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Infants Thinner at Birth Exhibit Smaller Kidneys for Their Size in Late Gestation in a Sample of Fetuses With Appropriate Growth

MICHELLE LAMPL,[1]* CHRISTOPHER W. KUZAWA,[1] AND PHILIPPE JEANTY[2]
[1]*Department of Anthropology, Emory University, Atlanta, Georgia 30322*
[2]*Women's Health Alliance, Nashville, Tennessee 37203-2131*

ABSTRACT Fetal ultrasound measurements were employed to investigate the relationship between weight and ponderal index at birth and kidney size during the second (23 weeks) and third (32 weeks) trimesters of pregnancy in a sample of 25 normally growing fetuses. Kidney volume and kidney volume / fetal weight ratio at 32 weeks are significantly and positively related to both weight and ponderal index at birth, controlling for sex, gestational age at birth, and day of ultrasound measurement. A second-degree polynomial relationship approximates the predictability of kidney volume fetal weight ratio at 23 weeks to that at 32 weeks, demonstrating shifting growth rates in fetal organ and body growth relationships during midgestation. Sex and parental size are suggested as contributing to these patterns. Females have a surge in renal growth between 23 and 32 weeks to catch up to earlier growing males, and maternal weight significantly predicts incremental growth in kidney volume and the kidney volume / fetal weight ratio at 32 weeks of gestation. The observation that fetuses relatively thin at birth have relatively smaller kidneys for their size in late gestation suggests that the influence of maternal weight on birth outcome may act through organ growth. Am. J. Hum. Biol. 14:398–406, 2002. © 2002 Wiley-Liss, Inc.

Birthweight is ubiquitously employed as a marker of prenatal growth in numerous studies positing adult morbidity sequelae of fetal development. Whether birthweight is a good proxy for fetal growth is debatable in this context. A question that remains to be answered is the following: What is it about size at birth that predicts later health in some individuals? Published epidemiological observations suggest that underlying relationships between organ growth and birth size may be important.

Research tracking traits such as blood pressure across developmental stages has reported inverse dose–response relationships across the entire range of birthweights. Observations that individuals of average birthweight have higher blood pressure than individuals of above-average birthweight (Barker et al., 1989, 1993; Osmond et al., 1993; Valdez et al., 1994) have provoked much debate regarding underlying mechanisms (Law and Shiell, 1996). While subsequent research has often focused on the study of low birthweight neonates and employed nutritional insufficiency as the fetal growth model of causation, an unanswered question is why adult disease risk has been observed to increase continuously and in a dose–response fashion as fetal size or the ponderal index at birth declines?

Organ-level studies may provide additional information. The present study employs fetal ultrasound measurements to investigate normal variation in birthweight with respect to kidney growth, an organ currently central to hypotheses linking the fetal environment with postnatal blood pressure regulation (Ingelfinger and Woods, 1999). A relationship between fetal kidney growth and adult blood pressure levels was first hypothesized over a decade ago, when Brenner et al. (1988) posited a direct relationship between kidney size and functional outcome. Observations of smaller kidneys in populations prone to hypertension provided early support and animal models extended these observations (Fassi et al., 1998; Langley-Evans et al., 1999; Merlet-Benichou et al., 1994). Controversy presently surrounds these propositions in humans (Manalich et al., 2000; Haycock 2001; Jones et al., 2001).

This investigation used ultrasonographic data to investigate the relationship between birth outcome in terms of weight and the

*Correspondence to: M. Lampl, Department of Anthropology, Emory University, Atlanta, GA. E-mail: mlampl@emory.edu

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ponderal index and fetal renal growth at two stages of gestation in a healthy sample with appropriate fetal growth. The number of functional units of the kidney, the nephron, is set at birth. The ultrasound measurements employed were selected to correspond roughly to the period before and after the critical period of most rapid renal growth proposed by Konje et al. (1996). These measures were used to investigate the relationship of kidney width, thickness, and length, and a derived variable, kidney volume to fetal weight ratio, with regard to birthweight and ponderal index. This is a hypothesis-generating study.

MATERIALS AND METHODS

Sample and fetal measurement protocol

The sample consisted of 25 maternal–fetal pairs, all of whom were employees at the same health care institution in Brussels, Belgium, and participants in a longitudinal growth study. All subjects volunteered under conditions of informed consent. The ultrasound measurements were obtained by a physician (PJ) using calipers and a Toshiba SAL 10A with a frame freeze and a 2.4 MHz transducer. Detailed descriptions of the study population and longitudinal measurement protocol have been published previously (Jeanty et al., 1984). Kidney length was measured in a longitudinal section of the fetus, either coronal or parasagittal, depending on fetal position. Antero-posterior and transverse diameters were obtained in an axial section of the kidney at the widest level observed by scanning up and down in the kidney. Only the most proximal kidney to the transducer was measured to avoid shadowing from the spine. Previous studies have identified no significant prenatal renal size differences based on laterality (Hsieh et al., 2000; Yu et al., 2000).

Derived measures

Kidney volumes at 23 and 32 gestational weeks were calculated using an equation that estimates volume from kidney width, thickness, and length, assuming an elliptical volume [$V = L \times W \times T\ (\pi/6)$]. A validation study using direct measurements of autopsy specimens found this technique to produce estimates that were highly correlated with direct measurement ($r = 0.96$; Jones et al., 1983). Mean estimated kidney volumes in the present sample correspond well with previously reported volumes (Lawson et al., 1981; Sagi et al., 1987), including gestational age-specific reference data derived from a larger ultrasound study of 261 healthy Belgian women (Jeanty et al., 1982).

Fetal weight was calculated using the method of Aoki (1990), which estimates fetal weight (EFW) from biparietal diameter (BPD), abdominal area (AA), and femur length (FL):

$$\mathrm{EFW} = (1.25647 \times \mathrm{BPD}^3) + (3.50665 \times AA \times FL) + 6.3$$

A recent validation study of four commonly used fetal weight prediction equations found this method to have highest validity and least systematic bias (Chien et al., 2000).

The ponderal index $\{100 \times [\text{weight (g)}/\text{length (cm)}^3]\}$ at birth was calculated using weight and recumbent length measures obtained immediately after birth. Gestational age at ultrasound measurement and at birth was calculated as time elapsed since last menstrual period (LMP). Gestational ages were confirmed using ultrasound measurement of crown–rump length at 8–10 weeks LMP. Gestational age at birth is included in all regression models investigating birth outcomes in these analyses.

Statistical methods

The first object of this study was to investigate the relationship between organ size and birth size as a dose–response relationship. The data were stratified by tertile of birthweight and ponderal index and the contribution of potential confounding factors was estimated on this basis. Trends across birth outcome tertiles were assessed using the nptrend statistic of Stata 6, which is an extension of the Wilcoxon rank-sum test for use with ordered groups (Stata Corp, 1999). Analysis of covariance was used to test for the nonequivalence of means among tertiles taking into consideration potential confounding factors, including gestational age in days at measurement and birth, sex, and maternal smoking. Sex differences in the timing of fetal renal growth have been previously reported (e.g., Gloor et al., 1997).

TABLE 1. Descriptive statistics for birth outcomes, parental characteristics, and day of ultrasound for total sample and stratified on tertile of ponderal index and weight at birth

			Tertiles ponderal index				Tertiles birth weight			
	All (SD)	Range	1 (SD)	2 (SD)	3 (SD)	P[1]	1 (SD)	2 (SD)	3 (SD)	P[1]
Birth characteristics										
Birthweight (g)	3,401 (347)	(2,610–3,990)	3,184 (306)	3,461 (299)	3,584 (339)	0.04	3,066 (241)	3,383 (101)	3,794 (124)	—
Birth length (cm)	50.6 (1.29)	(48–53)	50.6 (1.13)	50.9 (1.36)	50.3 (1.49)	—	49.3 (1.00)	50.9 (0.83)	51.6 (0.74)	0.00
Ponderal index (g/cm^3)	2.63 (0.18)	(2.22–2.99)	2.46 (0.11)	2.62 (0.06)	2.82 (0.10)	—	2.55 (0.20)	2.57 (0.13)	2.76 (0.12)	0.03
Gestational age (days)	274 (8.1)	(255–289)	276 (7.5)	272 (7.6)	275 (9.8)	—	275 (10.1)	270 (8.7)	277 (3.49)	—
Sex (female)	48%	—	33%	50%	63%	—	44%	63%	38%	—
Parental characteristics										
Mother's height (cm)	165.0 (6.6)	(153–175)	166.6 (4.3)	161.3 (7.2)	165.3 (5.5)	—	164.9 (7.0)	165.6 (6.2)	164.6 (7.3)	—
Father's height (cm)	179.5 (6.5)	(168–191)	179.1 (7.2)	178.6 (6.6)	180.3 (6.6)	—	179.3 (6.9)	179.4 (6.7)	179.6 (6.6)	—
Mother smoked in pregnancy	20%	—	22%	25%	13%	—	11%	38%	13%	—
Primagravida	72%	—	89%	63%	63%	—	78%	88%	50%	—
Day of ultrasound measurement										
Ultrasound #1 (days PLM[2])	164 (8.9)	(148–178)	162 (10.2)	164 (7.2)	166 (9.6)	—	166 (7.8)	160 (10.7)	166 (7.1)	—
Ultrasound #2 (days PLM[2])	225 (6.9)	(208–239)	224 (4.8)	225 (1.9)	226 (11.4)	—	221 (6.6)	226 (6.6)	228 (6.4)	—
Number	25	—	9	8	8	—	9	8	8	—

[1]nptrend *Stata* 6.
[2]PLM = post-last-mensturation.

TABLE 2. Mean fetal weight, kidney volume, and KV-FW ratio in total sample and stratified by tertiles of ponderal index and weight at birth

	All (SD)	Range	Tertiles ponderal index (birth) 1 (SD)	2 (SD)	3 (SD)	P^*	Tertiles birth weight 1 (SD)	2 (SD)	3 (SD)	P^*
23 weeks										
Fetal weight	648	(420–978)	601	682	667	—	627	618	702	—
(g)	(148)		(118)	(174)	(156)		(111)	(200)	(126)	
Kidney volume	2.31	(1.13–4.01)	2.12	2.42	2.42	—	2.31	2.03	2.56	—
(cm^3)	(0.75)		(0.63)	(0.76)	(0.91)		(0.73)	(0.75)	(0.78)	
KV-FW ratio	3.59	(1.98–5.38)	3.54	3.60	3.62	—	3.68	3.37	3.70	—
(cm^3/kg)	(0.88)		(0.91)	(0.88)	(0.96)		(0.89)	(0.88)	(0.94)	
32 weeks										
Fetal weight	1976	(1296–2425)	1965	1995	1969	—	1829	2014	2103	0.08
(g)	(266)		(259)	(177)	(365)		(274)	(288)	(159)	
Kidney volume	7.22	(5.07–10.11)	6.46	7.13	8.17	0.04	6.27	7.43	8.08	0.02
(cm^3)	(1.42)		(1.04)	(1.22)	(1.5)		(1.09)	(0.91)	(1.6)	
KV-FW ratio	3.69	(2.43–5.24)	3.29	3.59	4.25	0.02	3.49	3.71	3.90	—
(cm^3/kg)	(0.75)		(0.31)	(0.63)	(0.93)		(0.80)	(0.33)	(1.0)	
Number	25	—	9	8	8	—	9	8	8	—

*nptrend *Stata* 6.

The second objective of this study was to investigate predictability between birth outcomes and relative kidney size during fetal development. Least-squares regression models were used to test for relationships between kidney volume and the kidney volume to fetal weight ratio (KV-FW) and each birth outcome entered as a continuous variable, controlling for confounding variables. Separate models were run to test for relationships with birthweight and ponderal index. All variables were converted to z-scores before analysis, allowing direct comparisons of the strength of regression coefficients in the two models. Statistical significance was accepted at $P = 0.05$ and all statistical investigations employed the computational assumptions of Stata 6.

RESULTS

Birth and parental characteristics are summarized in Table 1 for the entire sample, stratified by tertiles of the ponderal index and weight at birth. The means (and standard deviations) for gestational age, weight, and ponderal index at birth for the sample were 274 ± 8.1 days, 3,401 ± 347 g, and 2.63 ± 0.18 g/cm^3, respectively. All births were term and there was no intrauterine growth retardation assessed by weight for gestational age. As expected, there was a significant trend in birthweight, length, and ponderal index across tertiles. No significant trends in other birth or parental variables were identified.

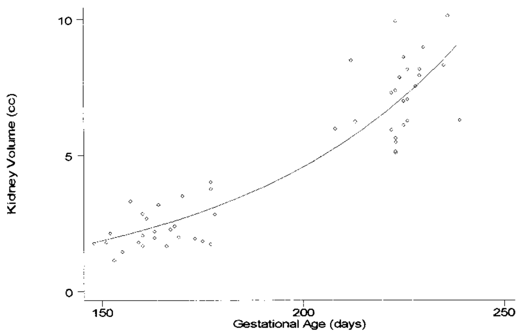

Fig. 1. Kidney volume (cc) estimates calculated from ultrasound measurements of kidney size [KV = L × W × T (π/6)] regressed on gestational age (days from last menstrual period). This curve is the fit of a two-parameter exponential growth curve, $y = 0.13 \times 1.02^x$ ($R^2 = 0.96$). For each individual in the study, ultrasound measurements were taken at average ages of 23 (±2) and 32 (±2) weeks' gestation.

Kidney growth appears to have been normal in this sample (Fig. 1). A comparison between a linear model, second to sixth degree polynomials, and a nonlinear exponential function identified the latter as the best fit of these data among the models tested by iterative least-squares techniques and inspection of residuals ($R^2 = 0.96$ for Fig. 1, with R^2 ranging from 0.84 for the linear model, 0.86 negative exponential, and 0.88

TABLE 3. Regression coefficients for models predicting 32-week KV-FW ratio (z-score) from birthweight and ponderal index, controlling for fetal weight, sex, maternal smoking, days of ultrasound, and birth (coefficients not shown)

Model	Beta	SE	T	*P*	95% C.I.	Model R^2
Birthweight (z-score)	0.432	0.198	2.179	0.040	(0.021, 0.844)	0.17
Ponderal index (z-score)	0.436	0.183	2.378	0.027	(0.056, 0.816)	0.20

TABLE 4. Regression coefficients for models predicting 32-week kidney length, width, and thickness from birthweight and ponderal index (z-score) controlling for sex, maternal smoking, days of ultrasound, and birth (coefficients not shown)

Model	Beta	SE	T	*P*	95% C.I.	Model R^2
Birth weight						
Kidney length (cm)	0.180	0.710	0.253	0.803	(−1.292, 1.652)	—
Kidney width (cm)	1.165	0.390	2.992	0.007	(0.358, 1.973)	0.39
Kidney thickness (cm)	0.876	0.412	2.128	0.045	(0.022, 1.730)	0.12
Ponderal Index						
Kidney length (cm)	0.265	0.666	0.399	0.694	(−1.115, 1.646)	—
Kidney width (cm)	0.618	0.414	1.494	0.149	(−0.240, 1.476)	0.22
Kidney thickness (cm)	0.874	0.382	2.289	0.032	(0.082, 1.666)	0.14

to 0.94 for increasing polynomials). Mean kidney volumes were 2.3 cm^3 and 7.2 cm^3 at 23 and 32 weeks, respectively, values very close to median values for gestational age, using reference data from a larger published ultrasound study of healthy Belgian women (Jeanty et al., 1982). Table 2 shows unadjusted means for fetal weight and kidney measurements taken at 23 and 32 weeks gestation in the entire sample, stratified by tertile of weight and the ponderal index at birth. Fetal weight at 32 weeks increased with increasing birthweight tertile and the size of the kidney increased across tertiles of both the ponderal index and weight at birth. In the unadjusted data, there were significant positive trends between kidney volume and tertile of weight and the ponderal index at birth (both $P = 0.01$). As larger babies tend to have larger kidneys, these trends were expected. Fetal weight at 32 weeks was considered a significant potential confounder and was controlled in regression models.

The kidney volume to fetal weight ratio (KV-FW ratio) provides an index of how large the kidney is relative to body size, which is a more useful proxy for the adequacy of renal growth. The mean KV-FW ratio did not change significantly between week 23 (3.59 ± 0.88 cm^3/kg) and week 32 (3.69 ± 0.75 cm^3/kg) measurements (Fig. 2). This is consistent with Gloor et al. (1997), who showed that the mean KV-FW ratio remained constant in a sample of 100 women measured between 19 and 40 weeks

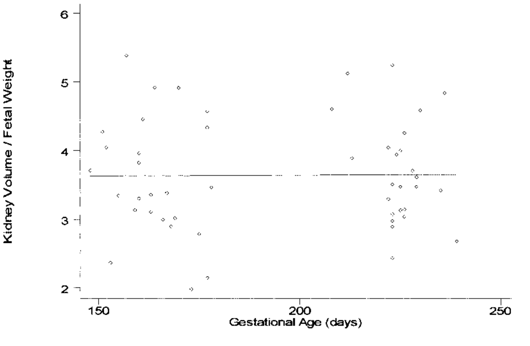

Fig. 2. Kidney volume/fetal weight ratio (cc/kg) regressed on gestational age (days from last menstrual period). For each individual in the study, ultrasound measurements were taken at average ages of 23 (±2) and 32 (±2) weeks' gestation. There are no significant differences in the means at these two ages. The linear regression illustrated here is expressed as y = 0.0002x + 3.592 (R^2 = 0.0001).

gestation, suggesting that this smaller sample is not biased in a meaningful way. At 32 weeks, the KV-FW ratio increased in a dose–response fashion with increasing tertile of ponderal index and weight at birth (Table 2). Controlling for day of measurement, sex, and maternal smoking, analysis of covariance identified only fetal weight at 23 weeks as statistically significantly different among tertiles of birthweight (P = 0.04). No significant differences were identified at either age for ponderal index tertiles. Analysis of covariance identified

TABLE 5. Regression coefficients for models predicting 32-week KV-FW ratio from 23-week KV-FW ratio (z-scores), controlling for sex, maternal smoking, and day of ultrasound (coefficients not shown)

Model	Beta	SE	T	*P*	95% C.I.	Model R^2
KV-FW 23 weeks	0.31	0.25	1.25	0.23	(−0.21, 0.84)	0.33
Linear model						0.18
KV-FW 23 weeks	0.36	0.22	1.65	0.12	(−0.1, 0.82)	0.04
Polynomial, degree 2	0.60	0.21	2.80	0.01	(0.15, 1.05)	0.41

maternal smoking and day of measurement as significant confounders for unsorted 23-week measurements ($P < 0.01$) and all regression models controlled for these variables.

Regression analyses identified that the relationship between the KV-FW ratio and both weight and the ponderal index at birth were significant after controlling for potential confounders (sex, maternal smoking, gestational age at measurement and birth, and fetal weight at 32 weeks), with *P*-values for the regression coefficients of 0.040 and 0.027, respectively (Table 3). Based on the regression coefficients, a change in birthweight of 1 SD (roughly 347 g) is associated with a change in relative kidney size during the third trimester equal to roughly 0.43 SDs. The relationship with the ponderal index was of similar magnitude.

To determine which specific dimensions of the kidney account for these relationships, kidney width, length, and thickness measured at 32 weeks were regressed on both birthweight and ponderal index z-scores, controlling for the same confounders (Table 4). Identical models were run for kidney dimensions measured at 23 weeks, but all results were nonsignificant and, therefore, are not reported. Consistent with the findings of Konje et al. (1997), kidney length is unrelated to both birth outcomes. Kidney width and thickness both relate positively to birthweight z-score, while kidney thickness relates positively to ponderal index z-score.

These results pertain to size for age observations. The present longitudinal data permit further inquiry into how fetal growth patterns may contribute to these outcomes. This is important because both this study and others report a consistent KV-FW ratio across fetal development at these ages, based on sample averages. However, the present analyses identified that only at 32 weeks does organ size significantly predict individuals' birth outcome. These results suggest that individuals are not consistent across development in organ to body growth ratios, or birth outcomes would already be predictable by 23 weeks. Thus, growth patterns at the individual level vary and kidney size to body weight ratio must be characterized by significant shifts during midgestational fetal growth.

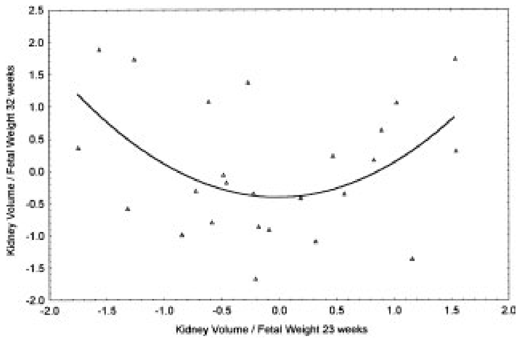

Fig. 3. Kidney volume/fetal weight ratio (cc/kg) at 32 weeks regressed on kidney volume/fetal weight ratio (cc/kg) at 23 weeks. The fitted curve is a second-degree polynomial, $y = 0.406 + 0.009\ x + 0.528\ x^2$, a least-squares best-fit ($P = 0.04$, R^2 0.41) by comparison with first through sixth degree polynomials (none significant). For each individual in the study, ultrasound measurements were taken at average ages of 23 (±2) and 32 (±2) weeks' gestation (days from last menstrual period).

Growth patterns within individuals were further investigated in the present sample. Controlling for sex, maternal smoking, and day of measurement, no statistically significant linear tracking was identified between KV-FW at 23 and 32 weeks (Table 5). A plot of the 23 vs. 32 week KV-FW measurements suggests a nonlinear U-shaped relationship (Fig. 3). A second-degree polynomial regression was a reasonable approximation of developmental relationships between 23 and 32 weeks KV-FW in this sample and a better fit by comparison with first to sixth degree polynomials (none of which were statistically significant), a reasonable array of initial hypothetical models for describing these data (Table 5). Thus, relatively larger KV-FW ratios at 32 weeks are associated with both high and low KV-FW ratios at 23 weeks.

Two sources are suggested for these relationships: sex differences and parental effects. Boys have a weakly larger KV-FW ratio at 23 weeks ($P = 0.09$), and girls subsequently catch up to boys as the result of greater incremental growth rates ($P = 0.08$). These observations are in line with previous descriptions of earlier renal growth spurts in males (Gloor et al., 1997).

Stratifying parental confounders by z-score above and below the mean suggests positive effects of paternal height on KV-FW at 32 weeks (χ^2, $P = 0.08$), and parental height and maternal weight on the growth increment between 23 and 32 weeks, with taller parents contributing to greater growth over the interval. The latter relationships are not statistically significant and would require a sample size at least twice the present one. Least-squares regression, controlling for maternal smoking, day of measurement, and sex, identifies that maternal weight significantly predicts kidney volume and KV-FW ratio at 32 weeks, as well as incremental growth in kidney volume between 23 and 32 weeks (P for variable and model <0.05 for all; R^2 0.29, 0.28, 0.16, respectively).

DISCUSSION

In this sample of healthy Belgian women with appropriately growing fetuses, thinner neonates at birth have smaller kidneys relative to the size of the body. The relative size of the fetal kidney during the third trimester of pregnancy, as indexed by the KV-FW ratio is a significant predictor of infant weight and ponderal index at birth. This effect appears to be a dose–response trend of increasing relative kidney size with increasing birth outcome tertile. These observations suggest that the ponderal index at birth may provide information about relative kidney size in mid- to late-gestation, but this remains to be confirmed in a larger sample.

The second-degree polynomial relationship describing the developmental pathways between KV-FW at 23 and 32 weeks suggests flexibility in fetal organ and body growth relationships during gestation, as final size is attained. Organ-to-body weight ratio predictive of birth outcome does not track linearly from early development, but is adjusted during mid-gestational growth. Thus, a fetus can have either a relatively small or relatively large KV-FW ratio at 23 weeks and grow to a relatively large, or small, KV-FW ratio by 32 weeks as the result of shifting growth rates.

Consideration of the factors that may be contributing to these growth patterns and, ultimately, to the ponderal index and birthweight in this study include fetal sex and parental size. The differential timing involved in renal growth due to sex may be one source of alternating z-score positions between individual fetuses and may be contributing to variance in linear predictability between KV-FW at 23 and 32 weeks gestational age.

Growth rate differences may have further implications. In this sample, the initially "good growers" (±1 z-score at 23 weeks) who subsequently fall below −1 z-score for KV-FW by 32 weeks are predominantly males whose mothers are <−1 z-score in weight or BMI and both fathers and mothers are below −1 z-score in height. Thus, among the factors that differentiate the fetuses who do and do not maintain an early robust growth rate appears to be parental height and maternal weight and, in this sample, sex. These observations may be artifacts of the small sample size, but they provide a reasonable working hypothesis for further ultrasound investigation.

If renal growth rate declines during the third trimester, the final KV-FW ratio may be decreased. This pattern is suggested here for some of the boys who experienced an early renal growth spurt, followed by attenuation and relatively less renal growth. The timing of this growth rate change can be important: Maximal nephrogenic development has been reported to occur during the third trimester, a critical period when final nephron endowment is set (Hinchliffe et al., 1992; Konje et al., 1996). In this sample, as weight and/or the ponderal index at birth decline, thinner kidneys of comparable length but reduced volume and/or parenchymal mass result. It is unclear whether the resulting size effects have functional consequences (Zhu et al., 1992).

The present study suggests that renal growth scales to birthweight in normally growing fetuses. This is not a surprising finding in light of previous observations that the kidney and other tubular structures scale to size in mammals (Prothera, 1996). The present within species observations are interesting, however, in identifying a trend with relative reduction in kidney size in smaller, thinner infants. Why would a fetus grow kidneys relatively small for the body? Or, put another way, how and why might a fetus grow a body relatively large for its kidneys? The parental stratification investigation suggests that there are contributions from maternal weight and short and thin mothers may prompt organ growth restraint.

It has recently been proposed that renal function is set by metabolic rate (Singer, 2001). From this perspective, it is interesting that maternal weight is a significant factor in fetal KV-FW. Perhaps maternal weight influences involve a transmission of information to the developing fetus regarding available energy and/or fetal metabolic rate. The observation that fetuses who are relatively thin at birth also have relatively smaller kidneys for their size links maternal weight influences on birthweight and organ growth with propositions concerning metabolic rate.

In view of the scaling relationship between growth of the kidney and total body, it is of interest that the period of most rapid renal growth coincides with the period of most rapid weight growth and adipose tissue deposition. The mechanisms explaining these observations remain to be clarified, but the coincidence in timing suggests that adipose tissue itself may be contributory via either leptin (Wolf et al., 1999) or renin-angiotensin interactions (Engeli et al., 2000; Alcom et al., 1996). The present observations provide a rationale to investigate linkages between late-gestation body growth and the growth and structural differentiation of the kidney.

This study, together with those of Konje et al. (1996, 1997), illustrates the utility of fetal ultrasound as a means to explore the dynamics of prenatal growth, not merely of the entire fetus, but of organs hypothesized to link birth outcomes with specific postnatal risk factors. Further studies are needed in a larger sample to extend these findings to parturition and to clarify the biological pathways linking relative kidney size to fetal weight growth.

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