Pulse wave velocity in children following renal transplantation

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Abstract

Background. Arterial stiffness (ASt) increases with age, a process accelerated by uraemia and reversed by transplantation (Tx). Increased ASt results in an elevated pulse wave velocity (PWV).

Methods. To compare the PWV of Tx patients (n = 25, age = 15.1/95% CI = 13.5–16.7/year) and healthy controls, three control groups were formed: matched for age (A), for height and weight (H/W) and for age and height (A/H), respectively. To avoid bias from the growth deficit of Tx, firstly Z-scores of PWV were calculated (PWV -Z). Second, the PWV/height (PWV/h) ratio was assessed. Pre-Tx serum Ca, P, PTH and the cumulative dose of calcitriol (cCTL) were also analysed. Finally, Tx patients were compared to ESRD patients (n = 11). PWV was measured by applanation tonometry.

Results. Tx were smaller than A and older than H/W. The PWV of Tx differed only from H/W and A/H. PWV -Z and PWV/h of Tx were increased compared to all control groups. They correlated with the Ca×P and cCTL before Tx and were independent of age. Patients with creatinine clearance >90 ml/min/1.73 m² or <1 year on dialysis had lower PWV-Z and PWV/h than ESRD.

Conclusion. Controls that matched for both age and height should be used to assess PWV in children with growth failure. PWV-Z is a universal age-independent parameter of PWV in cases of growth retardation; PWV/h is a simple alternative of PWV-Z. Ca×P and cCTL are major determinants of ASt after Tx. PWV may be reduced after Tx suggesting that the uraemia-induced cardiovascular changes might be reversible.

Keywords: arterial stiffness; calcitriol; growth failure; pulse wave velocity; transplantation

Introduction

Cardiovascular disease is the leading cause of morbidity and mortality among patients with end-stage renal disease (ESRD) [1]. The aetiology is multifactorial, including alterations of calcium-phosphate homeostasis, lipid metabolism, chronic inflammation, systemic hypertension and anaemia, leading together to arteriosclerosis, atherosclerosis and left ventricular hypertrophy [2–5].

Early arteriosclerosis has recently been described in children with ESRD [6–8] or renal transplantation [9].

Tx may reduce the overall cardiovascular risk caused by uraemia by slowing down and/or even reversing the pathological processes [10].

One consequence of the changes of the arteries in uraemia is an increase of the arterial wall stiffness. Information on ASt can be obtained from the measurement of the pulse wave velocity (PWV) [11,12].

Previously we established the normal values of PWV in children. We also described increased PWV in children with ESRD [13].

The aim of the present study was first to evaluate PWV in children who underwent Tx, to assess which form of PWV is most suitable in patients after Tx.

Our second goal was to evaluate the determinants of PWV in Tx patients. For this, known cardiovascular risk factors such as blood pressure (BP), calcium (Ca), phosphate (P) and parathyroid hormone (iPTH) levels as well as the cumulative dose of calcitriol were analysed.

Finally, we compared PWV of the Tx patients of the present study to similar data of patients with ESRD studied previously [13].

Subjects and methods

Patients

Transplanted patients. Twenty-five transplanted patients (aged 15.1/95% CI = 13.5–16.7/year, 15 males) were examined.

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Table 1. Clinical characteristics of transplanted patients (Tx) and the healthy controls

<table>
<thead>
<tr>
<th>Age group (years)</th>
<th>PWV (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 to &lt;8</td>
<td>7.3 (7.2–7.5)</td>
</tr>
<tr>
<td>8 to &lt;10</td>
<td>9.1 (8.9–9.2)</td>
</tr>
<tr>
<td>10 to &lt;13</td>
<td>11.2 (10.9–11.4)</td>
</tr>
<tr>
<td>13 to &lt;16</td>
<td>14.7 (14.5–15.0)</td>
</tr>
<tr>
<td>16 to &lt;19</td>
<td>17.5 (17.1–17.8)</td>
</tr>
<tr>
<td>19 to &lt;21</td>
<td>20.3 (19.3–21.3)</td>
</tr>
</tbody>
</table>

Data shown as mean (95% CI).

The time spent on dialysis prior to Tx was 9 (0–60) months [median (range)]. Three of them were transplanted pre-emptively.

The diagnoses leading to ESRD were (number of patients in parentheses) focal segmental glomerulosclerosis (9), polycystic kidney disease (4), renal hypoplasia (3), Prune Belly syndrome (2), vesicoureteric reflux and renal scarring (4), chronic tubulointerstitial nephritis (2) and nephrocalcinosis (1).

Seventeen patients had hypertension and received antihypertensive treatment. The diagnosis of hypertension was established previously [13]. To assess the effect of sustained hypertension on PWV, we divided the Tx patients into groups, according to the time spent on dialysis (cutting point: >1 year on dialysis, data shown in Table 5) and according to the GFR (cutting point: clearance of creatinine (CCI) <90 ml/min/1.73 m², data shown in Table 6).

Patients with chronic renal failure. We compared PWV of the Tx patients to similar data of 11 patients with ESRD studied previously [13]. To assess the effect of sustained hypertension on PWV, we divided the Tx patients into groups, according to the time spent on dialysis (cutting point: >1 year on dialysis, data shown in Table 5) and according to the GFR (cutting point: clearance of creatinine (CCI) <90 ml/min/1.73 m², data shown in Table 6).

Control group. The database of 133 healthy controls established previously [13] was expanded; altogether, data from 188 healthy subjects aged 6–23 years were included in this study.

Using this database, three subgroups of children were formed (n = 25). The controls were chosen pairwise for each individual transplanted patient. The healthy pairs in the first group were adjusted to the patients’ age and gender (A); children with date of birth closest to the patients’ data were selected. The second control group was adjusted to height, weight and gender (H/W) in a similar manner; children with height and weight closest to the patients’ values were selected. The third control group was adjusted to age, height and gender (A/H); children with age and height closest to the patients’ values were selected.

The basic characteristics of the patients and the control groups are shown in Table 1.

In search of a more universal technique for the comparison between children of different age groups and with different body dimensions, two methods were assessed.

First, age-dependent means and confidence intervals of PWV of the normal population were calculated for six age groups (6 to <8, 8 to <10, 10 to <13, 13 to <16, 16 to <19, 19 to <21).
Table 3. Simple and multiple linear regression analysis of PWV and age, weight, height, systolic, diastolic blood pressure and heart rate in 188 healthy children and young adults

<table>
<thead>
<tr>
<th></th>
<th>Simple regression analysis</th>
<th>Multiple regression analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ß</td>
<td>CI</td>
</tr>
<tr>
<td>Age (years)</td>
<td>0.6</td>
<td>0.49–0.72</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>0.51</td>
<td>0.38–0.63</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>0.44</td>
<td>0.31–0.57</td>
</tr>
<tr>
<td>RRsys (mmHg)</td>
<td>0.45</td>
<td>0.32–0.58</td>
</tr>
<tr>
<td>RRdia (mmHg)</td>
<td>0.27</td>
<td>0.13–0.41</td>
</tr>
<tr>
<td>HR (1/min)</td>
<td>−0.29</td>
<td>−0.43–(−0.15)</td>
</tr>
</tbody>
</table>

RRsys, systolic blood pressure; RRdia, diastolic blood pressure; HR, heart rate.

Table 4. Laboratory data of the transplanted (Tx) patients before Tx, 12 months after Tx and at the PWV measurement

<table>
<thead>
<tr>
<th>Btx</th>
<th>Tx12</th>
<th>Mtx</th>
<th>*P &lt; Tx12 versus BTx</th>
<th>#P &lt; MTx versus BTx</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>10.3 (9.1–11.6)</td>
<td>11.5 (10.3–12.7)*</td>
<td>15.1 (13.7–16.6)*</td>
<td>NS</td>
</tr>
<tr>
<td>Serum Ca (mmol/l)</td>
<td>2.41 (2.30–2.51)</td>
<td>2.53 (2.46–2.59)</td>
<td>2.50 (2.44–2.56)</td>
<td>NS</td>
</tr>
<tr>
<td>Serum P (mmol/l)</td>
<td>1.95 (1.68–2.19)</td>
<td>1.49 (1.40–1.59)*</td>
<td>1.45 (1.33–1.57)#</td>
<td>0.05</td>
</tr>
<tr>
<td>Ca×P (mmol²/mmol)</td>
<td>4.67 (4.01–5.32)</td>
<td>3.77 (3.54–4.00)*</td>
<td>3.62 (3.33–3.91)#</td>
<td>0.05</td>
</tr>
<tr>
<td>iPTH (pg/ml)</td>
<td>311 (134–488)</td>
<td>44 (27–62)*</td>
<td>51 (35–68)#</td>
<td>0.05</td>
</tr>
<tr>
<td>Creatinine (µmol/l)</td>
<td>641 (580–702)</td>
<td>97 (81–124)*</td>
<td>105 (86–124)*</td>
<td>0.001</td>
</tr>
</tbody>
</table>

Btx, data before transplantation; Tx 12, data 1 year after transplantation; MTx, data at the measurement. Data are shown as mean (95% CI).

Table 5. Effect of the clearance of creatinine (CCl) on PWV

<table>
<thead>
<tr>
<th></th>
<th>Tx (n = 25)</th>
<th>ESRD (n = 11)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Groups</td>
<td>First group &gt;90 ml/min/1.73 m²</td>
<td>Second group &lt;90 ml/min/1.73 m²</td>
</tr>
<tr>
<td></td>
<td>(n = 13)</td>
<td>(n = 12)</td>
</tr>
<tr>
<td>Age (years)</td>
<td>14.9 (13.4–16.4)</td>
<td>15.0 (11.6–18.5)</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>153 (146–160)</td>
<td>141 (131–152)#</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>49.2 (41.5–56.9)*</td>
<td>45.1 (36.5–53.6)</td>
</tr>
<tr>
<td>CCl (ml/min/1.73 m²)</td>
<td>100.5 (90.8–125.6)*</td>
<td>65.3 (54.0–76.1)*</td>
</tr>
<tr>
<td>Height-Z</td>
<td>−0.58 [−0.76–(−0.31)]</td>
<td>−0.66 [−0.96–(−0.36)]</td>
</tr>
<tr>
<td>Weight-Z</td>
<td>−0.16 [−0.33–(−0.01)]</td>
<td>−0.23 [−0.39–(−0.08)]</td>
</tr>
<tr>
<td>Time on dialysis (months)</td>
<td>8 (0–60)</td>
<td>18 (0–36)</td>
</tr>
<tr>
<td>PWV (m/s)</td>
<td>5.30 (4.86–5.74)**</td>
<td>5.58 (5.16–6.01)</td>
</tr>
<tr>
<td>PWV-Z</td>
<td>0.67 (0.02–1.32)**</td>
<td>1.46 (0.83–2.09)#</td>
</tr>
<tr>
<td>PWV/h (1/s)</td>
<td>3.47 (3.19–3.76)**</td>
<td>3.98 (3.64–4.32)#</td>
</tr>
</tbody>
</table>

Tx, transplanted patients; ESRD, end-stage renal disease; Height-Z, height Z-score; Weight-Z, weight Z-score; PWV-Z, Z-score of PWV; Z-score, standard deviation score; PWV/h, PWV/height; CCl, clearance of creatinine according to Schwartz [19].

Data are shown as mean (95% CI) except for the time on dialysis that is given as median (range).

* P < 0.001 first group or second group versus ESRD.
** P < 0.05 first group versus ESRD.
# P < 0.05 first versus second group.
§ data from [13].

and 19 to <21-year-old children and young adults) according to Cheung et al. [15]. Thereafter, the height ages of the patients were assessed by means of standard growth charts [16]. Height age was defined as the age corresponding to the 50th percentile height value identical to the patient’s height. Finally, PWV standard deviation scores (PWV Z-scores) normalized for height age in the patient population were calculated using the control PWV data for age (Table 2).

The Z-scores of PWV (PWV-Z) of the A, H/W and A/H controls were calculated similarly.

The second method was based on preliminary analyses by univariate regression analysis to identify determinants of PWV that revealed age, height and weight as highly significant factors. Thus, to find an age-independent variable for PWV, the relation of the ratios of PWV to age, height, weight and body surface area (BSA) was assessed.
Methods

**PWV measurement.** PWV was measured by applanation tonometry [17] using the PulsePen device (DiaTecne s.r.l., Milan, Italy) [18] interfaced with a computer—as described previously [13].

The probe was connected to a hand-held ECG unit. The pressure and electrocardiographic signals were transmitted to a computer. The pulse wave was calibrated by measuring BP immediately after each recording. The software provides absolute arterial pressure values, an assessment of arterial pulse wave contours, an estimation of reflection waves and measurements of PWV.

Aortic PWV was measured by sequential recordings of the arterial pressure wave at the carotid and femoral arteries, and by measurement of the distance from the carotid sampling site to the suprasternal notch and from the suprasternal notch to the femoral sampling site. Aortic PWV is defined as the distance of the sampling sites divided by the time difference between the rise delay of the distal and proximal pulse belonging to the ECG qRs complex, and is calculated by the software.

All measurements were done twice to confirm reproducibility. The intra-observer coefficient was 5.7%. We discarded recordings when the systolic or diastolic variability of consecutive waveforms was >10% or when the amplitude of the pulse wave signal was <80 mV.

All measurements were performed by O.C. and E.K. The inter-observer coefficient of variation was 6.1%.

**Laboratory and clinical data.** Data of serum Ca, P, iPTH and creatinine were reviewed retrospectively before and twelve months after Tx. A cross-sectional evaluation was performed, and CCl was calculated at the time of PWV measurement according to Schwartz et al. [19].

Serum Ca, P and creatinine were measured by routine laboratory methods. Intact parathyroid hormone (1–84) was determined by an immunochemiluminometric two-site assay (CIBA-CORNING, Frenwald, Germany).

Cumulative doses of calcitriol and time on dialysis were assessed as additional risk factors for AS.

**Statistical analysis.** Database analysis was performed using the STATISTICA 7.1 software (Stat Soft., Inc., USA). Data are presented as mean and 95% confidence intervals (CI) unless indicated otherwise.

Laboratory data were compared by Student’s t-test or analysis of the variance (ANOVA) where appropriate. The Mann–Whitney U-test was used to compare data with non-normal distribution. Univariate regression analysis was applied to assess the associations between PWV-Z, PWV/h and the clinical data. The factors influencing PWV in healthy patients and in the Tx group were assessed by standard (all at once) multiple regression analysis. A ‘P’-value of <0.05 was considered as statistically significant.

**Ethics**

The study was conform to the Helsinki declaration and was approved by the local ethical committee. Parental informed consent was obtained from all subjects participating in the study.

**Results**

**Healthy controls**

In this healthy population, the PWV values did not differ significantly between male and female subjects at any given age, permitting us to pool the data for further analysis [males versus females, 4.89 (4.65–5.08) versus 4.98 (4.84–5.12) m/s, P = NS].

The mean PWV of the 188 healthy children was 4.93 (4.81–5.05) m/s. There was a linear correlation of PWV with age, height, weight, SBP and DBP and a negative correlation with the heart rate. By multivariate analysis, only age remained the significant determinant of PWV in healthy children (Table 3).
Transplanted patients

Method assessment. As shown in Table 1, Tx patients were smaller and lighter than A both in absolute terms or if expressed as height and weight Z-scores (height-Z; weight-Z); furthermore, they were older than the H/W controls. There was no difference between the anthropometric data of Tx and A/H. There was no difference between the BMI of Tx and the controls. ESRD patients had a slightly lower BMI Z-score (BMI-Z) than Tx; however, both were within limits of the normal \([-0.08 \sim 0.20\) versus 0.07 (0.00 to 0.16), \(P < 0.05\)] indicating the absence of significant malnutrition in the patient groups.

Although within the normal range, the systolic BP of Tx was higher than that of the control groups, the diastolic BP differed only from the H/W and A/H controls. Tx had an increased HR compared to A.

The PWV of Tx patients did not differ from A; however, they had increased PWV values compared to H/W and A/H.

The PWV-Z of Tx differed from the corresponding PWV-Z of all control groups. There was no difference between the PWV-Z values of A, H/W and A/H groups (Table 1).

Dividing PWV by age (\(\beta = -0.79 /-0.88\) to -0.70, \(P < 0.001\)), weight (\(\beta = -0.63 /-0.74\) to -0.51, \(P < 0.001\)) or BSA (\(\beta = -0.51 /-0.64\) to -0.39, \(P < 0.001\)) did not suppress the age dependence of the indexed variables. However, the age dependence disappeared completely after dividing PWV by height (PWV/h, \(\beta = -0.09 /-0.23\) to -0.06, \(P = \text{NS}\)).

PWV/h of Tx differed significantly from A, H/W and A/H as well as from the whole control group. There was no difference between PWV/h of A, H/W and A/H (Table 1).

There was a highly significant correlation between values of PWV-Z and PWV/h (\(\beta = 0.88 /0.79-0.94\)/ \(<0.00001\)).

Determinants of PWV in Tx patients. The laboratory data of the Tx patients are shown in Table 4.

Ca did not change after Tx; creatinine, \(P\) and \(Ca \times P\) as well as iPTH decreased significantly. The laboratory parameters at the evaluation 1 year after transplantation (Tx12) were similar to those at the last control, at the time of the PWV measurement (mTx).

There was a positive correlation between both the PWV-Z and PWV/h values and the calcium × phosphate product (Ca×P) before Tx (\(\beta = 0.56 /0.13-0.98\)/ \(P = 0.03\) and \(\beta = 0.58 /0.16-0.99\)/ \(P = 0.03\), respectively) and the cumulative dose of calcitriol administered during ESRD before Tx (\(\beta = 0.83 /0.5-1.15\)/ \(P = 0.0009\) and \(\beta = 0.81 /0.47-1.14\)/ \(P = 0.002\), respectively).

By multivariate regression analysis, the cumulative dose of calcitriol was the main factor that influenced Ast following Tx (\(\beta = 0.734 /0.33-1.09\)/ \(P = 0.01\) and \(\beta = 0.58 /0.28-0.89\)/ \(P = 0.01\) for PWV-Z and PWV/h, respectively).

There was no correlation between PWV-Z and PWV/h and the pre- and post-transplantation \(P\), iPTH, systolic or diastolic BP Z-score, heart rate.

PWV data of the Tx patients compared to similar data of patients with ESRD studied previously [13]. As shown in Table 5, patients with a \(CCI < 90 \text{ ml/min/1.73 m}^2\) had lower PWV-Z and PWV/h than those with \(CCI > 90 \text{ ml/min/1.73 m}^2\) or the ESRD population. There was no difference between the \(CCI < 90 \text{ ml/min/1.73 m}^2\) group and the ESRD population [13].

Patients with a dialysis time <1 year had lower PWV-Z and PWV/h than the ESRD patients [13] (Table 6).

Discussion

Uraemia increases the risk of cardiovascular mortality due to accelerated arteriosclerosis [20]. Studies in adults after renal transplantation have demonstrated that cardiovascular morbidity and mortality decrease dramatically compared to ESRD; however, they still remain at least 3–5 times higher than those in the general population [1]. Premature vascular calcification is present already in children with ESRD and also following Tx [8,21,22].

PWV is a useful parameter of Ast in adult hypertension and ESRD [23–25]; however, data in uraemic children are scarce [7,13,26].

In a study on 14 children on haemodialysis, Covic et al. found increased PWV compared to healthy age- and height-matched children [26].

In a previous study, we could confirm increased PWV in children on dialysis. However, only a weak tendency of increased PWV in ESRD could be demonstrated compared to age-matched healthy children. However, our patients' height was significantly below that of the controls, due to the effect of uraemia on growth. Thus, by using height- and weight-matched controls we did find a significantly increased PWV in ESRD [13]. The bias of growth retardation could also be avoided by using the age-independent PWV/h, in other words by normalizing PWV to height [13].

The use of controls matched by height is a well-established necessity in paediatrics. Bone mineral density and BP are examples where reference to height is necessary rather than the automated use of age-matched controls [27–30].

Evidence that the dimensions of the arterial tree are intimately related to height are provided by morphological studies [31,32]. The physiological basis of the influence of body size on the arterial wall properties was provided by Senzaki et al. who established reference ranges for age-associated changes in arterial pulsatile properties in children. Arterial compliance of the proximal aorta was estimated by cardiac catheterization in 112 paediatric patients (age 6 months to 20 years). They found a progressive increase in arterial compliance, a comprehensive measure of arterial buffering capacity, despite a decrease in arterial wall elasticity. They concluded that the increase in arterial size that accompanies the increased body size outweighs the effects of age on intrinsic elastic properties of arterial walls [33].

Further evidence on the influence of body dimensions on the elastic properties of the arteries was given by Jourdan et al., who performed sono graphic evaluation of arterial wall morphology and elasticity and assessed the interacting anthropometric factors in 247 healthy subjects aged 10–20 years. They concluded that both intima–media thickness and Ast change with age and body size and that morphological and functional measures of large arteries
should be normalized to take account of changes during adolescence [34].

In the present study, using identical technical equipment as previously [13], we were able to confirm an increased PWV in the Tx population compared to the height/weight and age/height-matched controls. However, similar to our ESRD study, the difference from the age-matched control group did not reach the level of significance due to the height deficit of the Tx population.

We used two methods to eliminate the bias caused by the growth retardation.

First, we calculated the normalized (height–age related) PWV-Z of the patient population using the normal values of 188 healthy children.

Secondly, we normalized PWV to height and compared the PWV/h to the more sophisticated PWV-Z.

By using PWV-Z and the PWV/h ratio, a significant difference between Tx and the control groups was found. We could also confirm that a shorter period of ESRD goes hand in hand with both lower PWV-Z and PWV/h, whereas Tx children dialysed for >1 year had values similar to those actually on dialysis. These results are in accordance with data from adults demonstrating a positive effect of early Tx on the cardiovascular system [35–37].

Similarly, patients with a better renal function had lower PWV-Z and PWV/h than children with poor CCl, who did not differ from the ESRD population on dialysis [13].

Disturbed calcium and phosphate metabolism are among the main factors leading to vascular calcification in uraemic adults and children [7,8,38–41].

Our patients had elevated levels of creatinine, P, iPTH and increased Ca × P prior to Tx that decreased following Tx. Analysing the factors involved in the increased PWV of Tx, we found close correlations between both PWV-Z and PWV/h and the pretransplant calcium–phosphate product as well as the cumulative dose of calcitriol prior to Tx. By multivariate analysis, the cumulative dose of calcitriol was the main determinant of both PWV-Z and PWV/h. There was no correlation between any of these parameters and PWV-Z or PWV/h following Tx.

Our data revealing a direct connection between the PWV-Z and PWV/h and the calcium–phosphate metabolism prior to Tx indicate that the ‘curaemic burden’ prior to Tx determines the properties of the arterial wall even long after Tx.

Endothelial dysfunction, due to low levels of 25-hydroxyvitamin D, has been suggested to be responsible for increased AST in adult patients with ESRD. According to London et al., the higher the serum 25-hydroxyvitamin D and 1,25-dihydroxyvitamin D levels, the lower the central PWV in ESRD patients without vitamin D supplementation [42]. Although levels of vitamin D were not measured in this study, our data strongly suggest that pharmacological doses of calcitriol may lead to an elevated cardiovascular risk in children with ESRD, and that the present form of management of secondary hyperparathyroidism is far from optimal [43].

Although within the normal range, Tx patients had higher SBP and HR than the controls, there was no correlation between the BP or HR and PWV-Z and PWV/h. This could be explained by the fact that the BP was controlled by antihypertensive drugs if necessary, aiming to hold the BP below the 90th percentile. Furthermore, the BP measured following Tx did not reflect the long-lasting effect of hypertension during the ESRD period.

A confounding factor influencing PWV might be the use of antihypertensive drugs. However, ACE inhibitors and calcium channel blockers are known to decrease PWV [44–46]. Thus, our patients had increased PWV despite the possible positive effect of antihypertensive treatment. A withdrawal of the antihypertensive drugs was not considered for ethical reasons.

Limitations

The relatively small sample size and the retrospective and cross-sectional design of the study are serious obstacles to a more detailed analysis.

It does not allow us to assess further parameters of interest like the role of cholesterol especially in patients with steroid-resistant nephrotic syndrome. Instead, it gives a snapshot of the individual parameters and does not necessarily reflect the whole atherogenic burden inflicted during the development of the ESRD by the single parameters studied.

As individual paediatric nephrology units have a limited number of patients as compared to adult facilities, a multicentre prospective approach is needed to establish the biological significance of the results.

Conclusion

This study demonstrates elevated PWV as a sign of increased AST in children with Tx. It also points to the necessity of appropriate controls in special paediatric populations. Thus controls matched for both age and height should be used to assess PWV in children with growth failure. The PWV normalized for height age (i.e. PWV-Z) provides a more universal parameter to avoid the bias caused by growth retardation. As the PWV-Z and PWV/h are closely related, PWV/h is an alternative, simple, age-independent measure of PWV.

Ca × P and the cumulative dose of calcitriol are closely related to increased AST.

After successful Tx, PWV is found to be lower than that in dialysed patients, which could imply that vascular changes in children are reversible; however, follow-up studies are needed to prove this hypothesis.

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Conflict of interest statement. None declared.

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