Reference ranges for plasma cystatin C and creatinine measurements in premature infants, neonates, and older children


Abstract

Aim—To establish a reference range in the paediatric population for the new glomerular filtration rate (GFR) marker, cystatin C, and to compare it with that of creatinine.

Methods—Cystatin C and creatinine were measured by particle enhanced nephelometric immunoassay (PENIA) and fixed interval Jaffé methods, respectively, in 291 children aged 1 day to 17 years, including 30 premature infants with gestational ages ranging from 24 to 36 weeks.

Results—In the premature infants, concentrations of both cystatin C and creatinine were significantly raised compared with term infants, with cystatin C concentrations being between 1.10 and 2.06 mg/litre and creatinine between 32 and 133 µmol/litre. In premature infants, there was no significant relation between gestational age and cystatin C or creatinine concentration. Creatinine concentrations fell to a nadir at 4 months of age, rising gradually to adult values by about 15–17 years of age, in contrast to cystatin C, which fell to a mean concentration of 0.80 mg/litre by the 1st year of life, and remained constant throughout adulthood up to the age of 50 years. Neither analyte showed any influence of sex.

Conclusion—The measurement of cystatin C, rather than creatinine, is more practical for monitoring GFR changes in the paediatric population.

Materials and methods

Creatinine

We measured serum and plasma creatinine concentrations using a fixed interval Jaffé method performed on the Monarch 2000 (Instrumentation Laboratory, Warrington, UK) with reagents supplied by the manufacturer. The method was calibrated using ReferII, A Calibrator (catalogue number 35261), an aqueous solution for creatinine calibration, on the Monarch 2000. We used Nycomed (Oslo, Norway) low, medium, and
high control materials for quality control. We obtained published age related reference ranges for creatinine via a literature search.\textsuperscript{14–24}

**CYSTATIN C**

We measured serum and plasma cystatin C concentrations using latex particle enhanced immunoassays; for the term neonates and the remaining children’s samples we performed the assay on the BNA (Behring Nephelometer Analyser; Dade Behring Marburg GmbH, Marburg, Germany).\textsuperscript{8} However, for the preterm infants, we used an in house assay validated as described previously\textsuperscript{7} because these samples were analysed before the BNA assay became available. The results of the in house assay have been shown to be directly comparable to the Dade Behring method.\textsuperscript{4} We calibrated both methods using a standard supplied by Dade Behring, made with purified cystatin C from human urine, and the value assigned by amino acid analysis. We used lyophilised cystatin C control sera from Dade Behring as the quality control material.

**PATIENTS**

Paediatric serum samples were collected from the routine biochemistry laboratory of the Royal London Hospital after the requested tests had been completed. All samples had been refrigerated by the laboratory within six hours of being collected. Upon collection for this study, all samples were immediately aliquoted into 1.5 ml polypropylene tubes and frozen to \(-70^\circ\text{C}\). The criteria for collecting the samples was that the patients were below the age of 19 years, that their electrolytes and renal function test results (creatinine and urea) were normal, and that they were in hospital because of an accident or minor surgery. Plasma samples, which were collected daily and stored at 4\(^{\circ}\text{C}\) before being sent, were also received from the Birmingham Children’s Hospital and immediately frozen upon receipt. Altogether 244 patient samples were collected; there were 112 female patients and 132 male patients, with ages ranging from 2 days to 17 years.

A further 47 plasma samples were collected from newborn infants who were in the neonatal unit or postnatal wards at the Royal London Hospital. Seventeen of these infants were 7 days old having been born at term. Thirty babies were 1 day old premature infants, 16 had been born at 24–28 weeks’ gestation, and 14 at 29–36 weeks’ gestation. Most infants born at 24–28 weeks’ gestation required ventilatory support, but were otherwise healthy. None was asphyxiated at birth, defined as an Apgar \(<5\) at five minutes or a cord pH \(<7.2\) at delivery, or had received nephrotoxic medication, and none was known clinically to have a specific renal abnormality. The gestational age was calculated from the first day of the mother’s last period, confirmed by ultrasound scans. Our study was approved by the ethics committee of the Royal London Hospital Trust. In total, there were 291 patient samples collected for our study.

**STATISTICAL ANALYSIS**

We performed all statistical analyses using the “Astute” statistical package (Diagnostic Development Unit, University of Leeds, UK). We performed tests of normality by means of the Kolmogorov-Smirnov and Anderson Darling tests, taking \(p < 0.05\) as a significant result. The Mann-Whitney U test was used, with \(p < 0.05\) taken as a significant result.

**Reference intervals**

The reference intervals for cystatin C were calculated using the mean (2 SD) of the log transformed data and for creatinine by using the 95th centiles of the untransformed data.

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**Figure 1** Box plot distributions showing (A) cystatin C and (B) creatinine values (10th, 25th, 50th, 75th, and 90th centiles) across the age groups. The categories of 24–28 and 29–36 weeks refer to the gestational ages of preterm babies. Dotted lines indicate 95\% confidence interval of adult range.\textsuperscript{19} Preterm babies born between 24–36 weeks’ gestation were 1 day old when samples were taken.
Reference ranges for plasma cystatin C and creatinine

†Includes term neonates whose sex was not categorised.

*Gestational age.

Creatinine reference intervals are non-parametric (median) with 2.5 to 97.5 centile range. Cystatin C reference intervals are parametric (mean (2 SD)) after log transformation.

The between batch coefficients of variation (n = 10) of the quality controls (QC) for each method were as follows: Jaffe creatinine (µmol/litre): low QC, 10.1% (mean, 50.1; SD, 5.3); medium QC, 1.3% (mean, 196.9; SD, 2.6); and high QC, 1.3% (mean, 485.1; SD, 6.1); PENIA creatatin C (mg/litre): QC, 2.6% (mean, 1.28; SD, 0.034).

The frequency distributions for cystatin C and creatinine were both non-Gaussian, even when separated by sex. Only cystatin C values reverted to a Gaussian distribution after log transformation. Neither of the analytes showed any significant sex differences using the Mann-Whitney test. Figure 1 shows box plot distributions of analyte concentrations across the age groups. Cystatin C concentrations were highest in premature and full term neonates, and gradually declined with increasing age until about 1 year, when adult values were reached (fig 1A). Creatinine concentrations were also highest in the premature and full term neonates during the 1st week of life, then dropped to approximately 40 µmol/litre, resulting in a very wide variation in values, followed by a progressive increase to adult concentrations during adolescence (fig 1B). The largest creatinine increases occurred at 9–17 years of age, the 1st month of life, greatly reducing the value of creatinine as an index of GFR in infants. Creatinine concentrations remained constant until 2 years of age, at which point they were seen to rise to adolescent values, in agreement with the findings of Schwartz et al.14

Table 1 Summary of reference range data obtained

<table>
<thead>
<tr>
<th>Age</th>
<th>All</th>
<th>Girls</th>
<th>Boys</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>Mean/median (range)</td>
<td>n</td>
</tr>
<tr>
<td>Cystatin C (mg/litre)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>24–28 weeks*</td>
<td>16</td>
<td>1.48 (0.65–3.37)</td>
<td>–</td>
</tr>
<tr>
<td>29–36 weeks*</td>
<td>14</td>
<td>1.65 (0.62–4.42)</td>
<td>–</td>
</tr>
<tr>
<td>0–3 months</td>
<td>50†</td>
<td>1.37 (0.81–2.32)</td>
<td>14</td>
</tr>
<tr>
<td>4–11 months</td>
<td>29</td>
<td>0.98 (0.65–1.49)</td>
<td>12</td>
</tr>
<tr>
<td>1–3 years</td>
<td>53</td>
<td>0.79 (0.50–1.25)</td>
<td>27</td>
</tr>
<tr>
<td>4–8 years</td>
<td>70</td>
<td>0.80 (0.49–1.29)</td>
<td>32</td>
</tr>
<tr>
<td>9–17 years</td>
<td>59</td>
<td>0.82 (0.53–1.29)</td>
<td>27</td>
</tr>
<tr>
<td>24–36 weeks*</td>
<td>30</td>
<td>1.56 (0.43–2.77)</td>
<td>–</td>
</tr>
<tr>
<td>&lt; 1 year</td>
<td>79†</td>
<td>1.20 (0.59–1.97)</td>
<td>34</td>
</tr>
<tr>
<td>1–17 years</td>
<td>182</td>
<td>0.80 (0.50–1.27)</td>
<td>87</td>
</tr>
<tr>
<td>Creatinine (µmol/litre)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>24–28 weeks*</td>
<td>16</td>
<td>78 (35–136)</td>
<td>–</td>
</tr>
<tr>
<td>29–36 weeks*</td>
<td>14</td>
<td>75 (27–175)</td>
<td>–</td>
</tr>
<tr>
<td>0–3 months</td>
<td>46†</td>
<td>47 (23–127)</td>
<td>11</td>
</tr>
<tr>
<td>4–11 months</td>
<td>29</td>
<td>42 (32–100)</td>
<td>12</td>
</tr>
<tr>
<td>1–3 years</td>
<td>53</td>
<td>45 (33–60)</td>
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<tr>
<td>4–8 years</td>
<td>70</td>
<td>57 (40–82)</td>
<td>32</td>
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<tr>
<td>9–17 years</td>
<td>59</td>
<td>66 (46–94)</td>
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</tr>
<tr>
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Creatinine reference intervals are non-parametric (median) with 2.5 to 97.5 centile range.

*Gestational age.
†Includes term neonates whose sex was not categorised.

Results
The between batch coefficient of variation (n = 10) of the quality controls (QC) for each method were as follows: Jaffe creatinine (µmol/litre): low QC, 10.1% (mean, 50.1; SD, 5.3); medium QC, 1.3% (mean, 196.9; SD, 2.6); and high QC, 1.3% (mean, 485.1; SD, 6.1); PENIA cystatin C (mg/litre): QC, 2.6% (mean, 1.28; SD, 0.034).

Discussion
This is one of the first studies to assess kidney function in premature infants and children using the new GFR marker, cystatin C. Although serum creatinine is the most widely used marker of renal function, it is insensitive to small changes in renal function and is proportional to muscle mass and body weight, which increase with growth. Cystatin C concentrations are unaffected by these physiological variables and might therefore reflect GFR more closely in the paediatric population.

We have compared creatinine and cystatin C values in children and adolescents, ranging from 24 weeks premature to 17 years of age. The creatinine concentrations across the age groups (fig 1B) confirmed the results of others, with high creatinine values at birth and during the 1st week of life, which then decreased to approximately 40 µmol/litre. A study by Feldman and Guignard17 showed that there was a wide range of creatinine values during the first 5 days of life in infants born at 30–40 weeks. These high creatinine concentrations at birth, possibly of maternal origin, declined dramatically during the 1st month of life, greatly reducing the value of creatinine as an index of GFR in infants. Creatinine concentrations remained constant until 2 years of age, at which point they were seen to rise to adolescent values, in agreement with the findings of Schwartz et al.14

Newborn infants have a
muscle mass that is 24% of body weight, and growth in infancy is not associated with a major change in the proportion of muscle mass. During childhood, accretion of muscle mass exceeds the increase in body weight so that by 11 to 13 years, 39% of body weight is muscle, approaching the value of 43% in male adults.

GFR measurement, by \( ^{51}\text{Cr}-\text{EDTA} \) clearance, has been shown to reach adult values of 114 ml/min/1.73 m\(^2\) by 18 months, and then to be constant up to 17 years.\(^{26}\) This makes the measurement of serum creatinine unreliable when its concentration rises continuously because of an increase in muscle mass. The cystatin C values in our study (fig 1A) mirror the reported GFR, falling to within the adult range by 1 year. Cystatin C is raised preterm until birth; the maternal contribution of cystatin C is unknown.

It has been shown that GFR increases with postconceptional age at a rate that accelerates with maturation.\(^{15} 16 27\) From 20 weeks of gestation, kidney weight and body weight have a linear relation to gestational age and body surface area.\(^{28}\) Although there are studies that have measured the changes of GFR occurring in the last weeks of gestation the results are not uniform. A study by Aperia et al,\(^{29}\) measuring creatinine clearance, showed that premature infants, born before 34 weeks’ gestation, had significantly lower GFRs than full term infants, and that this difference persisted for up to 3–5 weeks postnatally. During the 1st week of life, the GFR increased significantly more in full term than preterm infants. Between 1 and 5 weeks of age the GFR increased at a slower rate in both sets of infants. Brion and colleagues\(^{30}\) have also shown that GFR measurement, using inulin and creatinine clearance, increases with gestational and postnatal age, whether expressed as absolute value (for each unit surface area) or for each kg body weight.

Creatinine concentrations were significantly different between the premature and term infants. This could be because of the different postnatal sampling points: the term samples were collected at day 2 versus day 1 for the premature infants.\(^{31}\) Although there are indications that creatinine reabsorption is increased in the preterm kidney,\(^{31}\) this is likely to be passive diffusion down a concentration gradient, a process unlikely to occur with a protein like cystatin C. Once filtered, cystatin C would normally be reabsorbed and degraded by the proximal tubular epithelial cells. In the neonate, the tubular length is less than in the adult so the proportion reabsorbed is likely to be much less, but the protein will still be removed and pass into the urine. The much smaller and statistically insignificant differences between the premature and term cystatin C concentrations suggests a smaller maternal contribution to the neonatal circulatory pool. Although a longer half life of cystatin C in the circulation might contribute to the sustained level at day 7 in the term infants, our own (unpublished, 1995) studies during adult donor nephrectomies suggest that it is, in fact, not significantly different to that of creatinine. There is evidence indicating that the longer half life of dextrans might be the result of differences in the permeability of the neonatal glomerulus; however, it is possible that this could be explained by the reduced GFR that is also present, rather than permeability differences. In previous work, looking at the glomerular permeability and tubular reabsorption of proteins in neonates, it was concluded that there was insufficient evidence to establish whether the increase in albumin excretion was the result of an increase in permeability or a decrease in tubular reabsorption.\(^{33}\) However, our data and that of others suggest that a protein with the molecular weight of cystatin C is unlikely to be retained to any great degree by the neonatal kidney. Whereas in the adult kidney, the passage of cystatin C through the glomerular barrier is less free than the much smaller creatinine molecule, it will be closer to that of creatinine in the neonate because of the greater overall permeability of the neonatal barrier.

In summary, we have shown that cystatin C is a better marker of GFR than creatinine in the paediatric population because it appears to mirror what is known about the maturation of renal function more closely. In premature infants, cystatin C is significantly raised at all gestational ages. Cystatin C concentrations in children reach adult values by the age of 1 year (range, 0.50–1.27 mg/litre; adult range, 0.51–0.98); therefore, a separate reference range is not required. Below the age of 1 year, cystatin C values are higher, reflecting the immaturity of the kidneys (< 1 year, 0.59–1.97 mg/litre). Creatinine does not show these trends and is influenced mainly by the increase in muscle mass during growth. At birth, the kidneys are immature and cystatin C concentration changes suggest it takes 12 months to attain maturity (in accord with reference GFR measurements), whereas serum creatinine concentrations are influenced by increasing muscle mass and do not reach adult values until after puberty. Cystatin C concentrations are effectively constant from 1 year of age upwards. This suggests that cystatin C might offer a considerable advantage to paediatric nephrologists in the measurement of GFR.

HF was supported by a grant from Dade Behring Marburg GmbH, Marburg, Germany. We are grateful to colleagues at the Birmingham Children’s Hospital for collection of some of the paediatric samples.

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Arch Dis Child 2000 82: 71-75
doi: 10.1136/adc.82.1.71

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