Original Article

Is abdominal adiposity in healthy Sri Lankan neonates different from the rest of the world?

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Background and Objectives: Adiposity at birth is a predictor of childhood obesity. Abdominal circumference (AC) at birth has been shown to correlate well with visceral adipose tissue and abdominal subcutaneous adipose tissue. Adiposity differs according to ethnicity and geography. The aim of this study was to describe the anthropometry derived adiposity phenotype in neonates from Colombo, Sri Lanka and compare it with global data. **Methods and Study Design:** Birth anthropometry was performed within 12-24 hours by the same investigator as part of a prospective cohort study on healthy term babies, at a tertiary care hospital in Colombo, Sri Lanka, 2015-2019. The anthropometry derived adiposity phenotype was indicated by skinfold thickness, AC and upper arm fat area (UFA) derived from the mid-upper arm circumference (MUAC). **Results:** Sri Lankan neonates had a significantly lower weight with significantly higher AC (n=337, 2.9±0.4 kg, 30.6±2.3 cm) compared to Canadian (n=389, 3.5±0.02 kg, 29.9±2.1 cm; $p<0.001$) and Australian (n=1270, 3.4±0.4 kg, 28.5±1.9 cm; $p<0.001$) neonates. Anthropometry derived adiposity at birth showed a significant correlation with weight and BMI of both mother and father ($p<0.05$) as opposed to their income or education ($p>0.05$). **Conclusions:** Healthy neonates from Colombo, Sri Lanka demonstrated significantly higher AC despite significantly lower weight, indicating increased abdominal adiposity compared to neonates from high-income countries as well as Indian neonates with the thin-fat phenotype.

Key Words: anthropometry derived adiposity, abdominal circumference, Sri Lankan neonate, birth anthropometry, abdominal adiposity at birth

INTRODUCTION

Adiposity at birth is a significant predictor of childhood obesity from 2 to 6 years of age.[1] Abdominal circumference at birth has been shown to have a high correlation with ultrasound measured abdominal adipose tissue, both subcutaneous and visceral.[2] Although there are only few studies describing the abdominal circumference at birth, waist circumference in children has been shown to be the best predictor of visceral adipose tissue assessed by MRI.[3] Abdominal obesity, based on waist circumference has also been reported as a better predictor of cardiovascular risk factors compared to BMI-defined obesity in children.[4] Skinfold thickness (SFT) is widely used as an indicator of subcutaneous adipose tissue.[5] Both waist circumference and SFT of subscapular and supra-iliac regions have been associated with increased risk of liver disease and metabolic dysregulation in children.[6]

Studies from New Zealand and the United Kingdom have revealed that Asian neonates have higher adiposity despite a smaller body size compared to Caucasians, thereby suggesting that adiposity differs according to ethnicity.[7,8]

The 'thin-fat phenotype' was first described in Indian neonates by Yajnik et al, in 2003. These babies had higher subscapular SFT depicting preserved subcutaneous adipose tissue indicating the 'fat' of the 'thin-fat' phenotype and were smaller in size with lower weight, length, circumferences of head, arm and abdomen indicating the 'thin' of this phenotype, when compared to British Caucasian babies.[9] The same 'thin-fat' phenotype was reported in South Asian neonates in the Netherlands when compared to Dutch Caucasian neonates as well as neonates of fourth to fifth generation Indian immigrants in Surinam, South America, South Indian neonates from Mysore, and in the Vellore birth cohort when compared to Caucasian babies born in Southampton, UK.[10-13] Persistence of this thin-fat phenotype at 4 years of age with higher SFT compared to the UK population was shown in the Mysore study.[12] Indian babies had higher abdominal

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adiposity in both subcutaneous and intra-abdominal compartments when assessed by MRI, despite having a very small abdominal circumference compared to the British babies.[14] The thin-fat phenotype has been described as fat being added to an already thin frame, where babies have a relatively high fat mass despite a low lean mass.[9] Pomeroy's analysis suggests that the low lean mass phenotype characteristic of the South Asian ancestry has existed for a minimum of 11,000 years.[15] Low lean mass appears to have been favoured through evolution as an adaptation to the hot climate by maximising heat loss via an increased surface area to volume ratio. In addition, repeated famines causing high mortality in South Asia in the 19th and 20th centuries are also thought to have led to the selection of genes associated with low lean mass through intergenerational plasticity.[15] Changing from hunter gatherers to agriculture during the Holocene era as well as the increase in sugar and fat content in the diet associated with reduced activity levels over the past 2 decades, are thought to result in a relatively high fat mass despite smaller anthropometric measurements.[16]

Although Sri Lanka is a low-middle-income country, it has excellent health indicators on par with middle and high-income countries.[17,18] Colombo has the highest monthly household income and the lowest poverty head count index amongst the 25 administrative districts in Sri Lanka.[19] Therefore, we were interested to know whether babies born in Colombo demonstrated the "thin-fat" phenotype described in Indian South Asians due to similar geography or if they differ based on better health indicators.

This is the first paper to describe anthropometry derived neonatal adiposity from Colombo, Sri Lanka. We also present a secondary analysis of our data to determine whether our study population demonstrates the "thin-fat" phenotype described in South Asian babies of Indian descent, and how the adiposity of our study population compares to published data from high-income countries.

METHODS

Study design and setting

Birth data was obtained as part of an observational, prospective, cohort study on infant body composition from birth to 2 years. The study was conducted at the Neonatal Unit of the University of Colombo, De Soyza Hospital for Women, Colombo, a tertiary care maternity hospital in Sri Lanka, from July 2015 to December 2019.

Study population

Trained research assistants visited the Obstetric Unit twice a day, on all weekdays and approached all the pregnant women admitted between 37 weeks and 41 weeks + 6 days period of amenorrhea (POA) and screened those who gave informed written consent to join the study. All consecutive mothers and babies fulfilling the inclusion criteria were selected via purposive sampling.

Inclusion criteria

Non-smoking mothers with a singleton pregnancy, between 37 weeks and 41 weeks + 6 days POA, aged more than 18 years, living in the study area (Colombo District), who intended to breastfeed and gave informed written consent were recruited prior to delivery. All newborns who did not have morbidity according to Supplementary Table 1 were included in the study.

Exclusion criteria

Women who lived outside the study area were excluded. Babies with an Apgar score <8 at 5 minutes of age or had congenital anomalies or required admission to the neonatal intensive care unit, or had morbidity were excluded.

Sample size calculation

Males vs females

The pooled standard deviation (SD) for upper arm fat area (UFA) was assumed to be 48 cm^2 according to the data given for Caucasian newborns.[20] A sample size of 161 per group (males vs females) were required to detect a true difference of 15 cm^2 in the mean UFA between boys and girls to achieve a power of 80% and a level of significance of 5% (two-sided).[20]

Comparison with global data

The pooled SD for mid upper arm circumference (MUAC) was 0.9 cm according to our data as well as for Pomeroy's study on Australian newborns.[21] A sample size of 159 per group (each country) was required to detect a true difference of 0.4 cm in the mean MUAC between our study data and the Australian newborns, to achieve a power of 80% and significance of 5% (two-sided).[21]

Data collection

Data were collected using interview-administered questionnaires and data recording forms. Gestational age was derived by antenatal ultrasound scan measurement of crown rump length at 8-13 weeks period of amenorrhea (POA). If this was not available, an ultrasound scan of biparietal diameter at 13-20 weeks POA, was used. Last regular menstrual period was used if both the above-mentioned ultrasound scan measurements were not available.

Anthropometry

Babies' measurements were undertaken within 12-24 hours of birth. Weight was measured to the nearest 5 g, using an electronic weighing scale (Seca 334, Seca Gmbh®, Hamburg, Germany) which was calibrated twice weekly. Length was measured using an infantometer (Seca 417®, Seca Gmbh, Hamburg, Germany) to the nearest 1 mm, and circumferences were measured using a non-stretchable measuring tape to the nearest 1 mm (Seca 212®, Seca Gmbh, Hamburg, Germany). Biceps, triceps, subscapular and supra-iliac SFT was measured using a Harpenden skinfold calliper to the nearest 0.2 mm (Baty International, Burgess Hill, West Sussex, UK). Each SFT was read after 2 seconds, consistent with the WHO Multicentre Growth Reference Study (MGRS).[22] Head circumference and mid upper-arm circumference (MUAC) were measured according to WHO-MGRS methodology.[22] Chest circumference was just below the nipple level) and abdominal circumference was measured at the level of the umbilicus.[9,23]

Quality control was ensured using similar methodology to the WHO-MGRS study.[22] All measurements were per-

Table 1. Socio demographic data of our study population

Characteristic	N=337
Maternal Age (years) (mean±SD, range)	29±6 (19-44)
Maternal education	
Years of formal education (mean ± SD, range)	11±3 (0-17)
School not attended	4 (1.1%)
Primary	12 (3.6%)
Secondary	302 (89.7%)
University	6 (1.7%)
Professional	13 (3.9%)
Maternal occupation	
Housewife	208 (61.7%)
Skilled manual work	82 (24.4%)
Unskilled manual work	7 (2.2%)
Managerial	31 (9.2%)
Clerical support	9 (2.5%)
Maternal BMI (kg/m^2) (mean ± SD, range)	24.5± 5.1 (12.1-39.9)
Paternal age (years) (mean ± SD, range)	32±6 (19-52)
Paternal education	
Years of formal education (mean ± SD, range)	11±2 (0-17)
School not attended	5 (1.4%)
Primary	57 (17.0%)
Secondary	260 (77.3%)
University	7 (2.0%)
Professional	8 (2.3%)
Paternal occupation	
Housework	1 (0.3%)
Student	2 (0.6%)
Skilled manual work	195 (57.8%)
Unskilled manual work	2 (0.6%)
Managerial	85 (25.2%)
Clerical support	52 (15.5%)
Paternal BMI (kg/m^2) (mean ± SD, range)	24.6± 5.9 (15.2-44.1)
Marital status	
Married	334 (99%)
Unmarried	3(1%)
Parity (mean ± SD, range)	2±1 (1-6)
Monthly family income (SLR) (1 USD=150SLR)	
Median (Inter quartile range)	30,000 (25,000-45,000)
1st quintile (Less than 23,518)	75 (22.4%)
2nd quintile (23,519 – 36,445)	144 (42.7%)
3rd quintile (36,446 – 51,862)	65 (19.3%)
4th quintile (51,863 – 81,371)	33 (9.7%)
5th quintile (81,371 upwards)	20 (5.9%)

formed with the same instruments and by the same investigator who was trained by an International Society for the Advancement of Kinanthropometry (ISAK) Level 2 accredited anthropometrist.

Technical error of measurement (TEM) was calculated as $\sqrt{\sum}(d_i^2 / 2n)$, where di is the difference between the i^{th} participant's test and retest measurements and n is the number of participants.[24] TEM% was calculated by dividing the TEM by the variable average value, i.e., the arithmetic mean calculated by averaging the mean values for the 1st and 2nd measurements. Intra-observer TEM considered acceptable for a skilled anthropometrist was 5% for SFT and 1% for other measures whereas inter-observer TEMs were 7.5% for SFT and 1.5% for other measures.[25] Intra-observer TEM was 0.0005% for weight, 0.01% for length, 0.01% - 0.03% for circumferences and 0.2% - 0.4% for SFT.

Each measurement was repeated independently by a second trained anthropometrist and quality control and observer reliability monitored. Intra-observer TEM was 0.0005% for weight, 0.01% for length, 0.03% - 0.08% for circumferences and 0.8% - 0.9% for SFT. If the difference between two measurements exceeded 50 g (birth weight), 7 mm (length), 5 mm (circumferences) and 1 mm (SFT), both observers independently repeated the measurement and, if necessary, a third time.[24] Standardization of anthropometry was conducted every 6 months. The inter-observer TEM was 0.09% for weight, 0.3% for length, 0.6% - 1.2% for circumferences, and 4.5% - 6.7% for SFT measurements.

The upper-arm composition was assessed using upper-arm muscle area (UMA), upper-arm fat area (UFA), arm-fat index (AFI), upper-arm fat estimate (UFE) and upper-arm muscle estimate (UME), calculated from MUAC and triceps (TSF) SFT.[26,27] Estimated muscle circumferences were calculated based on the equation of Gurney and Jelliffe.[28]

Mid-arm muscle circumference (MAMC)(cm) = limb circumference (cm) – π (limb skinfold). Triceps SFT is considered as limb SFT (cm).

Upper limb fat area was calculated based on the equations of Frisancho as follows:[29]

Limb area (cm^2) = (limb circumference (cm))^2/4 π

Upper limb muscle area (UMA) (cm^2) = (muscle circumference (cm))^2/4π

Upper limb fat area (UFA) (cm^2) = limb area (cm^2) − muscle area (cm^2).

Arm fat index (AFI), upper-arm fat estimate (UFE) and upper-arm muscle estimate (UME) were calculated as follows, as described by Jaswant, Rolland-Cachera and Frisancho.[26,27,29]

$AFI = UFA/\{(MUAC)^2/ (4 \times \pi)\} \times 100$

$UFE= MUAC \times (TSF/2)$

$UME= \{(MUAC)^2/ (4\times\pi)\}-UFE$

The inter observer TEM for body mass index (BMI)=0.8%, ponderal index (PI)=1.4%, MAMC=1.7%, UMA=3.5%, UFA=6.5%, AFI=6%, UFE=7%, UME=3.8% and sum of SFT=4.2%.

Comparison of newborn anthropometry and derived adiposity to similar data from other countries

A PubMed and Google Scholar search on anthropometry and its derived adiposity at birth using the keywords "newborn", "neonate", "anthropometry", "adiposity" identified papers which reported on newborn anthropometry derived adiposity. Studies available in English which included babies born between 37-42 weeks gestation, from singleton pregnancies, measured within 0 – 5 days of birth, which reported a measure of adiposity i.e., upper arm adiposity, abdominal circumference or SFT, were included in the study. Abdominal circumference was included, only if measured at the level of the umbilicus. The Southampton UK babies' abdominal circumference was measured at the level of the xiphisternum and was not included. Anthropometric measurements were conducted by a trained person/s in all studies. Different instruments were used for measurement.

Ethics approval

The Ethics Review Committee of the Faculty of Medicine, University of Colombo reviewed the protocol and approved the study (EC-14-145).

Statistical analysis

Statistical analysis was completed using SPSS version 26.0 for Windows. T-test for independent samples were used for the comparison between males and females. Spearman correlation was used to determine the association between each anthropometric measure and parental factor, due to the non-normal distribution of the parental factors as assessed by the Shapiro Wilk test. Published data on newborn anthropometry and derived adiposity from other countries were compared to our study data, by conducting paired comparisons using the independent samples T test on the published summary data of each study versus our study findings.

RESULTS

All mothers admitted to the University Unit on weekdays during the study period were screened (n=4140), however only 427 mothers fulfilled the inclusion criteria prior to delivery. A significant proportion of mothers had come from different parts of the island, to deliver at a tertiary care centre and did not qualify based on living outside the study area. Only 344 mothers consented to participate in the study after delivery, as many had difficulties in committing to the monthly follow-up required for the longitudinal study. Seven records were not included, due to incomplete birth data, resulting in a study population of 337 newborns. Socio demographic characteristics of the study population are described in Table 1.

The majority of parents were married (98.8%) and the mean age of mother and father was 29 and 32 years, respectively. Both parents had a mean duration of 11 years of education. All except 3 fathers were employed whereas the majority (61.7%) of mothers were housewives. The median family monthly income was Sri Lankan Rupees 30,000 (200 USD). Many babies were delivered vaginally (62%). The mean gestational age was 39 weeks and 51% were males. All babies received the first breastfeed within the first hour and were exclusively breastfed at the time of discharge. Differences in anthropometry and derived adiposity at birth between girls and boys are given in Table 2 as mean and SD.

Boys were bigger than girls at birth, with a significantly higher ($p<0.05$) weight, length, head and chest circumference. However, there was no significant difference in BMI, ponderal index, measures of muscle mass or fat mass, except for a marginally higher abdominal circumference / length ratio in girls ($p=0.051$).

Associations between anthropometric measures of neonatal adiposity and parental factors in our study population revealed that abdominal circumference showed a positive correlation with maternal weight ($r=0.154$, $p=0.004$), maternal BMI ($r=0.126$, $p=0.018$) and paternal BMI ($r=0.243$, $p=0.036$). Similarly, abdominal circumference / length was correlated with maternal weight ($r=0.118$, $p=0.028$), maternal BMI ($r=0.109$, $p=0.042$), paternal weight ($r=0.237$, $p=0.038$) and paternal BMI ($r=0.280$, $p=0.015$). Subscapular SFT showed a positive correlation with maternal weight ($r=0.205$, $p<0.001$), maternal BMI ($r=0.135$, $p=0.012$) and maternal height ($r=0.105$, $p=0.049$). Monthly income, parental age and parental education was not significantly correlated ($p>0.05$) with any of the anthropometric measures of adiposity.

Anthropometry derived adiposity in our study population of urban Sri Lankan neonates were compared with similar published data from around the world which were based on neonates born as the outcome of a singleton pregnancy, at a gestation of 37 weeks or more. The timing of measurements varied from 0 to 5 days. Abdominal circumference was taken for comparison only when measured at the level of the umbilicus.

Table 3 shows the comparison of anthropometric data of our study population, denoted as the Sri Lankan data, with published data from other countries.

Our study population UFA and SFT were significantly ($p<0.001$) higher than the US neonates despite smaller size with significantly lower weight and length. Abdominal circumference was not measured in the US population.[20]

Our study population had no significant difference in subscapular SFT despite smaller size as evidenced by significantly lower weight, length, head circumference and triceps SFT compared to the Canadian Caucasians

Table 2. Comparison of birth anthropometry between males and females

Parameter	Male (n=174)	Female (n=163)	*p* value
Weight (kg)	2.98±0.5	2.84±0.4	0.004
Length (cm)	49.0±2.4	47.9±2.1	<0.001
HC (cm)	34.1±1.3	33.5±1.2	<0.001
CC (cm)	32.7±2.6	32.1±1.9	0.010
Body Mass Index (BMI)(kg/m^2)	12.4±1.2	12.3±1.5	0.985
Ponderal index (PI) (kg/m^3)	25.2±2.5	25.8±3.6	0.083
Fat mass			
AC (cm)	30.8±2.4	30.5±2.1	0.26
AC/length	0.63±0.0	0.64±0.0	0.051
UFA (cm^2)	2.4±0.7	2.3±0.5	0.319
AFI	26.0±4.5	26.1±3.7	0.804
UFE (cm^2)	2.6±0.8	2.5±0.6	0.321
Skinfolds			
Biceps (mm)	4.4±0.9	4.4±0.9	0.682
Triceps (mm)	4.8±1.1	4.7±0.9	0.577
Subscapular (mm)	5.1±1.4	5.0±1.2	0.697
Supra-iliac (mm)	4.2±1.1	4.2±1.0	0.958
Sum of skinfolds (mm)	18.5±3.8	18.4±3.4	0.866
Muscle mass			
MUAC (cm)	10.7±0.9	10.5±0.9	0.17
MAMC (cm)	9.2±0.8	9.1±0.8	0.163
UMA (cm^2)	6.8±1.2	6.6±1.1	0.165
UME (cm^2)	6.6±1.1	6.4±1.1	0.179

HC: head circumference; CC: chest circumference; AC: abdominal circumference; UFA: upper arm fat area; AFI: arm fat index; UFE: upper arm fat estimate; MUAC: mid upper arm circumference; MAMC: mid arm muscle circumference; UMA: upper arm muscle area; UME: upper arm muscle estimate.
All values are given as mean and standard deviations.

and Canadian South Asians. Amongst the Canadian neonates, Canadian South Asians showed a higher waist circumference, higher triceps and subscapular SFT despite being smaller in size (lower weight, length and head circumference), when compared to the Canadian Caucasians.[30]

Our study population was significantly bigger in size than rural Indian neonates, in Pune in all parameters including SFT and abdominal circumference and had significantly higher subscapular SFT than the Caucasian babies in Southampton, UK, despite being significantly smaller in size with lower weight, length, and head circumference.[9] Abdominal circumference could not be compared due to the difference in the site of measurement.9 Similarly, significantly higher triceps and subscapular SFT was reported despite being smaller in size with significantly lower weight and head circumference compared to the 4th generation Indian immigrants in Surinam, South America. Abdominal circumference was not significantly different in our study population and the 4th generation Indian neonates, in Surinam.[11]

Compared to Australian neonates, our study population showed significantly higher abdominal circumference with no significant difference in the subscapular SFT, despite being significantly smaller with lower weight, head circumference, mid-upper-arm-circumference and triceps SFT.[21]

DISCUSSION

Female neonates in our cohort were smaller than their male counterparts with significantly lower weight, length and head circumference, similar to the WHO growth standards. Despite a smaller body size, female babies had a marginally increased abdominal circumference / length ratio (p=0.051) with no significant differences in other fat mass indicators, suggestive of increased abdominal adiposity, compared to males. Increased adiposity in female neonates, was also described using UFA at birth in USA, using SFT at birth in UK, intrahepatocellular lipid deposition in MRI at 13 days of life in UK, and using 18O dilution method at 4-6 months of age in Sri Lanka. [20,31,32,33]

Neonatal adiposity has been found to be associated with parental adiposity with evidence of intergenerational transmission.[34-36] This led us to look for an association between the anthropometry derived adiposity in neonates with parental anthropometry. We found that both maternal and paternal anthropometry were associated with different aspects of neonatal adiposity. Maternal weight and BMI correlated with subscapular skinfold thickness, abdominal circumference and UFA in the offspring suggesting that maternal anthropometry affected both central and peripheral fat deposition in the offspring and contributed to both subcutaneous and visceral adipose tissue. Paternal weight and BMI correlated with neonatal abdominal circumference suggesting that paternal anthropometry predominantly affected abdominal adiposity. Ornellas et al and Catalano et al reported similar findings where both paternal obesity and maternal BMI were found to be strong predictors for childhood obesity.[37,38] The lasting effect of paternal obesity on their offspring was demonstrated by its correlation with the offspring's growth hormone levels at 2 years of age.[39] Intergenerational transmission of adiposity has been reported as the most likely explanation for the effect of parental adiposity on neonatal adiposity.[37]

Table 3. Comparison of anthropometric parameters and its derivatives of our study with other published studies

	SL M=174 F=163	USA.C M=40 F=40	USA.Afri M=30 F=30	Canada.C A=389	Canada.A A=400	Pune A=631	UK A=338	Surinam A=39	Australia M=668 F=602
W (kg)									
A	2.91±0.4	3.3±0.4 ($p<0.001$)		3.52±0.02 ($p<0.001$)	3.28±0.02 ($p<0.001$)	2.66±0.35 ($p<0.001$)	3.49±0.48 ($p<0.001$)	3.16±0.5 ($p=0.004$)	
M	2.98±0.5	3.35±0,4	3.31±0.4						3.50±0.4 ($p<0.001$)
F	2.84±0.4	3.40±0,5	3.28±0.5						3.38±0.4 ($p<0.001$)
L (cm)									
A	48.5±2.3	50±1.7 ($p<0.001$)		50.2±0.1 ($p<0.001$)	52.1±0.1 ($p<0.001$)	47.7±2 ($p<0.001$)	49.8±1.9 ($p<0.001$)	48.7±2.1 ($p=0.579$)	
M	49.0±2.4	51.2±2.7	50.0±1.7						
F	47.9±2.1	51.2±2.3	50.1±2.1						
HC (cm)									
A	33.8±1.3			34.9±0.1 ($p<0.001$)	34.1±0.1 ($p<0.001$)	31±1.2 ($p<0.001$)	35.2±1.3 ($p<0.001$)	34.3±1.3 ($p=0.027$)	
M	34.1±1.3								35.4±1.3 ($p<0.001$)
F	33.5±1.2								34.8±1.1 ($p<0.001$)
PI kg/m^3									
A	25.5 ±3			29.9 ±0.2 ($p<0.001$)	23.3±0.2 ($p<0.001$)	24.5±2.5 ($p<0.001$)	28.2±2.3 ($p<0.001$)	27.2±2.6 ($p<0.001$)	
M	25±3								
F	26±3								
MUAC (cm)									
M	10.7±0.9	10.0±0.8 ($p<0.001$)	10.2±0.9 ($p=0.006$)			9.7±0.9 ($p<0.001$)	11.5±1 ($p<0.001$)	10.6±1.2	10.7±0.9 ($p<0.001$)
F	10.5±0.9	10±0.8 ($p=0.001$)	10.1±1.0 ($p=0.038$)						10.9±0.9 ($p<0.001$)
Abd (cm)									
A	30.6±2.3					28.6±1.9 ($p<0.001$)		31.1±2.4 ($p=0.221$)	
M	30.8±2.4								28.8±1.9 ($p<0.001$)
F	30.5±2.1								28.3±1.98 ($p<0.001$)

W: weight; L: length, HC: head circumference; PI: ponderal index; MUAC: mid-upper arm circumference; Abd: abdominal circumference; B: biceps skinfold thickness; T: triceps skinfold thickness; SUB: subscapular skinfold thickness; SI: suprailiac skinfold thickness; UFA: upper arm fat area; SL: Sri Lanka, USA: United States of America; C: Caucasian; Afri: African; A: Asian; UK: United Kingdom; Pune: Indian; A: all; M: male; F: female.

Significance shown in comparison to the Sri Lankan data via independent sample, unequal variance, T test.

Table 3. Comparison of anthropometric parameters and its derivatives of our study with other published studies (cont.)

	SL M=174 F=163	USA.C M=40 F=40	USA.Afri M=30 F=30	Canada.C A=389	Canada.A A=400	Pune A=631	UK A=338	Surinam A=39	Australia M=668 F=602
Waist (cm)									
A				29.9±2.1	31.1±0.1				
B (mm)									
M	4.4±1.0	3.1±0.8 ($p<0.001$)	3.1±0.5 ($p<0.001$)						
F	4.4±1.0	3.2±0.7 ($p<0.001$)	3.1 ±0.7 ($p<0.001$)						
T (mm)									
A	4.8±1.0			5.4±0.1 ($p<0.001$)	6.2±0.1 ($p<0.001$)	4.2 ($p<0.001$)		4.6 ($p<0.001$)	
M	4.8±1.9	3.5 ± 0.6 ($p<0.001$)	3.7±0.6 ($p<0.001$)						4.9±0.9 ($p<0.001$)
F	4.7±0.9	3.8±0.9 ($p<0.001$)	3.7±0.9 ($p<0.001$)						5.0±0.9 ($p<0.001$)
SUB (mm)									
A	5.1±1.3			5.2±0.1 ($p=0.144$)	5.6±0.1 ($p=0.144$)	4.2 ($p<0.001$)	4.6 ($p<0.001$)	4.8 ($p<0.001$)	
M	5.1±1.4	4 ±0.9 ($p<0.001$)	4.5±0.8 ($p=0.002$)						5.3±1.0 ($p<0.001$)
F	5.0±1.2	4.7+0.9 (F) ($p=0.044$)	4.9±1.4 $p=0.574$						5.5±1.4 ($p<0.001$)
SI (mm)									
M	4.2±1.0	3.6±0.6 ($p<0.001$)	3.6±0.9 $p=0.002$						
F	4.2±1.0	4.0±0.8 ($p=0.097$)	4.0±1.4 $p=0.638$						
T+ SUB (mm)									
A	9.8±2.0			10.6±0.1 ($p<0.001$)	11.7±0.1 ($p<0.001$)				
UFA (cm^2)									
M	240 ±67	166± 46 ($p<0.001$)	180±37.7 $p<0.001$						
F	233±54	181± 48 ($p<0.001$)	177±51.5 ($p<0.001$)						

W: weight; L: length; HC: head circumference; PI: ponderal index; MUAC: mid-upper arm circumference; Abd: abdominal circumference; B: biceps skinfold thickness; T: triceps skinfold thickness; SUB: subscapular skinfold thickness; SI: suprailiac skinfold thickness; UFA: upper arm fat area; SL: Sri Lanka; USA: United States of America; C: Caucasian; Afri: African; A:Asian; UK: United Kingdom; Pune: Indian; A: all; M: male; F: female.

Significance shown in comparison to the Sri Lankan data via independent sample, unequal variance, T test.

Our study population also demonstrated significantly higher abdominal circumference suggestive of increased abdominal adiposity and relatively preserved or increased subscapular SFT, despite significantly smaller size, compared to American, British, Canadian and Australian neonates.[9,20,21,30] Similar findings were noted in the comparison of Canadian South Asians to Canadian Caucasian neonates by Anand et al.[30] Higher subscapular SFT at birth in African-Americans, Hispanics and Asians compared to Caucasians and higher abdominal adiposity as quantified by MRI in South Asian neonates compared to Chinese neonates in Singapore are also in agreement with our study findings.[40,41]

Significantly higher abdominal circumference, indicating abdominal adiposity was a more consistent finding in our study population, compared to skinfold thickness indicating higher subcutaneous adipose tissue. Higher abdominal circumference together with higher skinfold thickness, indicating higher visceral and subcutaneous adipose tissue, in our study population from Colombo Sri Lanka, differ from the thin-fat phenotype described by Yajnik in the Pune study, where the smaller Indian baby demonstrated a smaller abdominal circumference with higher skinfold thickness implying increased subcutaneous but not visceral adipose tissue.[9] This implies that our study population from Colombo Sri Lanka with a significantly higher abdominal circumference may have a higher amount of abdominal adiposity with higher risk of obesity associated complications compared to the Indian baby who was also reported to have increased subcutaneous and visceral fat via MRI compared to their Caucasian counterparts, despite a smaller abdominal circumference.[14] Sri Lanka's excellent health indicators, which have surpassed the rest of South Asia and are on par with high and upper middle-income countries, may indicate a greater lifestyle change in Sri Lanka, that is closer to that of high-income countries, with higher consumption of refined sugars and fats along with lower activity levels. This life-style change may increase the risk of abdominal adiposity in Sri Lankans compared to other South Asians in neighbouring countries and explain the higher abdominal circumference in our study population that makes them different from the thin-fat phenotype described in Indian newborns.

Healthy neonates born in Colombo Sri Lanka had a significantly higher abdominal circumference, indicating higher abdominal adiposity despite smaller size compared to babies from high income countries. Childhood adiposity as early as 3 years was associated with non-alcoholic fatty liver disease (NAFLD), in 17-year-old adolescents.[42] Sri Lanka has a high prevalence of NAFLD in adulthood (34%) compared to Africa (13.8%), Middle East (31%), and India (16.6%).[43,44] Further studies are needed to establish if babies with higher abdominal circumference at the time of birth is linked to the increased incidence of NAFLD in Sri Lanka.

Strengths of our study include the availability of both parent's anthropometric data and anthropometry being conducted by a single trained investigator while adhering to strict quality control measures, as evidenced by good intra-observer and inter-observer TEM. Limitations of the study include not having a direct measure for abdominal adiposity and using abdominal circumference as a proxy. We were limited to the use of published summary data as raw data was not available for the global comparisons.

Healthy neonates from Colombo Sri Lanka, had significantly higher abdominal adiposity despite being significantly smaller in size than neonates in high-income countries. Female neonates demonstrated higher abdominal adiposity than males with marginally higher abdominal circumference / length ratio despite being significantly smaller at birth. The phenotype of Sri Lankan neonates differed from the thin-fat phenotype described in Indian babies with significantly lower abdominal circumference, implying that Sri Lankan babies are at increased risk of central adiposity compared to Indian babies. Parental weight and BMI correlated with neonatal adiposity in our study population in contrast to family income implying that intergenerational transmission may have a larger effect on neonatal adiposity compared to socioeconomic status.

Further studies are indicated to measure body composition which should be correlated with abdominal circumference which can be used as a screening tool to assess abdominal adiposity from birth. Further studies are also required to establish whether higher abdominal adiposity as indicated by abdominal circumference at the time of birth, is linked to the increased incidence of metabolic syndrome and NAFLD in Sri Lanka. A conceptual diagram summarising how anthropometry predicts adiposity including the geo-ethnic difference is shown in Figure 1.

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AUTHOR DISCLOSURES

The authors declare that there is no conflict of interest.

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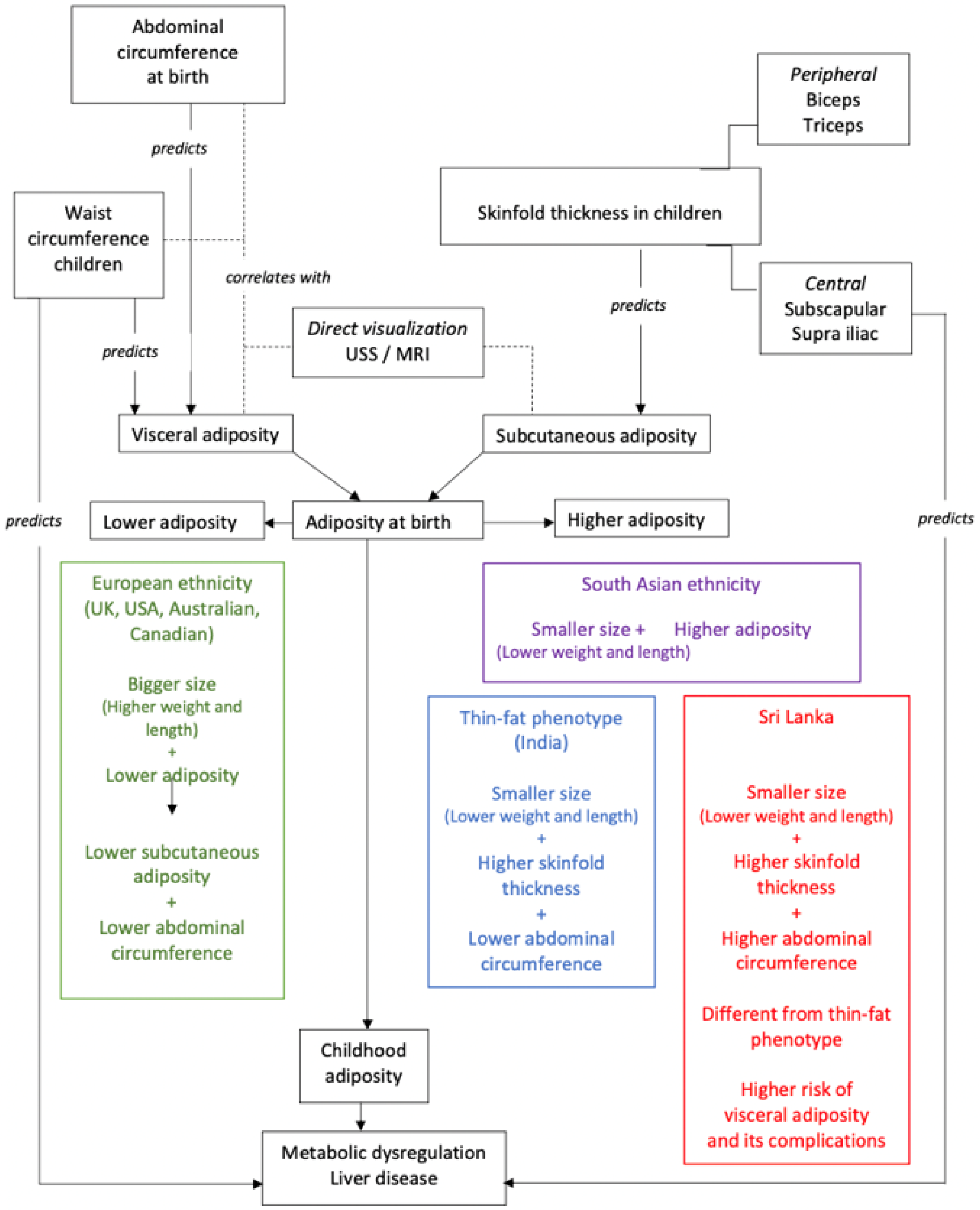

Figure 1. Conceptual diagram of how anthropometry can predict adiposity and the geo-ethnic difference.

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Supplementary table 1. Newborn morbidity taken as exclusion criteria

	Newborn morbidity
1	Seizures
2	Respiratory distress syndrome
3	Transient tachypnoea of newborn
4	Bronchopulmonary dysplasia
5	Pneumothorax
6	Meconium aspiration syndrome
7	Hypoxic ischaemic encephalopathy
8	Neonatal sepsis
9	Intrauterine infection
10	Fetal infection
11	Fetal inflammatory syndrome
12	Necrotising enterocolitis
13	Meningitis
14	Anaemia requiring transfusion
15	Hypotension requiring inotropes
16	Intraventricular haemorrhage
17	Periventricular leukomalacia
18	Polycythemia requiring partial exchange transfusion
19	Patent ductus arteriosus
20	Congenital abnormality
21	Any other serious condition requiring admission to the neonatal intensive care unit