. Similar to our study, Salomon et al. [30] evaluated the impact of using different charts and reported that between 2.6 and 23.6% of measurements would be classified as abnormal using three different charts of fetal biometry that are commonly used. Cheng et al. [31], studied the impact of replacing Chinese ethnicity-specific fetal biometry charts with the INTERGROWTH 21st standard. They observed that the INTERGROWTH AC, HC and FL z scores were significantly lower than those in the Chinese growth reference. They concluded that adopting the INTERGROWTH standard would lead to a significant number of fetuses being at risk

Table 4 Performance of the prenatal growth charts in relation to the neonatal charts (≤ 5th percentile)

Prenatal growth charts	Neonatal standards	Observation									
		TP	FP	FN	TN	Total	Se (%)	Sp (%)	PPV (%)	NPV (%)	FPR (%)
HADLOCK	IG 21	30	30	81	878	1019	27.1	96.7	50.0	91.5	3.3
	FENTON	34	26	102	857	1019	25	97.1	56.7	89.4	2.9
	GROW	26	34	41	918	1019	38.8	96.4	43.3	95.7	3.6
FMF	IG21	59	106	52	802	1019	53.2	88.3	35.8	93.9	11.7
	Fenton	67	98	69	785	1019	49.3	88.9	40.6	91.9	11.1
	GROW	43	122	24	830	1019	64.2	87.2	26.1	97.2	12.8
BARCELONA	IG 21	38	43	73	865	1019	34.2	95.3	46.9	92.2	4.7
	Fenton	43	38	93	845	1019	31.6	95.7	53.1	90.1	4.3
	GROW	33	48	34	904	1019	49.3	94.9	40.7	96.4	5
IG21	IG 21	25	21	86	887	1019	22.5	97.6	54.4	91.2	2.3
	Fenton	27	19	109	864	1019	19.8	97.9	58.8	88.9	2.2
	GROW	22	24	45	928	1019	32.8	97.5	47.8	95.4	2.5
WHO	IG 21	37	43	74	865	1019	33.3	95.3	46.3	92.1	4.7
	Fenton	42	38	94	845	1019	30.9	95.7	52.5	89.9	4.3
	GROW	31	49	36	903	1019	46.3	94.9	36.7	96.2	5.1
NICHD	IG 21	27	25	84	888	1019	24.3	97.2	51.9	91.3	2.8
	Fenton	29	23	107	860	1019	21.4	97.4	55.7	88.9	2.6
	GROW	24	28	43	924	1019	35.8	97.1	46.2	95.6	2.9
MICKOLWYZK	IG 21	14	9	97	899	1019	12.6	99.1	60.9	90.3	1.0
	Fenton	14	9	122	874	1019	10.3	98.9	60.9	87.8	1.0
	GROW	13	10	54	942	1019	19.4	98.9	56.5	94.6	1.1
GROW	IG 21	21	17	90	899	1019	18.9	98.1	55.3	90.8	1.9
	Fenton	21	17	115	866	1019	15.4	98.9	55.3	88.3	1.9
	GROW	20	18	47	934	1019	29.8	98.1	51.3	95.2	1.9

FEN fenton, *FMF* Fetal Medicine Foundation, *FN* false negative, *FP* false positive, *FPR* false positive rate, *IG* intergrowth, *GROW* gestation related optimum weight, *NICHD* National Institute of Child Health and Human Development, *NPV* negative predictive value, *PPV* positive predictive value, *Se* sensitivity, *Sp* specificity, *TN* true negative, *TP* true positive, *WHO* World Health Organization

P value < 0.001 for all rows

of misdiagnosis of small fetal size. Daniel et al while constructing a new Israeli growth chart observed that the Hadlock and the INTERGROWTH 21st standards had significant high false positive rates for SGA fetuses in their population [32]. In our study also, when compared to the neonatal standards, the prenatal charts had FPR range of 1.9–18.38%. This requires careful introspection for the likely consequences of over medicalization of normal pregnancies.

The wide variability in the growth charts is explained by the different methodology adopted in the construction of these charts. Growth charts can be either growth standards or references [33]. Growth standards are constructed from data obtained from fetuses that grow under ideal conditions. Reference charts on the other hand are prepared from a mixed population that includes both low and high risk pregnancies. Prescriptive growth charts are prepared with strict inclusion criteria, and are therefore prospective longitudinal in their study design. Descriptive growth charts are often derived from local, unselected healthy population with inadequate methodology [34]. The growth charts can be population specific (population growth charts) or often used globally for several populations (international standards). A growth chart customized for physiological variables including maternal ethnicity, parity, height and weight, is termed as a customized growth chart [35].

The analysis of NICHD data also showed that the percentage of fetuses classified ≤ 5th centiles for EFW, when using the white standard was substantially higher for the black, Hispanic and the Asian population [36, 37]. In our study, the Hadlock chart could detect more cases of SGA fetuses than the Asia specific NICHD, implying that the growth environment and constraints for our population is similar to the white population of the US in 1991, and is different from the Asian population in the US. This also suggests that besides the influence of ethnicity, socio-demographic factors also impact fetal growth.

Keeping in mind the incidence of uteroplacental insufficiency of 7.9% (n = 80/1019) which provides an indication of the proportion of growth restricted fetuses in our study, the sensitivity figures at a cutoff of ≤ 5th of Mikolajczyk (9.5–12.6%), an India specific chart and the GROW fully customized standard (14.4–18.9%) was the closest. Similarly, the incidence of neonates ≤ 10th centile in the GROW customized neonatal standard was closest at 13%, compared to Fenton's chart (23.8%) and the INTERGROWTH chart (21%). These suggest that the use of customised charts may provide better performance for the detection of suboptimal fetal growth. The benefits of using customised charts for assessment of fetal growth are however inconclusive [38, 39]. A recent systematic review observed that SGA fetuses detected by both customized and population based curves had a high incidence of adverse outcomes, but the reported point estimates for customized SGA tend to be higher, and for instances of fetal death, were more than double [40].

Our study compared the charts, both prenatal and postnatal of varying conceptual designs and methodology. Use of an unselected mixed risk population justified the aim of the study which was to assess the applicability of growth charts as screening tools. The chief limitation of our study was the comparison of the prenatal growth charts with the neonatal standards rather than adverse perinatal outcomes. As mentioned in the foregone discussion, neonatal charts also varied in their performance. The absence of uniform obstetric-neonatal protocols in India for delivery and neonatal care of the growth restricted fetus precluds us from analyzing the data on adverse perinatal outcome in our study.

Studies focusing on comparing prenatal growth charts with adverse perinatal outcomes need to be conducted on unselected population to assess their true performance. Prenatal charts may be used to quantify the birthweights and then compared with neonatal charts and adverse neonatal outcomes. The predictive accuracy of growth charts with the addition of biophysical and biochemical markers should be explored.

To conclude, the wide variation in the performance of growth charts for the detection of small for gestational age fetuses indicates the need for clear discretion from the clinician's side and the need for supportive information from other modalities, before assigning a fetus as small for gestational age or growth restricted.

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Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest.

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