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Customised birthweight centiles predict SGA pregnancies with perinatal morbidity

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Objectives To determine the following: (1) the proportion of babies reclassified as small or appropriately grown using customised and population centiles; and (2) the relative risks of perinatal morbidity, including abnormal umbilical Doppler studies, in babies classified as small for gestational age (SGA) and appropriate for gestational age (non-SGA) using the two centile calculations.

Design Cohort study in SGA and general hospital populations.

Setting National Women's Hospital, Auckland, NZ.

Population A cohort of SGA pregnancies ($n = 374$) and a general obstetric population ($n = 12{,}879$).

Methods Pregnancy outcomes were compared between 'non-SGA both' ($\geq$10th% by population and customised centiles) and those who were 'SGA both' ($<$10th% by population and customised centiles), 'SGA customised only' (SGA by customised but non-SGA by population centiles) and 'SGA population only' (SGA by population but non-SGA by customised centiles).

Main outcome measures Maternal and newborn morbidity and perinatal death.

Results In the SGA cohort 271 (72%) babies were 'SGA both', 27 (7%) were 'SGA customised only', 32 (9%) were 'population SGA only' and 44 (12%) were 'non-SGA both'. In the general obstetric population 863 (6.7%) babies were 'SGA both', 445 (3.5%) were 'customised SGA only', 285 (2.2%) were 'population SGA only' and 11,286 (88%) were 'non-SGA both'. Perinatal death and newborn morbidity including nursery admission and long hospital stay were increased and comparable between 'SGA both' and 'customised SGA only' in both study populations. Newborn morbidity was low and comparable between 'population SGA only' and 'non-SGA both'. No perinatal deaths occurred in 'population SGA only' babies. Abnormal Doppler studies were more common in 'SGA both' or 'customised SGA only' but not in 'population SGA only' groups compared with 'non-SGA both'.

Conclusions Customised birthweight centiles identified small babies at risk of morbidity and mortality. Use of customised centiles is likely to detect more babies at risk of perinatal morbidity and mortality than would be detected by population centiles.

INTRODUCTION

Traditionally, birthweight has been classified using population-based sex-adjusted centiles with a baby being described as small for gestational age (SGA) if the birthweight is $<$10th centile.[1] A number of these so-called SGA babies are probably constitutionally small normal babies and are not growth restricted. Infant sex, gestation at delivery and the maternal variables — parity, ethnicity, weight and height — all have independent effects on birthweight. Entry of these variables, along with birthweight and gestation, into a simple computer program (Gestation network centile calculator http://www.gestation.net/birthweight_centiles/birth-weight_centiles.htm) generates a customised birthweight centile for an individual baby, which reflects the physiological characteristics of the pregnancy.[2]

Only one previous study has applied these centiles to a large cohort of SGA babies.[3] In this Swedish study births were classified as SGA using both population and customised centiles and the rate of perinatal deaths and low Apgar scores were compared between the two classifications of SGA. Stillbirths, neonatal deaths and low five-minute Apgar scores were all more common in babies small by customised centiles compared with those identified as small by population centiles alone. This study utilised a national database of births and only a few perinatal outcomes could be assessed. One other study reported more detailed perinatal outcomes in a group of high risk pregnancies ($n = 217$) of whom one-third were SGA by customised centiles.[4] In this study babies who were classified as SGA by customised centiles had higher rates of delivery for fetal distress, neonatal nursery admission and ventilation than those

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who were small by population centiles alone. More studies in well-characterised cohorts of SGA pregnancies are required to determine the role of customised birthweight centiles in predicting perinatal morbidity in these pregnancies.

Antenatal umbilical artery Doppler studies subclassify SGA pregnancies into those with high (abnormal umbilical Doppler) and low risk (normal umbilical Doppler) of perinatal morbidity.[5] If customised birthweight centiles identify SGA pregnancies at high risk of morbidity, then abnormal umbilical Doppler studies should also occur commonly in these pregnancies. No previous studies have explored this relationship in detail.

Two previous studies have applied customised centiles to general obstetric populations.[3,6] The first study, conducted in the United States, reported that serious neonatal morbidity and perinatal mortality were more common in babies classified as SGA after adjusting for maternal age, size and black *versus* white ethnicity compared with those who were classified as SGA by population centiles. In the second study carried out in Sweden, low five-minute Apgar scores and perinatal deaths were more common in babies SGA by customised compared with population centiles.[3] Further studies in other populations are required to determine the generalisability of these earlier studies of customised centiles and their role in prediction of morbidity in general populations.

The aims of the current study were to determine in a cohort of SGA pregnancies and in a general obstetric population (1) the proportion of babies who would be reclassified using the two different centile calculations and (2) the relative risks of perinatal morbidity in babies classified as SGA and non-SGA using the two different centile calculations.

We hypothesised that in our SGA cohort and in the general obstetric population customised birthweight centiles would better identify pregnancies and babies with perinatal morbidity and mortality than population centiles. Evidence to support this hypothesis would include the following: (1) similar low rates of perinatal morbidity in babies SGA by population centiles but reclassified as appropriately grown by customised centiles compared with babies who were non-SGA by both criteria; (2) similar high rates of morbidity in babies SGA by customised centiles but non-SGA by population centiles compared with babies who were SGA by both customised and population centiles.

Secondary hypotheses were as follows: (1) that mothers of babies SGA by population centiles but reclassified as non-SGA after application of customised centiles would be constitutionally small; and in the SGA cohort (2) abnormal umbilical artery Doppler studies would occur more commonly in babies SGA by customised centiles.

METHODS

This study population was derived from a cohort of 474 singleton pregnancies who were suspected to be SGA antenatally (abdominal circumference $<$10th% on antenatal scan)[7] and were born between 1993 and 1997 at National Women's Hospital, a tertiary referral centre in New Zealand. The study population were participants in a series of antenatal[8,9] and postnatal studies.[10,11] These studies were approved by the Auckland ethics committee.

In 374 of the suspected SGA pregnancies maternal data on height and booking weight were available, as well as ethnicity and parity, enabling calculation of a customised birthweight centile at delivery. These 374 mothers and babies comprise the SGA study population.

All SGA pregnancies had a scan at $<$20 weeks and umbilical Doppler studies within two weeks of delivery. Babies with chromosomal or congenital abnormalities confirmed antenatally or postnatally were excluded. Detailed perinatal data were available for all pregnancies about maternal demographics, pregnancy complications, Doppler results, indications for delivery, newborn morphometry and morbidity. Trained sonographers in a clinical ultrasound department performed the ultrasound scans and Doppler studies. Umbilical Doppler studies were performed, with the patient semirecumbent, from a mid-segment of cord during fetal quiescence and apnoea with a high pass filter of $\leq$100 mHz. Uterine artery Doppler studies were obtained bilaterally at the apparent crossing of the external iliac artery by the uterine artery.[12]

Birthweight was measured in the delivery room using electronic scales accurate to within 5 g. Newborn length, to the nearest mm, was measured in a neonatometer within 48 hours of delivery by a research midwife.

The National Women's Hospital database of births from 1993 to 2000 (N = 68,456) was utilised for the study of application of customised centiles to a general obstetric population. Individual patient data were checked for errors and completeness against the clinical record by a clerk after delivery. To be consistent with methodology in other studies, women with multiple pregnancies and or congenital abnormalities[2,3] (N = 4379) were excluded. The remaining women, except the 4707 on whom the customised centiles were created,[13] with the necessary data to calculate customised centiles (height, booking weight, ethnicity, parity, infant sex and gestation) made up the general study population (N = 12,879). Birthweight was measured to the nearest 10 g in the delivery room. Ethnicity was that stated on the database which was self-determined by the mother. Pregnancy and newborn morbidity was assessed from variables routinely recorded in the obstetric database including: caesarean section, caesarean section for fetal distress, induction of labour, Apgar scores, preterm delivery, newborn resuscitation, neonatal nursery admission and newborn days in hospital. Some of the babies in the SGA cohort also make up part of the general population (n = 133). They were not excluded as the aim for this part of the study was to determine how customised centiles performed in a general (not low risk) hospital population. As this part of the study utilised an anonymised data set, ethical approval was not required.

DEFINITIONS

Customised SGA was customised birthweight <10th% using the New Zealand centile calculator.[13]

Population SGA was sex-adjusted birthweight <10th%.[1]

Non-SGA was birthweight ≥10th% by customised[13] and population parameters.[1]

'SGA both' included babies who were <10th% by both customised and population parameters, 'customised SGA only' included babies who were SGA by customised centiles but non-SGA by population centiles, 'population SGA only' included babies who were SGA by population centiles but non-SGA by customised centiles and 'non-SGA both' included babies who were ≥10th% by both customised and population centiles.

Abnormal umbilical Doppler was >95th% for gestation[14] and abnormal uterine Doppler was any uterine RI >0.58.[15]

Gestational hypertension was defined as blood pressure of at least 140/90, taken on two occasions at least 4 hours apart, with an increase of at least 15 mmHg in diastolic blood pressure, after the 20th week of pregnancy. Pre-eclampsia was gestational hypertension with >0.3 g of protein per 24 hours or ≥2+ protein on urinalysis in the absence of urinary tract infection.

Prelabour caesarean section for fetal distress was caesarean carried out because of an abnormal antenatal cardiotocograph and/or biophysical profile prior to the onset of labour. Caesarean section for fetal distress in labour was carried out because of an abnormal cardiotocograph and or scalp pH. Total caesarean section for fetal distress included prelabour and in labour caesarean sections for fetal distress.

Hypoglycaemia was defined as blood glucose <2.6 mmol/L >4 hours after delivery or requiring intravenous glucose therapy for hypoglycemia.

Long nursery or hospital stay was >10 days.

Perinatal deaths included babies with no evidence of congenital abnormality who were either stillborn and delivered after 20 weeks of gestation or were liveborn and died in the first 28 days after birth.

Composite morbidity was a newborn hospital stay of >10 days and/or perinatal death. This definition was chosen pragmatically as both of these outcome measures were available in both data sets.

Babies were admitted routinely to the newborn nursery if birthweight was <2 kg, gestation <35 weeks or if they required fluids or oxygen. Blood glucose monitoring incubator therapy, intravenous antibiotics and phototherapy were available in the postnatal wards.

STATISTICAL METHODS

Customised birthweight centiles were calculated from the Gardosi bulk centile calculator (http://www.gestation.net/birthweight_centiles/centile_dowload.htm), which was applied to our SGA and general hospital databases. The centile calculator used for this study was developed using a regression model derived from Auckland births.[13] Statistical analysis for the SGA cohort and the general hospital population was carried out using Statview (SAS Institute, Cary, NC, 1998) and SAS, respectively. The asymptotic 95% confidence intervals are given for the relative risks. Relative risks were calculated for the various subgroups of SGA compared with the referent group 'non-SGA both' and for the comparison of 'customised SGA' *versus* 'customised non-SGA'. For comparisons of maternal size the referent group was 'SGA both'. For continuous measures analyses were done using ANOVA followed by the Tukey–Kramer multiple comparison test or the Mann–Whitney *U* test as appropriate. For the dichotomous variables the relative risk and the asymptotic 95% confidence intervals were calculated making no adjustments for multiple comparisons.

RESULTS

The SGA study population comprised 374 SGA pregnancies, suspected antenatally, with sufficient maternal data to calculate customised birthweight centiles. At delivery 298 babies (80%) were SGA by customised centiles (customised SGA) and 303 (81%) were SGA by population centiles (population SGA). Two hundred and seventy-one (72%) babies were SGA by both customised and population centiles ('SGA both'), 27 (7%) babies were SGA by customised centiles but non-SGA by population centiles ('customised SGA only'), 32 (9%) were SGA by population but non-SGA by customised centiles ('population SGA only') and 44 (12%) were ≥ to the tenth centile by both criteria ('non-SGA both'; Table 1).

Mothers of the babies who were reclassified as non-SGA by customised centiles ('population SGA only') were shorter and lighter with lower body mass indices than mothers of babies who were 'SGA both' ($P \leq 0.001$ for all comparisons) (Table 1). They were also more likely to be nulliparous [72% *vs* 51% RR 1.4 (1.1–1.8)]. In contrast mothers of babies who were reclassified as SGA by customised centiles but were non-SGA by population centiles ('customised SGA only') were heavier at booking ($P = 0.04$) and had a trend to greater body mass indices ($P = 0.06$) than mothers of 'SGA both'.

The prevalence of pre-eclampsia, abnormal Doppler studies and caesarean for fetal distress were all greater in mothers of babies who were 'SGA both' or 'customised SGA only' compared with the referent group 'non-SGA both' (Table 2). The prevalence of these morbidities was also comparable between 'SGA both' and 'customised SGA only'. Very abnormal umbilical Doppler studies (RI > 0.8) were almost totally confined to 'SGA both' and 'customised SGA only' pregnancies. Of 15 cases with absent or reversed end diastolic velocity in the umbilical artery 13 were in the 'SGA both' group and 2 were in the 'customised SGA only' group.

Table 1. Maternal demographic details in the SGA cohort.

$N = 374$	Customised SGA		Customised non-SGA	
	SGA both, $n = 271$	Customised SGA only, $n = 27$	Population SGA only, $n = 32$	Non-SGA both, $n = 44$
Age (years)	28.5 [6]	28 [4.6]	28.3 [6.0]	26.6 [5.6]
	$P = 0.03$	$P = 0.23$	$P = 0.13$	–
Height (cm)	163 [6.8]	164.3 [4.6]	159 [6.2]	164 [4.6]
	$P = 0.35$	$P = 0.78$	$P = 0.004$	–
Body mass index	24.1 [4.7]	25.9 [6.1]	21 [3.3]	22.6 [3.7]
	$P = 0.06$	$P = 0.004$	$P = 0.14$	–
Booking weight (kg)	64 [13.9]	69.9 [16.5]	53 [8.3]	60.6 [9.7]
	0.12	0.005	0.01	–
Nulliparous	138 (51)	12 (44)	23 (72)	24 (55)
	0.9 (0.7–1.3)	0.8 (0.5–1.3)	1.3 (0.9–1.9)	1
European ethnicity	180 (66)	15 (56)	20 (63)	28 (64)
	0.9 (0.8–1.2)	0.8 (0.6–1.3)	1.0 (0.7–1.4)	1
Smoker	105 (39)	4 (15)	7 (23)	10 (23)
	1.7 (1.0–3)	0.7 (0.2–1.9)	1.0 (0.4–2.3)	1

Values are presented as mean [SD] or *n* (%), as appropriate. Relative risks and *P* values, which appear below *n* (%) and mean [SD], are for comparison with referent group which is 'non-SGA both'.

Similarly rates of abnormal Doppler studies and caesarean section for fetal distress were comparable between 'population SGA only' and 'non-SGA both'. The three pregnancies in the 'population SGA only' group and seven of the eight with abnormal umbilical Doppler studies in the 'non-SGA both' group had resistance indices just above the 95th centile.

Indices of newborn morbidity including long hospital stay, nursery admission and composite morbidity were increased and comparable between 'SGA both' and 'customised SGA only' but 'customised SGA only' babies were delivered on average two weeks earlier than 'SGA both' ($P = 0.002$). In contrast, newborn morbidity was low and was comparable between 'population SGA only' and 'non-SGA both' for preterm delivery, nursery admission and long hospital stay. Whereas other outcome measures were available for the whole SGA cohort data on hypoglycaemia were available for 92% of babies, 95% of 'SGA both', 100% of 'customised SGA only', 66% of 'population SGA only' and 89% of 'non-SGA both'. 'Population SGA only' had an increased rate of hypoglycaemia compared with 'non-SGA both' [RR 3.8 (1.1–14)] (Table 3).

All seven perinatal deaths were in the 'SGA both group'. Only six babies had a five-minute Apgar score <6 and they

Table 2. Maternal morbidity and Doppler results in SGA cohort.

$N = 374$	Customised SGA		Customised non-SGA	
	SGA both, $n = 271$	Customised SGA only, $n = 27$	Population SGA only, $n = 32$	Non-SGA both, $n = 44$
Pre-eclampsia	38 (14)	8 (30)	3 (9)	0
	–	–	–	–
Abnormal umbilical Doppler	119 (44)	12 (44)	3 (9)	8 (18)
	2.4 (1.3–4.6)	2.6 (1.3–5.6)	0.5 (0.2–1.8)	1
Umbilical RI > 0.8	46 (17)	6 (22)	0	1 (2)
	7.5 (1.1–53)	9.8 (1.2–77)	–	1
Abnormal uterine Doppler	65 (47)	13 (62)	2 (13)	8 (20)
	2.4 (1.2–4.5)	3.1 (1.5–6.3)	0.3 (0.1–1.5)	1
Total LSCS	109 (40)	14 (52)	9 (28)	3 (7)
	5.9 (2.0–18)	7.6 (2.4–24)	4.1 (1.2–14)	1
Prelabour LSCS fetal distress	42 (15)	5 (19)	1 (3)	1 (2)
	6.8 (1–48)	8.1 (1–66)	1.4 (0.1–21)	1
LSCS in labour fetal distress	17 (6)	1 (4)	1 (3)	0
	8.7 (1.2–61)	9.8 (1.2–77)	2.8 (0.3–29)	1
Total LSCS fetal distress	59 (21)	6 (27)	2 (6)	1 (2)
	9.6 (1.4–67)	9.8 (1.2–77)	2.8 (0.3–29)	1

Values are presented as mean [SD] or *n* (%), as appropriate. RI = resistance index; LSCS = lower segment caesarean section. Relative risks, which appear below *n* (%), are for comparison with referent group which is 'non-SGA both'.

Table 3. Newborn size and morbidity in SGA cohort.

$N = 374$	Customised SGA		Customised non-SGA	
	SGA both, $n = 271$	Customised SGA only, $n = 27$	Population SGA only, $n = 32$	Non-SGA both, $n = 44$
Birthweight (g)	2048 [575]	2024 [658]	2676 [193]	2905 [432]
	$P < 0.0001$	$P < 0.0001$	$P = 0.0007$	–
Delivery gestation (weeks)	36.5 [3.0]	34.7 [3.1]	38.6 [1.3]	38.0 [2.2]
	$P = 0.001$	$P < 0.0001$	$P = 0.23$	–
Preterm delivery	122 (45)	19 (70)	2 (6)	11 (25)
	1.8 (1.1–3)	2.8 (1.6–5)	0.3 (0.1–1.1)	1
Ponderal Index	2.29 [0.28]	2.30 [0.31]	2.52 [0.21]	2.53 [0.32]
	$P < 0.0001$	$P < 0.0001$	$P = 0.80$	–
Ponderal Index < 10th%	126 (46)	6 (22)	11 (33)	12 (27)
	1.7 (1.0–2.8)	0.8 (1.6–5)	1.3 (0.6–2.5)	1
Hospital days (median, IQR)	7 (1, 16)	19 (4, 34)	4 (2, 6)	4.5 (3, 6)
	$P < 0.0001$	$P < 0.0001$	$P = 0.67$	–
Long hospital stay	115 (42)	16 (59)	3 (9)	3 (7)
	6.2 (2.1–19)	8.7 (2.8–27)	1.4 (0.3–6.4)	1
Admitted to nursery	166 (61)	19 (70)	3 (9)	11 (25)
	2.5 (1.5–4)	2.8 (1.6–5)	0.4 (0.1–1.2)	1
Long nursery stay	93 (55)	15 (71)	0	3 (27)
	5 (1.7–15)	8.2 (2.6–26)	–	1
Hypoglycaemia	105 (41)	14 (67)	6 (28)	3 (8)
	5.5 (1.8–16)	9 (2.9–28)	3.8 (1.1–14)	1
Perinatal death	7	0	0	0
	–	–	–	–
Composite morbidity*	122 (45)	16 (59)	3 (9)	3 (7)
	6.6 (2.2–20)	8.7 (2.8–27)	1.4 (0.3–6.4)	1

Values are presented as mean [SD] or *n* (%), as appropriate. IQR = interquartile range. Relative risks and *P* values, which appear below *n* (%) and mean [SD], are for comparison with referent group which is 'non-SGA both'.

* Defined as perinatal death and or prolonged hospital stay.

Table 4. Maternal demographic and pregnancy details in the general hospital population.

$N = 12{,}879$	Customised SGA		Customised non-SGA	
	SGA both, $n = 863$	Customised SGA only, $n = 445$	Population SGA only, $n = 285$	Non-SGA both, $n = 11{,}286$
Age (years)	28.4 [5.6]	28.5 [5.4]	27.0 [5.2]	28.7 [5.5]
	$P = 0.24$	$P = 0.76$	$P < 0.0001$	
Height (cm)	162 [6.2]	167 [5.4]	155 [6.3]	163 [6.6]
	$P < 0.0001$	$P < 0.0001$	$P < 0.0001$	
Weight (kg)	67.1 [15.3]	82.7 [17.1]	53.9 [8.0]	73.2 [18.6]
	$P < 0.0001$	$P < 0.0001$	$P < 0.0001$	
BMI	25.6 [5.6]	29.7 [6.1]	22.3 [3.6]	27.5 [6.6]
	$P < 0.0001$	$P < 0.0001$	$P < 0.0001$	
Nulliparous	412 (48)	119 (27)	193 (68)	4633 (41)
	1.2 (1.1–1.3)	0.7 (0.6–0.8)	1.7 (1.5–1.8)	1
European	327 (38)	131 (29)	72 (25)	4198 (37)
	1.0 (0.9–1.1)	0.8 (0.7–0.9)	0.7 (0.6–0.8)	1
Induction for IUGR	175 (20)	54 (12)	28 (10)	180 (1.6)
	12.7 (10.5–16)	7.6 (5.7–10.2)	6.2 (4.2–9)	1
Total LSCS	206 (24)	89 (20)	56 (20)	2338 (21)
	1.2 (1.0–1.3)	1.0 (0.8–1.2)	1.0 (0.8–1.2)	1
LSCS for fetal distress	98 (11.4)	38 (8.5)	20 (7)	480 (4.2)
	2.7 (2.2–3.3)	2.0 (1.5–2.8)	1.7 (1.1–2.5)	1

Values are presented as mean [SD] or *n* (%), as appropriate. BMI = body mass index, IUGR = intrauterine growth restriction, LSCS = lower segment caesarean section. Relative risks and *P* values, which appear below *n* (%) and mean [SD], are for comparison with referent group which is 'non-SGA both'.

Table 5. Perinatal morbidity and newborn size in the general hospital population.

$N = 12{,}879$	Customised SGA		Customised non-SGA	
	SGA both, $n = 863$	Customised SGA only, $n = 445$	Population SGA only, $n = 285$	Non-SGA both, $n = 11{,}286$
Delivery gestation (weeks)	38.6 [2.1]	38.5 [2.9]	39.3 [1.1]	39.1 [1.8]
	$P < 0.0001$	$P < 0.0001$	$P < 0.0001$	–
Delivered < 37 weeks	106 (12)	92 (21)	20 (7)	842 (7)
	1.7 (1.4–2)	2.8 (2.3–3.4)	0.9 (0.6–1.4)	1
Birthweight (g)	2516 [423]	2826 [547]	2785 [198]	3507 [532]
	$P < 0.0001$	$P < 0.0001$	$P < 0.0001$	–
Resuscitation	256 (30)	116 (26)	69 (24)	2568 (23)
	1.3 (1.2–1.5)	1.2 (1–1.3)	1.1 (0.9–1.3)	1
Admitted to nursery	272 (38)	114 (33)	24 (12)	1257 (15)
	2.6 (2.3–2.9)	2.2 (1.9–2.6)	0.8 (0.5–1.1)	1
Hospital stay > 10 days	117 (14)	57 (13)	4 (1.4)	402 (3.6)
	3.8 (3.1–4.6)	3.6 (2.8–4.7)	0.4 (0.2–1.1)	1
Perinatal death	38 (4.4)	10 (2.2)	0	49 (0.4)
	10 (6.7–15)	5.2 (2.6–10)	–	1
Composite morbidity*	155 (18)	67 (15)	4 (1.4)	451 (3.9)
	4.5 (3.8–5.3)	3.8 (3.0–4.8)	0.4 (0.1–0.9)	1

Values are presented as mean [SD] or *n* (%), as appropriate. Relative risks and *P* values, which appear below *n* (%) and mean [SD], are for comparison with referent group which is 'non-SGA both'.

* Defined as perinatal death and or prolonged hospital stay.

were all 'SGA both' (data not shown). There was no difference in mean umbilical artery pH between groups (data not shown) and only 14 (4%) babies had an umbilical artery pH < 7.15, 10 of whom were 'SGA both', two who were 'population SGA only' and two who were in the 'non-SGA both' group.

Customised centiles were also applied to the general hospital population with data on maternal height and weight, $n = 12{,}879$. One thousand three hundred and eight babies (10.1%) were customised SGA and 1148 (8.9%) were population SGA (Table 4). Eight hundred and sixty-three (6.7%) were SGA by both customised and population centiles ('SGA both'), 445 (3.5%) were SGA by customised but not population centiles ('customised SGA only'), 285 (2.2%) were SGA by population centiles alone ('population SGA only') and 11,286 (88%) were ≥ to the 10th centile by both criteria ('non-SGA both').

Mothers of babies who were SGA by population criteria alone ('population SGA only') were significantly lighter, shorter and had lower body mass indices than those who were 'SGA both' ($P < 0.001$ for all comparisons, Table 4). They were also more likely to be nulliparous [68% *vs* 48% RR 1.4 (1.3–1.6)] and less likely to be European [25% *vs* 38% RR 0.7 (0.5–0.8)] than those who were 'SGA both'. In contrast mothers of babies who were 'customised SGA only' were significantly taller, heavier and had greater body mass indices than those who were 'SGA both' ($P < 0.001$ for all comparisons).

Relative risks for induction of labour because of suspected intrauterine growth restriction (IUGR), a measure of antenatal recognition of suboptimal fetal growth, was similar between the three SGA groups. Total caesarean section rates did not differ between groups but the rate of caesarean for fetal distress was similar in the three SGA groups and was greater than in 'non-SGA both'.

Babies who were 'customised SGA only', and would not have been detected by population centiles, had high rates of morbidity with relative risks comparable to babies who were 'SGA both' (Table 5).

However, babies who were 'population SGA only' had low rates of morbidity similar to those who were 'non-SGA both' in need for resuscitation, neonatal nursery admission and long hospital stay, even though babies who were 'population SGA only' were on average 700 g lighter at birth than those who were 'non-SGA both'. Composite morbidity was significantly less common in the 'population SGA only' group than in 'non-SGA both' [RR 0.35 (0.1–0.93)].

There were 97 perinatal deaths in babies with no evidence of congenital abnormality in this cohort (7.5/1000). Forty-nine percent (48) of these dead babies were SGA by customised centiles. Ten babies (10% of perinatal deaths) would not have been detected as SGA by population centiles but were reclassified as small ('customised SGA only') after application of customised centiles. No perinatal deaths occurred in 'population SGA only' babies. Relative risk of perinatal death was high in 'SGA both' [RR 10 (6.7–15.4)] and 'customised SGA alone' [RR 5.2 (2.6–10)] compared with 'non-SGA both'.

DISCUSSION

This is the first study to apply customised birthweight centiles to a large cohort of well-characterised SGA pregnancies recognised antenatally. After application of customised birthweight centiles to our SGA cohort almost

exactly the same number of babies were found to be <10th centile by customised criteria [298 (80%)], as were <10th centile by population criteria [304 (81%)]. However, the 27 babies (7%), who would not have been detected by population criteria but were reclassified SGA by customised centiles ('customised SGA only'), had rates of morbidity very similar to those who were SGA by both customised and population criteria. In contrast, the 32 babies (9%) who were <10th centile by population criteria but were reclassified as normally grown after application of customised centiles ('population SGA only') had low rates of morbidity comparable to those babies who were appropriately grown by both criteria, and there were no perinatal deaths in this group.

A novel aspect of our study of customised centiles in SGA pregnancies is that all babies in our SGA cohort had umbilical Doppler studies performed within two weeks of delivery. Abnormal umbilical Doppler studies were more common in 'SGA both' and 'customised SGA only' babies and very abnormal umbilical Doppler studies (resistance index >0.8) were almost totally confined to these groups with only 1 case occurring in a 'non-SGA both' baby. All cases of absent or reversed end diastolic velocity occurred in 'SGA both' or 'customised SGA only' babies. Our data are in keeping with results from the only previous study that reported umbilical Doppler results, in a small number of pregnancies, in relation to customised centiles.[3]

Abnormal umbilical Doppler studies identify the subgroup of SGA babies that experience perinatal morbidity and mortality.[5,16] Investigators have termed SGA babies with normal umbilical Doppler studies as small normal babies as they do not have evidence of major placental problems[17] and speculated that these small babies are constitutionally small.[18] Recently it has been recommended that the term fetal growth restriction be reserved for SGA babies with abnormal umbilical Doppler studies hence evidence of placental problems.[17] The data from our study, which demonstrate that low customised centiles are highly associated with abnormal umbilical Doppler studies, support this concept and suggest that customised centiles also help identify babies with true growth restriction.

In our SGA cohort maternal morbidity, as assessed by the prevalence of pre-eclampsia and caesarean section for fetal distress, was greater in mothers who delivered customised SGA babies ('SGA both' and 'customised SGA only') whereas rates in 'population SGA only' were not different to 'non-SGA both'. Similarly almost all caesarean sections performed prior to the onset of labour for suspected fetal distress were in babies who were customised SGA. Only one previous study in high risk pregnancies has assessed these morbidities in relation to babies classified as small by customised *versus* population centiles.[3] This study also reported higher rates of caesarean section for fetal distress in babies who were customised SGA.

Similarly measures of newborn morbidity assessed in this SGA cohort were more common in babies who were 'SGA both' or 'customised SGA only' than those reclassified as normal ('population SGA only'). The rates of newborn morbidity in these 'population SGA only' babies were very low and comparable to 'non-SGA both' for preterm delivery, nursery admission and long hospital stay. The only measure of morbidity that was increased in 'population SGA only' compared with non-SGA babies was hypoglycaemia. Further prospective studies in SGA pregnancies are necessary to determine whether there is a real increase in hypoglycaemia in these babies or whether the increased rates seen in our study reflect disproportionate rates of newborn blood sampling in subgroups of our SGA babies.

In the general hospital population 10.1% of babies were SGA by customised centiles and 8.9% were SGA by population centiles. After application of customised centiles slightly more babies were reclassified as SGA ['customised SGA only' 445 (3.5%)] than were reclassified as appropriately grown ['population SGA only' 285 (2.2%)].

One possible criticism of our study, in the general obstetric population, is that a customised birthweight centile could only be calculated in the 20% of women in the database with recordings of height and booking weight. This could have introduced bias into our study population. However, the consistency between the results of our study and earlier studies[3,4,6] suggests that any bias that may exist is not substantial.

As in the SGA cohort, all measures of newborn morbidity including preterm delivery, need for resuscitation at birth, newborn nursery admission, prolonged hospital stay and composite morbidity were greater in customised SGA babies when compared with those 'population SGA only' and those who were 'non-SGA both', further suggesting that classification of size at birth by customised centiles better identifies babies with major complications than population centiles.

Most importantly, in both study populations, all perinatal deaths in SGA babies were in those who were 'SGA both' or 'customised SGA only'. There were no deaths in babies reclassified as normal after application of customised centiles ('population SGA only'). Half of all perinatal deaths in the general population were SGA by customised centiles. Ten additional babies (10% of perinatal deaths) would not have been detected as SGA by population centiles but were reclassified as small ('customised SGA only') after application of customised centiles. These data are consistent with the findings of others and suggest that customised birthweight centiles perform better than population centiles in identifying small babies with perinatal deaths.[3,6]

After application of customised centiles 25% of population SGA babies in the general population were reclassified as appropriately grown ('population SGA only'). We found that mothers of these babies were shorter, lighter, had lower body mass indices and were more likely to be nulliparous than women whose babies were SGA by both customised and population criteria. This finding has been

reported previously[3] and in our study was consistent in both the SGA and general obstetric population suggesting that these babies are constitutionally small because of maternal characteristics.

In both the SGA cohort and the general obstetric population rates of morbidity in these 'population SGA only', babies were very low and comparable to those seen in babies who were non-SGA by both criteria. At birth these 'population SGA only' babies were about 200 g lighter than those who were 'non-SGA both' in the SGA cohort and 700 g lighter in the general obstetric population. However, length of hospital stay and newborn nursery admission did not differ between the two groups. In the general obstetric population the relative risk of composite morbidity was actually lower in 'population SGA only' compared with 'non-SGA both' [RR 0.35 (0.13–0.93)]. The overall very low rate of morbidity in these 'population SGA only' babies along with their low rate of abnormal umbilical Doppler studies provides further confirmation that these babies are likely to be constitutionally small and not growth restricted. Failure of detection of these babies (25% of our general obstetric population SGA babies) by application of customised centiles is unlikely to result in substantial morbidity in these babies.

Similarly, mothers of babies who were not SGA by population criteria but were classified as SGA by customised criteria ('customised SGA only') were heavier than those who had babies who were SGA by both criteria. In keeping with one previous report[19] perinatal morbidity and mortality in these babies, who would not have been detected by usual classification using population centiles, was substantial and similar to that found in those who were SGA by both customised and population criteria ('SGA both').

CONCLUSION

Customised birthweight centiles, when applied to a cohort of SGA pregnancies and to a general obstetric population, identify small babies who are at increased risk of morbidity and mortality in the perinatal period. Implementing use of customised birthweight centiles at birth is likely to result in detection of more babies who experience perinatal morbidity and mortality than would be detected by using population centiles.

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