

Mineral Metabolism and Vascular Damage in Children on Dialysis

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ABSTRACT

Cardiovascular disease is increasingly recognized as a life-limiting problem in young patients with chronic kidney disease, but there are few studies in children that describe its determinants. We studied the association of intact parathyroid hormone (iPTH) levels and their management on vascular structure and function in 85 children, ages 5–18 years, who had received dialysis for ≥ 6 months. Compared to controls, dialysis patients had increased carotid intima-media thickness and pulse-wave velocity. All vascular measures positively correlated with serum phosphorus levels, while carotid intima-media thickness and cardiac calcification score also correlated with iPTH levels. Patients with mean time-integrated iPTH levels less than twice the upper limit of normal ($n = 41$) had vascular measures that were comparable to age-matched controls, but those with iPTH levels greater than twice the upper limit of normal ($n = 44$) had greater carotid intima-media thickness, stiffer vessels, and increased cardiac calcification than controls. Patients with increased carotid intima-media thickness had stiffer vessels and a greater prevalence of cardiac calcification. There was a strong dose-dependent correlation between vitamin D and all vascular measures, and calcium intake from phosphate binders weakly correlated with carotid intima-media thickness. In conclusion, both iPTH level and dosage of vitamin D are associated with vascular damage and calcification in children on dialysis.

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Cardiovascular disease is the most common cause of death in young adults with chronic kidney disease (CKD).¹ Altered morphologic properties of the large arteries can be seen from the second decade of life,^{2–6} imparting a 700-fold increased risk for death over the age-adjusted normal population.⁷ In recent years, attention has focused on the role of calcium (Ca), phosphate (PO₄), and parathyroid hormone (PTH) as potentially modifiable risk factors in the development and progression of vascular disease.^{8–10}

Intact PTH (iPTH) levels of two to four times the upper limit of normal (ULN) are recommended for patients who are on dialysis^{11,12} on the basis of bone histomorphometry studies in children¹³ and adults. This is because as CKD

progresses, continued stimulation of the parathyroid glands by high plasma PO₄ and low Ca levels leads to parathyroid gland hypertrophy and re-setting of the calcium-sensing receptor so that higher than normal levels of ionized Ca are required to alter PTH secretion. This “skeletal resistance” to PTH results in low-turnover (ady-

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namic) bone disease and an inability of bone to buffer fluxes in serum calcium, resulting in ectopic soft tissue calcification. However, it has to be remembered that high iPTH levels are *per se* a risk factor for vascular disease and soft tissue calcification.^{10,14,15}

At Great Ormond Street Hospital, we aim to prevent the escape of the parathyroid glands from normal control mechanisms by dietary and therapeutic intervention. We have shown that keeping iPTH levels in the normal range in stages 1 through 4 CKD and <2 ULN in children who are on dialysis maintains normal growth velocity¹⁶ and bone mineral density,¹⁷ but the presence of renal osteodystrophy was ubiquitous in children with CKD irrespective of iPTH levels.¹⁸

These long-standing differences in management of secondary hyperparathyroidism among pediatric renal units in the United Kingdom have given us the opportunity to study the impact of a wide range of iPTH levels and their management on vascular structure and function. We hypothesized that maintaining iPTH levels <2 ULN throughout the

course of CKD will prevent vascular damage and calcification in children who are on dialysis.

RESULTS

Dialysis and Control Groups

Diagnoses of the 85 study children (45 boys) were dysplasia ($n = 50$), inherited nephropathies ($n = 13$), cystic kidney disease ($n = 6$), primary tubular disorders ($n = 6$), renovascular disorders ($n = 4$), malignancies ($n = 3$), and metabolic disorders ($n = 3$). Comparisons between control subjects and groups I and II are shown in Table 1.

Carotid intima-media thickness (cIMT) and brachioradial pulse-wave velocity (PWV) were significantly greater in the dialysis population than in the control group (Table 2). The duration of dialysis was associated with an increasing cIMT ($r = 0.31$, $P = 0.04$) but not with PWV or the presence of cardiac calcification. The time spent in stage 4 CKD, age at initiation of dialysis, dialysis modality, and pres-

Table 1. Demographic, clinical, anthropometric, and biochemical characteristics of patients and control subjects^a

Characteristic	Control Subjects (n = 40)	Group I (n = 41)	Group II (n = 44)	P (Group I versus II)
Age (yr; mean \pm SD)	13.2 \pm 4.8	12.6 \pm 3.9	13.5 \pm 3.2	0.30
Gender (male/female)	21/19	24/17	21/23	0.89
Estimated GFR (ml/min per 1.73 m ² ; mean \pm SD)	111.0 \pm 8.8	9.1 \pm 8.0	7.6 \pm 3.7	0.25
Time in stage 4 CKD (yr; mean \pm SD)	–	5.8 \pm 3.5	5.0 \pm 4.3	0.26
% with residual renal function	–	39	42	0.82
Age at start of dialysis (yr; mean \pm SD)	–	9.8 \pm 5.1	8.8 \pm 3.9	0.34
Time on dialysis (yr; mean \pm SD)	–	2.2 \pm 1.7	2.4 \pm 1.9	0.09
Dialysis modality at point of study (PD/HD)	–	32/9	32/12	0.09
% CKD time spent on dialysis	–	39.4 \pm 31.2	44.2 \pm 36.3	0.08
Height SDS (mean \pm SD)	0.5 \pm 2.6	–1.4 \pm 1.7	–1.6 \pm 2.1	0.75
BMI SDS (mean \pm SD)	0.9 \pm 0.9	–0.5 \pm 1.4	–0.4 \pm 1.9	0.06
Systolic BP index (mean \pm SD) ^b	0.9 \pm 0.1	1.2 \pm 0.4	1.2 \pm 1.2	0.09
No. of antihypertensive medications (range)	0	1 (0 to 2)	1 (0 to 3)	0.07
Hemoglobin (gm/dl; mean \pm SD)	13.3 \pm 1.1	11.7 \pm 1.5	10.9 \pm 2.4	0.61
Albumin (g/L; mean \pm SD)	41 \pm 0.6	39 \pm 3.8	37 \pm 3.7	0.92
Total cholesterol (mMol/L; mean \pm SD)	3.3 \pm 1.3	4.4 \pm 0.8	3.9 \pm 1.3	0.75
Triglycerides (mMol/L; mean \pm SD)	0.9 \pm 2.2	1.3 \pm 1.3	1.6 \pm 1.0	0.67
Serum PO ₄ level (mMol/L; mean \pm SD)	0.9 \pm 0.3	1.4 \pm 0.3	2.1 \pm 0.8	<0.0001
Serum Ca (albumin adjusted; mMol/L; mean \pm SD)	2.2 \pm 0.2	2.4 \pm 0.1	2.4 \pm 0.3	0.15
% of episodes with Ca \geq 2.5 mMol/L per patient	0	5	11	0.08
Ca \times PO ₄ product (mMol ² /L ² ; mean \pm SD)	3.3 \pm 0.3	3.5 \pm 0.6	4.9 \pm 0.9	<0.0001
Serum iPTH (fold ULN; mean \pm SD)	N/D	0.7 \pm 0.6	6.0 \pm 5.2	<0.00001
Parathyroidectomy	0	0	1 (partial)	–
PO ₄ binders (n [%])				
patients on Ca-based PO ₄ binders	–	36 (88)	26 (59)	0.08
sevelamer with or without Ca-based PO ₄ binders	–	5 (12)	18 (41)	
Cumulative intake of elemental Ca from PO ₄ binders (g/kg; mean \pm SD)	–	119 \pm 71	131 \pm 112	0.07
Calcitriol (vitamin D ₃ ; μ g/kg; mean \pm SD)	–	49.6 \pm 14.6	85.7 \pm 29.9	<0.0001

Group I: Mean time-integrated serum iPTH \leq twice ULN (upper limit of normal). Group II: mean time-integrated serum iPTH > twice ULN.

^aBMI, body mass index; HD, hemodialysis; N/D, not done; PD, peritoneal dialysis; SDS, SD score.

^bMeasured BP/95th centile BP for age, gender, and height.

Table 2. Comparison of carotid artery structure, vascular stiffness, and calcification scores between dialysis and control patients and between groups I and II

Parameter	Control Subjects (n = 40)	Dialysis (n = 85)	P	Dialysis Patients		P
				Group I (n = 41)	Group II (n = 44)	
cIMT (mm; mean ± SD)	0.38 ± 0.01	0.46 ± 0.12	0.002	0.39 ± 0.01	0.58 ± 0.02	<0.0001
Aortic PWV (m/s; mean ± SD)	N/D	7.14 ± 1.2	–	5.81 ± 1.2	8.63 ± 2.3	0.03
Brachioradial PWV (m/s; mean ± SD)	5.1 ± 1.0	8.89 ± 1.9	0.03	9.06 ± 2.1	8.57 ± 1.8	0.82
Cardiac calcification (n [%])	N/D	17 (20%)	–	5 (12%)	12 (27%)	0.004
Agatston score (mean ± SD)	–	21.3 ± 30.1	–	11.9 ± 10.3	65.6 ± 278; median 85.3 (0 to 2039)	0.01
Coronary arteries (n [%])	–	13	–	3 (7%)	10 (22%)	0.02
Valves (n [%])	–	5	–	2	3	–
Aorta (n [%])	–	7	–	1	6	–

ervation of residual renal function did not correlate with any vascular measures.

Vascular Measures and Calcification Score in Groups I and II

cIMT.

cIMT showed a strong linear correlation with iPTH ($r = 0.71$, $P = 0.0001$), PO_4 ($r = 0.51$, $P < 0.0001$; Figure 1) and $Ca \times PO_4$ ($r = 0.65$, $P < 0.0001$). The cIMT in group I was comparable to the control group (0.39 ± 0.01 versus 0.38 ± 0.01 mm; $P = 0.44$) and significantly lower than in group II (0.58 ± 0.02 ; relative risk 3.7; $P < 0.0001$; Figure 2).

PWV.

Aortic PWV also showed a positive correlation with PO_4 levels ($r = 0.39$, $P = 0.03$) and $Ca \times PO_4$ ($r = 0.37$, $P = 0.018$). Aortic PWV was greater in group II than in group I (8.63 ± 2.3 versus 5.81 ± 1.2 m/s; $P = 0.03$; Table 2). However, the brachioradial PWV did not correlate with any demographic or biochemical parameters.

Cardiac Calcification Scores.

The calcification score was associated with iPTH levels ($r = 0.39$, $P = 0.03$; Figure 3) and serum PO_4 ($r = 0.34$, $P = 0.03$) but did not correlate with age, duration of CKD, or time on

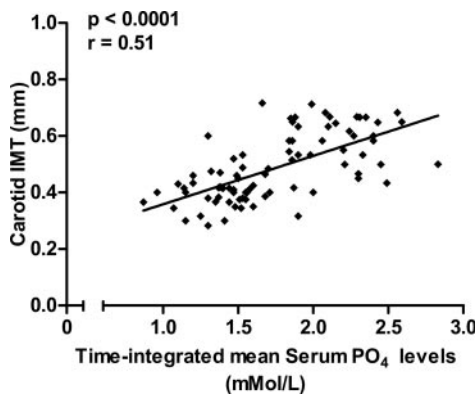


Figure 1. Correlation of cIMT with mean time-integrated serum PO_4 level.

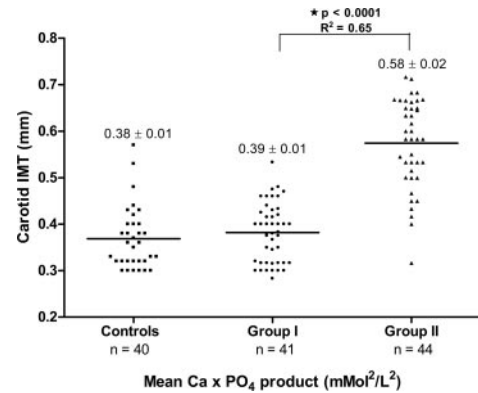


Figure 2. Comparison of cIMT levels among control subjects, group I, and group II. Group I, mean time-integrated serum iPTH ≤ 2 ULN; group II, mean time-integrated serum iPTH > 2 ULN.

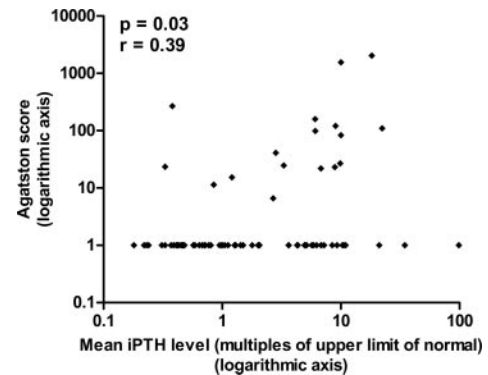


Figure 3. Correlation of Agatston score for cardiac calcification with mean time-integrated iPTH levels.

dialysis. Five (12%) patients in group I and 12 (27%) in group II ($P = 0.004$) had calcification (relative risk 2.3; Table 2). Calcification was graded¹⁹ as minimal (Agatston score < 10) in four, mild (score 11 to 100) in six, moderate (score 101 to 400) in five, and severe (score > 400) in two. Moderate and severe grades of calcification were seen only in group II. There was no definite anatomic pattern of calcium deposition in the vessels or valves. Three (17%) of 17 patients who were younger than 10 yr had calcification as

compared with 14 of 68 (20%) who were older than 10 yr.

Effect of PO₄ Binders and Vitamin D Therapy on Vascular Measures

Eighteen (41%) patients in group II received sevelamer with or without calcium-based PO₄ binders compared with only five (12%) in group I (Table 1). The group of patients on sevelamer were older (15.1 ± 4.1 yr), had a longer dialysis vintage (3.0 ± 1.9 yr) and were predominantly on hemodialysis (73%) as compared with the overall cohort. The mean elemental Ca intake from the prescribed dosage of PO₄ binders was marginally greater in group II than in group I (Table 1). Although the elemental Ca intake from PO₄ binders did not correlate with any of the vascular measures in the overall cohort, after exclusion of patients who received sevelamer, the IMT did show a weak correlation with calcium-containing PO₄ binder dosage ($r = 0.19$; $P = 0.054$).

The vitamin D dosage showed a strong dosage-dependent correlation with cIMT ($r = 0.65$, $P < 0.001$), aortic PWV ($r = 0.17$, $P = 0.03$), and calcification score ($r = 0.28$, $P = 0.02$; Table 3, Figure 4). Patients with calcification ($n = 17$) received a 2.8-fold higher vitamin D dosage than those without calcification (21.9 ± 8.9 versus 53.7 ± 13.4 μg/kg, $P = 0.0001$).

Correlations between Vascular Measures

cIMT was associated with aortic PWV ($r = 0.41$, $P < 0.0001$) and the calcification score ($r = 0.32$, $P = 0.002$): Patients with calcification ($n = 17$) had significantly higher cIMT than those without calcification (0.55 ± 0.11 versus 0.45 ± 0.12 mm; $P = 0.004$; Figure 5).

Predictors of cIMT, Aortic PWV, and Calcification Score

On multiple regression analysis, the vitamin D dosage was the strongest predictor of cIMT, aortic PWV, and calcification, whereas iPTH levels were an independent predictor of cIMT and calcification (Table 3).

DISCUSSION

This is the largest pediatric study in the youngest cohort of

Table 3. Multiple regression analysis for independent predictors of cIMT, aortic PWV, and calcification score

Variable	Standardized Coefficient (β)	P	Model R ²
cIMT			0.74
vitamin D dosage	0.65	<0.001	
iPTH level	0.72	<0.0001	
PO ₄ level	0.51	0.001	
Aortic PWV			0.23
vitamin D dosage	0.17	0.03	
Cardiac calcification (Agatston) score			0.54
vitamin D dosage	0.28	0.02	
iPTH level	0.53	<0.001	

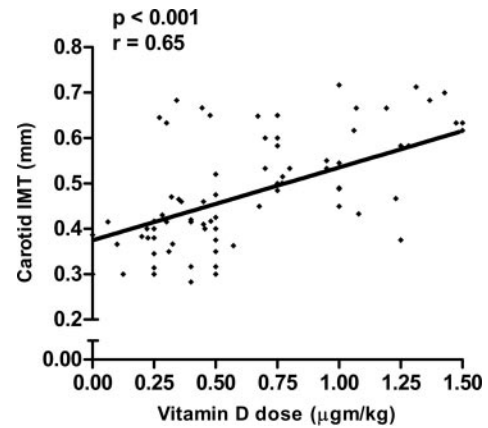


Figure 4. Correlation of cIMT with the mean calcitriol dosage.

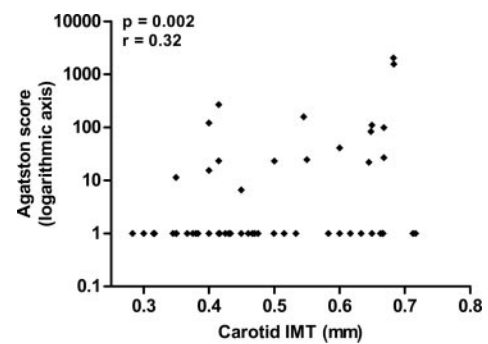


Figure 5. Correlation of Agatston score for cardiac calcification with cIMT.

CKD patients on dialysis that describes vascular changes and the impact of iPTH control and vitamin D treatment on these. We show that both hyperparathyroidism and its management with vitamin D have an impact on structural and functional vascular changes that begin as early as the first decade of life.

Uremia is a vasculopathic process. Children provide an ideal opportunity to study the uremic influences on the arterial wall because they rarely have risk factors such as diabetes, dyslipidemia, and hypertension that are prevalent in adults.^{14,20} The patients in our study were carefully selected so that they were free of such confounders, and capitalizing on detailed serial biochemistry over ≥3.5 yr, we were able to demonstrate the impact of iPTH and its management on the vascular phenotype. Whereas PO₄ has been shown to be an independent risk factor for cardiovascular disease,⁸ including increased IMT,^{4–6} vessel stiffness,^{3,21} and left ventricular hypertrophy,⁵ PTH *per se* may contribute to vascular injury *via* mechanisms other than its effect on Ca-PO₄ homeostasis. It would be impossible to extricate the individual effects of PO₄ and PTH and the medications used in their regulation. PTH may mediate vascular damage by playing a permissive role in arteriolar wall thickening and myocardial interstitial fibrosis,¹⁰ increasing triglycerides and LDL cholesterol and contributing to chronic hypertension; progression of these vascular changes is reduced after parathyroidectomy.²² Thus, although it is now widely accepted practice to aim for PO₄ levels within the normal range,

the optimal level for iPTH is as yet unclear. Results of this hypothesis-generating study will allow for a prospective randomized trial to evaluate the cardiovascular benefits of maintaining iPTH levels <2 ULN using the lowest possible dosage of vitamin D.

The long-term consequences of vascular damage are particularly important in children, who have a lifetime of renal replacement therapy ahead of them. Studies in adults with CKD have shown that approximately 65% have coronary calcification at the start of dialysis,²³ suggesting that prevention of secondary hyperparathyroidism is in fact key to the prevention of vascular damage and calcification. We and others have shown that endothelial dysfunction²⁴ and vascular damage^{2–6} begin early in the course of CKD. The vascular damage is only partially reversible after transplantation²⁵ and use of lipid-lowering agents,²⁶ folate,²⁷ or arginine supplementation²⁸ has little effect. Goodman *et al.*²⁹ and others²³ have shown that once a nidus of calcification forms in the soft tissues, “calcium begets calcium” such that patients with preexisting calcification are at greatest risk for accelerated calcification. Thus, the prevention of secondary hyperparathyroidism from the earliest stages of CKD is key to preventing the development and progression of vascular calcification.

In young adults with childhood-onset CKD, Groothoff *et al.*³⁰ reported a significant increase in arterial stiffness but normal IMT, whereas a similar study by Oh *et al.*³¹ showed increased IMT and calcification in 92% of his cohort. However, these studies in young adults can support only speculations of the potential changes in children who are on dialysis because it is possible that uremia multiplies the natural age-related vascular damage. Evidence of vascular changes in children who are on dialysis has come from observational studies that have shown increased IMT,^{4–6} stiffer vessels,³ and calcification,^{2,29,32} and linked these with PO_4 levels and $\text{Ca} \times \text{PO}_4$; however, patients in these studies were older than in our cohort and often had comorbidity, and the small patient numbers and widely variable duration of CKD and time on dialysis may have resulted in confounders in their analyses.

The management of secondary hyperphosphatemia with use of calcium-based PO_4 binders has been under considerable debate with concerns that the Ca intake from PO_4 binders results in calcium overload and ectopic soft tissue calcification.^{4,11,12,14,29} This study was not designed to determine the vascular effects of different PO_4 binders; sevelamer was used only as a second-line agent in our patients with persistently high iPTH levels and hypercalcemia. Goodman *et al.*,²⁹ Litwin *et al.*,⁴ and Briese *et al.*³³ showed a positive correlation between the cumulative PO_4 binder dosage and coronary calcification or cIMT, and in our study, IMT showed a weak correlation with PO_4 binder dosage approaching statistical significance. However, adolescents and young adults are notoriously non-compliant with PO_4 binder medication, making it difficult to assume that the prescribed dosage of PO_4 binder is indeed what the patient consistently receives.

In our study, the vitamin D dosage was the most important

predictor of increased arterial thickness, stiffness, and calcification. Although the prescribed dosage of vitamin D is also a surrogate marker of the severity of hyperparathyroidism, the vitamin D dosage predicted vascular damage independent of iPTH levels. The role of vitamin D in the pathogenesis of vascular calcification has been shown in other observational studies^{4,5} as well as in *ex vivo*³⁴ and *in vitro* models.³⁵ Although the primary role of vitamin D is to increase the gastrointestinal absorption of calcium, it also significantly increases PO_4 absorption. Moreover, vitamin D acts on the vascular smooth muscle cells *via* the vitamin D receptor and can induce proliferation and osteoblastic differentiation of these cells.³⁵

We found a significant positive correlation among cIMT, aortic stiffness, and presence of cardiac calcification, suggesting that the vascular damage is widespread, involving both large muscular arteries such as the carotids and elastic vessels such as the aorta. Unlike aortic PWV, the brachioradial PWV, although increased, did not correlate with any demographic or biochemical parameter or with other vascular measures. It is known that vascular damage in the aorta begins earlier than in the brachioradial vasculature,²¹ suggesting that the lack of correlations with brachioradial changes may in fact be the result of dissociation in time rather than a difference in underlying pathology, as discussed in one other study.³⁶ A positive correlation between cIMT and calcification may suggest that deposition of Ca-PO_4 crystals in the arterial media may be at least partly responsible for the increased cIMT. Carotid artery ultrasound, a cheap, easily available, highly reproducible, and non-invasive test to measure cIMT, may reliably substitute other methods for detection, monitoring, and prognostication of vascular damage in dialysis patients.

On multiple regression analysis, the age at study or time spent in CKD or on dialysis did not show any significant correlation with the vascular measures. Although increased vascular damage with age and dialysis vintage has been reported,^{4,29–31} this may in fact be the result of prolonged hyperparathyroidism and its consequences on the vasculature. Goodman *et al.*²⁹ showed calcification only in patients who were older than 20 yr, but the group with calcification had significantly higher PO_4 and $\text{Ca} \times \text{PO}_4$ than those without calcification. Subsequent studies by Eifinger *et al.*³² and Civitali *et al.*² documented coronary calcification in pediatric dialysis patients. In our cohort, age did not correlate with any vascular measure: The youngest patient with calcification was 5.8 yr.

Although we were unable to perform a randomized study, the groups were well matched for cardiovascular risk factors. The iPTH assay varied among participating centers, and the inter-assay variability of various PTH assays must be recognized.³⁷ Because of small patient numbers, our study lacked the power to show any potential differences in vascular measures on the basis of dialysis modality. Pediatric dialysis populations are currently limited because of a high transplantation rate; in the largest comparable study,⁴ only 37 children were on dialysis.

In conclusion, we have shown that both the iPTH level and

the vitamin D dosage are significant and independent predictors of vascular damage and calcification in children who are on dialysis.

CONCISE METHODS

Study Design

Eighty-five children were recruited from four children's renal units in the United Kingdom. Children who were aged 5 to 18 yr, had received dialysis for at least the preceding 6 mo, and had been in stage 4 CKD (GFR ≤ 30 ml/min per 1.73 m²) for ≥ 3 yr were included. Patients with underlying vasculitis, diabetes, uncontrolled hyperlipidemia (serum cholesterol ≥ 5 mMol/L despite statin therapy), uncontrolled hypertension (systolic BP ≥ 95 th centile for age despite therapy), and smokers were excluded. Because vascular measures are age dependent and normative data are available only for children who were older than 10 yr,³⁸ we compared our patient group with 40 age- and gender-matched healthy control subjects who were studied contemporaneously.

A total of 103 eligible patients were identified, and 97 agreed to participate. Seven were excluded because of criteria identified at the first visit or unwillingness to undergo scans. Vascular measures were performed on 90 dialysis patients and 40 control subjects (five patients' scans were of poor quality and excluded from analysis). Informed written consent was obtained from all parents or caregivers and from children when appropriate. The study was approved by a multicenter research ethics committee.

CKD-specific cardiovascular risk factors were measured from the start of stage 4 CKD, giving a minimum of 3.5 yr of cumulative data for all children. Serum Ca, PO₄, and iPTH levels and the dosages of elemental calcium intake from phosphate binders and vitamin D were recorded at monthly intervals. Because the iPTH assay varied among centers, iPTH was expressed as multiples of the ULN. In control subjects, biochemical values from a single blood test at the time of the scans were used. Patients were divided into two groups on the basis of mean time-integrated serum iPTH levels: Group I with serum iPTH < 2 ULN and group II with iPTH > 2 ULN. Patients in group II included those for whom the unit policy was to aim for iPTH levels > 2 ULN and also those with noncompliance to treatment despite an intention to keep iPTH levels < 2 ULN. In all centers, calcium-based phosphate binders were used for management of hyperphosphatemia, with sevelamer introduced only for those with hypercalcemia and persistently high iPTH levels. Alphacalcidol (1- α hydroxyvitamin D₃) was used in all patients, titrating the dosage against iPTH levels, with temporary discontinuation when hypercalcemia resulted. All children received regular dietary advice.

All patients underwent a carotid artery ultrasound scan to measure cIMT, applanation tonometry for aortic and brachioradial PWV, and a multislice computed tomography (CT) scan to look for coronary artery and valvular calcification. In the control group, aortic PWV was not measured because permission was not granted for femoral artery measures, and CT was not undertaken because of radiation concerns.

All vascular scans were performed at Great Ormond Street Hospital after a midweek session of hemodialysis or overnight cycling peri-

toneal dialysis. Scans were performed by two trained operators who were blinded to the patients' clinical and biochemical details. Intraobserver and interobserver reproducibility of measurements (determined by measurement of cIMT and PWV twice, 2 wk apart in 10 randomly selected children) was 1.9 and 2.2 μ m, respectively, for cIMT and 0.11 and 0.23 m/s, respectively, for PWV.

Carotid Ultrasonography for cIMT

B-mode ultrasound of both common carotid arteries was performed (Vivid 7; GE Medical, Horton, Norway). On a longitudinal image of the vessel, 1 to 2 cm proximal to the carotid bulb, the optimal image was acquired on the R wave of the electrocardiogram (ECG) and frozen in diastole, and the distance between the leading edge of the lumen-intima interface and the media-adventitia interface on the far wall of the artery was measured using electronic calipers.

Applanation Tonometry for PWV

Applanation tonometry was performed with a micromanometer (SPC-301; Millar Instruments, Houston, TX) in the carotid, radial, and femoral arteries. An ECG gated signal and standard anthropometric measurements were used. PWV was computed from contour analysis of 10 consecutive pressure waveforms recorded consecutively in the carotid-radial and carotid-femoral arteries to give the brachioradial and aortic PWV, respectively.

Multislice-Spiral CT for Cardiac Imaging

A 16-slice spiral CT scan was performed (Somatom Sensation 16; Siemens Medical Solutions, Erlangen, Germany) using the standard calcium-scoring protocol (12-slice acquisition, 120 kV, 30 mAs, nominal slice width 3.0 mm, slice collimation 1.5 mm, gantry rotation time 0.42 s, and table feed 5.6 mm/rotation) and prospective ECG triggering. The Agatston score was determined for coronary arteries, cardiac valves, and aorta using standard methods.³⁹

Statistical Analyses

Results are presented as means \pm SD. All data were analyzed in a linear manner and then between the two groups of dialysis patients. The *t* test, Mann-Whitney *U* test, or Fisher exact *t* test was used as appropriate. From univariate analysis, variables that were associated with vascular measures with $P < 0.15$ were entered into a stepwise multiple regression analysis. $P \leq 0.05$ was considered statistically significant. Statistical analyses were performed using SPSS 12.0.1 (SPSS, Chicago, IL).

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DISCLOSURES

None.

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