Chapter 6: Adequacy of Haemodialysis (Urea Reduction Ratio)

Summary

- 4% of UK patients were on twice weekly dialysis, although in N Ireland it reached 11%.
- Synthetic dialyser membranes were used in most patients in England, Wales and Scotland, with N Ireland using modified cellulose.
- High Flux dialysis was used in 25% of HD patients in N Ireland compared with 12% for other UK countries.
- The dialysate calcium concentrations in use in England and Wales are equally split between 1.5 mmol/L and 1.25 mmol/L.
- 78% of HD patients on thrice weekly dialysis achieve a URR ≥65%, which continues the annual improvement seen in achievement of dialysis adequacy.
- Standardisation of post dialysis urea sampling methodology remains a problem.

Introduction

The lowering of Blood Urea concentration, as a marker for waste nitrogen products derived from the diet and protein breakdown, is one measure of the delivered 'dose' of haemodialysis (HD). The 'adequacy' of dialysis treatment has been related to this dose through studies of patient survival and is given by the ratio between pre- and post-dialysis concentrations of Urea. The overall delivered dose is a multiple of the efficiency of individual treatments and their frequency.

The Renal Association 3rd Standards Document p.25 suggests that:

HD should take place at least three times per week in nearly all patients. Reduction of dialysis frequency to twice per week because of insufficient dialysis facilities is unacceptable. (Good practice)

Every patient receiving thrice weekly HD should show:

- ***either urea reduction ratio (URR) consistently >65%***
- ***or equilibrated Kt/V of >1.2 (calculated from pre- and post-dialysis urea values, duration of dialysis and weight loss during dialysis). (B)***

Recommendations

Patients receiving twice weekly dialysis for reasons of geography should receive a higher sessional dose of dialysis, with a total Kt/V urea (combined residual renal and HD) of >1.8. If this cannot be achieved, then it should be recognised that there is a compromise between the practicalities of dialysis and the patient's long-term health. (Good practice)

Measurement of the 'dose' or 'adequacy' of HD should be performed monthly in all patients. All dialysis units should collect, and report to the Registry, data on pre- and post-dialysis, urea values, duration of dialysis, and weight loss during dialysis. (Good practice)

Haemodialysis frequency

In Chapter 3 of this report is a summary of the national renal survey undertaken on behalf of the Department of Health. All UK renal units were surveyed and questions included information on the frequency of dialysis, reasons for use of twice weekly dialysis, length of time on dialysis and types

Table 6.1. Summary table of HD process measures

Process measures	England	Wales	Scotland	N. Ireland	UK
Number of renal units	52	5	10	4	70
% of patients on twice weekly	4%	8%	0.6%	11%	4%
Unit median (range)	2% (0–36%)	2% (0–15%)	0.4% (0–2%)	12% (1–17%)	2% (0–36%)
Reasons for twice weekly:					
Geographical reasons	3%	7%	25%	–	3%
Preserved renal function	60%	89%	50%	70%	64%
Financial restrictions	9%	–	–	15%	9%
Lack of facilities	10%	–	–	15%	10%
Others	18%	4%	25%	–	15%
Prescribed 3–5 hours on HD	95%	95%	93%	100%	95%

of dialysis membranes used. The summary in Table 6.1 shows that very few patients were on twice weekly dialysis with the main reason for use of twice weekly dialysis a 'preserved renal function'.

All UK renal units returned data of the frequency of use of twice weekly dialysis. Only those with >3% of HD patients on twice weekly have been included in Table 6.2. An intermediate group have around 8% (Freeman, Preston, Southend) and seven English units are in double figures – Addenbrooke's 18, Broomfield 14, Ipswich 18.5, Queen Alexandra 17, Walsgrave 14, Wordsley 15 and Norfolk & Norwich 38% (66 of 175). Broomfield, Ipswich and Wordsley were reporting from a patient base of less than 100 patients under treatment. Two Welsh units are in double figures – UH Wales 15% and Ysbyty Gwynedd 11% (7 of 64). The figures were high from three of the four reporting Northern Ireland units – Antrim 17, Belfast City 10 and Tyrone 15%, although the latter two treat only 81 and 101 patients respectively. None of the Scottish units reported appreciable twice weekly haemodialysis.

These findings are consistent with those presented in the 2002 Registry report, although there have been major reductions in twice weekly treatment in Addenbrooke's (39 to 18%), and lesser changes in Nottingham, Oxford, Southend and two of the Northern Ireland units. Ipswich, Norwich and Wordsley show an increase. No change in pattern is observed for Broomfield, Freeman, Preston and Walsgrave.

It is difficult to know how much these results represent a partial response to the collaborative audit process, although large changes would seem most likely to be due to re-consideration of policy and lack of change or increase, may well be due to resource constraints rather than clinical decision. The figures for the East Anglian hospitals, suggest that a constraint on facilities is being managed through an undesirable reduction in dialysis frequency.

A trend in clinical management, to gradually increase dialysis dose as native kidney clearance diminishes and for some units to start dialysis earlier in the course of declining renal function may account for some of these differences[1–3].

Table 6.2. UK Hospitals with > 3% of patients on 2x/ week HD

Hospital name	% on 2x HD
Norfolk & Norwich University Hospital	37.7
Ipswich Hospital	18.5
Addenbrookes Hospital	18.3
Queen Alexandra Hospital	17.0
Antrim Hospital	16.8
Wordsley Hospital	15.3
University Hospital of Wales	14.9
Tyrone County Hospital	14.8
Broomfield Hospital	13.9
Walsgrave Hospital	13.7
Ysbyty Gwynedd	10.9
Belfast City Hospital	10.0
Southend Hospital	8.8
Royal Preston Hospital	8.0
Freeman Hospital	7.0
Royal Infirmary Manchester	5.6
Guy's and St Thomas's Hospital	5.2
Basildon Hospital	5.2
Hull Royal Infirmary	5.0
Royal London Hospital	5.0
Nottingham City Hospital	5.0
Lister Hospital	4.9
Derriford Hospital	4.1
St James's University Hospital	3.8
Arrowe Park Hospital	3.7
Churchill Hospital	3.5
Gloucester Royal Hospital	3.3
Leeds General Infirmary	3.1

Dialyser membranes

The Registry has not previously reported on membranes in use in the UK. These data were collected in the 2003 national survey questionnaire. Table 6.3 shows that in England Wales and Scotland most patients were on synthetic membranes (57%, 82%, and 64% respectively). This contrasts with N Ireland, where most patients were on modified cellulose membranes (64%), but there was also the highest use of high flux membranes at 25%.

In Table 6.4, only Hope Hospital in Manchester used standard cuprophane membranes.

Dialysate Calcium

For this year's report an additional telephone survey (speaking to the nurse in charge of the haemodialysis unit on that day) was carried out of 34 main renal and 20 satellite units asking whether they had a standard dialysate calcium concentration that was used for most patients. Results in Table 6.5, were categorised from high to low dialysate calcium. Several renal units indicated that they had no standard dialysate calcium to be used and that it depended on doctor's instructions. Surprisingly this response was more common from satellite units where there is often no medical presence.

Achieved URR (Prevalent patient cohort)

The Renal Association Standards are highlighted at the start of this chapter. In view of a lack of progress in Unit recording of dialysis duration and the weight loss associated with each treatment, only the URR, the fractional reduction of urea concentration, are available for Registry calculation and display.

Table 6.3. Summary of dialyser membranes by country

	England	Wales	Scotland	N. Ireland	UK
Standard membrane	1% (1-1%)	0% (0–0%)	0% (0–0%)	0% (0–0%)	1% (1–1%)
Modified cellulose	29% (29–29%)	7% (6–8%)	29% (28–31%)	64% (59–68%)	29% (29–29%)
Synthetic membrane	57% (57–58%)	82% (80–84%)	58% (56–60%)	11% (9–13%)	57% (57–57%)
High Flux membrane	12% (12–12%)	11% (9–12%)	13% (12–13%)	25% (21–28%)	13% (13–13%)
Units	50	5	10	4	69

Table 6.4. Dialyser membranes by centre

	Hospital name	Modified cellulose %	Synthetic %	High flux %
Eng	Addenbrookes Hospital	2	98	0
Eng	Arrowe Park Hospital	0	92	8
Eng	Basildon Hospital	70	0	30
Eng	Broomfield Hospital	100	0	0
Eng	Churchill Hospital	0	99	1
Eng	Cumberland Infirmary	No data	No data	No data
Eng	Derby City General Hospital	94	0	6
Eng	Derriford Hospital	0	85	15
Eng	Dorset County Hospital	0	67	33
Eng	Freeman Hospital	0	100	0
Eng	Gloucester Royal Hospital	0	100	0
Eng	Guy's and St Thomas's Hospital	0	100	0
Eng	Hammersmith & Charing Cross Hospital	0	87	12
Eng	Heartlands Hospital	100	0	0
Eng	Hope Hospital	0	0	0
Eng	Hull Royal Infirmary	95	4	1
Eng	Ipswich Hospital	0	86	14
Eng	James Cook University Hospital	100	0	0
Eng	Kent & Canterbury Hospital	2	98	0
Eng	Kings College Hospital	88	0	12
Eng	Leeds General Infirmary	5	95	0
Eng	Leicester General Hospital	0	100	0
Eng	Lister Hospital	0	0	100
Eng	New Cross Hospital	97	0	3
Eng	Norfolk & Norwich University Hospital	0	100	0
Eng	North Staffordshire Royal Infirmary	0	98	2
Eng	Northern General Hospital	15	0	85
Eng	Nottingham City Hospital	0	100	0
Eng	Queen Elizabeth Hospital	32	68	0
Eng	Royal Berkshire Hospital	94	0	6
Eng	Royal Cornwall Hospital (Treliske)	100	0	0
Eng	Royal Devon and Exeter Hospital	0	100	0
Eng	Royal Free Hospital	4	80	16
Eng	Royal Infirmary Manchester	0	90	10
Eng	Royal Liverpool University Hospital	0	90	10
Eng	Royal London Hospital	98	2	0
Eng	Royal Preston Hospital	0	58	42
Eng	Royal Shrewsbury Hospital	30	60	10
Eng	Royal Sussex County Hospital	0	100	0
Eng	Southend Hospital	75	0	25
Eng	Southmead Hospital	38	42	20
Eng	St George's Hospital	100	0	0
Eng	St Helier Hospital	0	100	0
Eng	St James's University Hospital	0	87	14

Table 6.4. (continued)

	Hospital name	Modified cellulose %	Synthetic %	High flux %
Eng	St Lukes Hospital	0	100	0
Eng	Queen Alexandra Hospital	0	88	12
Eng	St Mary's Paddington	100	0	0
Eng	Sunderland Royal Hospital	0	100	0
Eng	Walsgrave Hospital	70	15	15
Eng	Wordsley Hospital	20	54	26
Eng	York District General Hospital	0	90	10
NI	Antrim Hospital	82	0	18
NI	Belfast City Hospital	80	0	20
NI	Daisy Hill Hospital	50	35	15
NI	Tyrone County Hospital	0	42	58
Sct	Aberdeen Royal Infirmary	99	1	0
Sct	Crosshouse Hospital	0	66	33
Sct	Dumfries & Galloway Royal Infirmary	0	0	100
Sct	Glasgow Royal Infirmary	25	75	0
Sct	Monklands District General Hospital	0	96	4
Sct	Ninewells Hospital & Medical School	0	32	68
Sct	Queen Margaret Hospital	0	90	10
Sct	Raigmore Hospital	100	0	0
Sct	Royal Infirmary of Edinburgh	7	86	7
Sct	Western Infirmary	50	50	0
Wls	Maelor General Hospital	0	80	20
Wls	Morriston Hospital	0	90	10
Wls	University Hospital of Wales	90	10	0
Wls	Ysbyty Glan Clwyd	100	0	0
Wls	Ysbyty Gwynedd	0	92	8

The figures show the URR data for the patient population of each named centre. Each centre has an abbreviated name (see Appendix H) and the number preceding this is the percentage of data missing in the data return for the 3 month period. The Standard states that adequacy measurements should be performed monthly.

The 2002 Report included a discussion on post dialysis blood sampling methodologies in use in England & Wales. The Renal Association 3rd Standards recommends 3 methods which are described in full at the end of this chapter:

- simplified stop blood flow sampling technique (early method)
- slow blood flow sampling technique (early method)
- stop dialysate – continue blood flow method (late method).

Registry staff this year again telephoned nurses at all main dialysis units, and many satellites, to identify sampling methodologies. Centres were grouped by early sampling methods (<5 minutes after stopping

Table 6.5. Dialysate calcium

	Main unit	Satellite
High 1.75 mmol/L	3 (9%)	1
Medium 1.5 mmol/L	14 (41%)	5
Low ≤1.25 mmol/L	14 (41%)	7
Variable	3 (9%)	7
Total	34	20

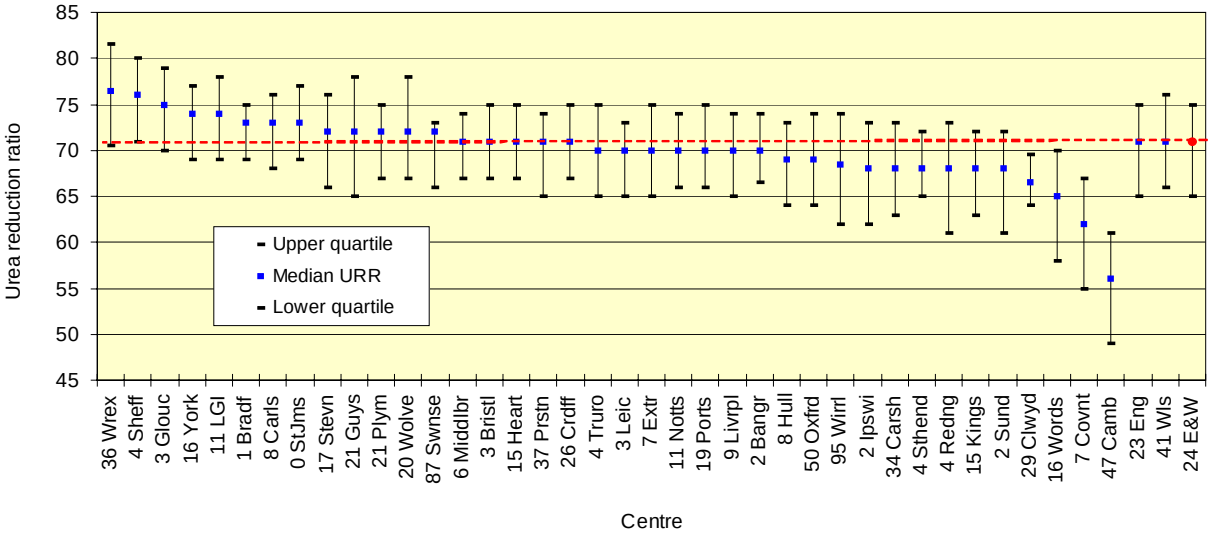

Figure 6.1. Median URR achieved in each renal unit

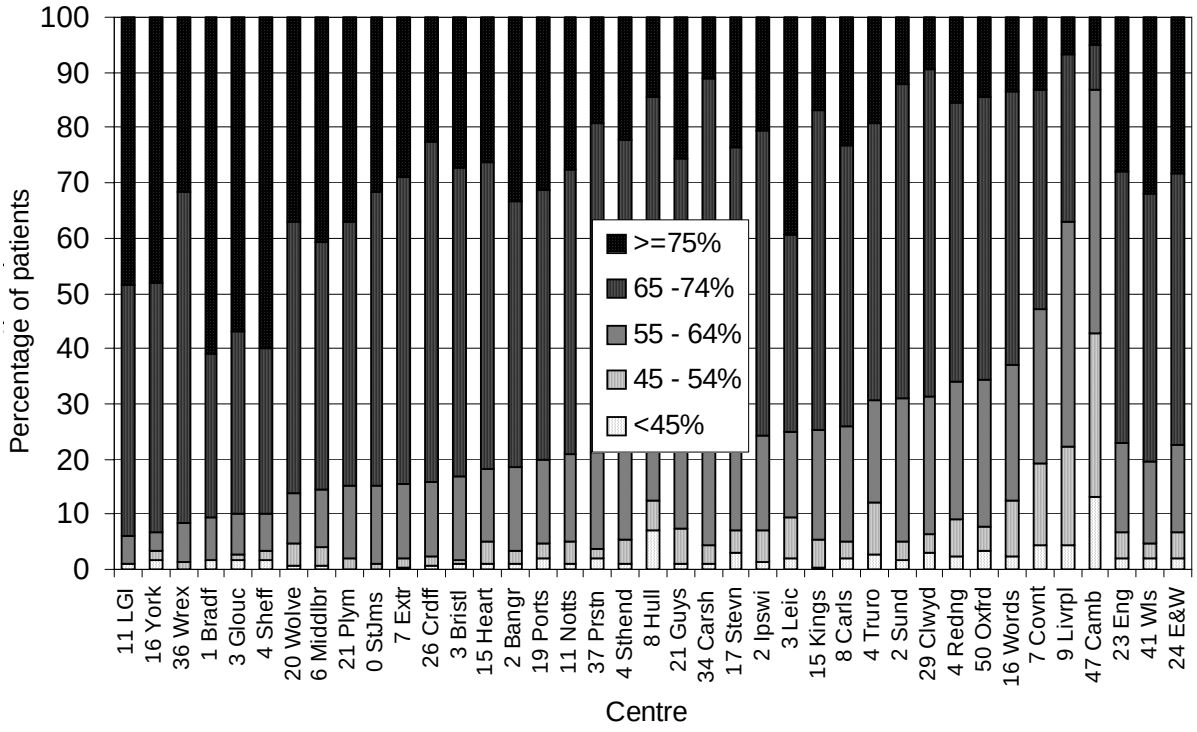

Figure 6.2. URR distribution, by centre

dialysate flow or slowing the blood flow) and late sampling (≥5 minutes). In Figure 6.3, showing the percentage of patients achieving a URR of over 65%, the centres indicated by a 'large closed circle' on the data point are believed to be using a 'late' post-dialysis sampling methodology for blood urea, which would be expected to give lower results for URR.

The median URR values, with interquartile ranges, for each Unit are shown in Figure 6.1. They include satellite treated patients with the main centre, but patients treated for less than three months at the time of sampling were excluded. There has been little redistribution of achievement between

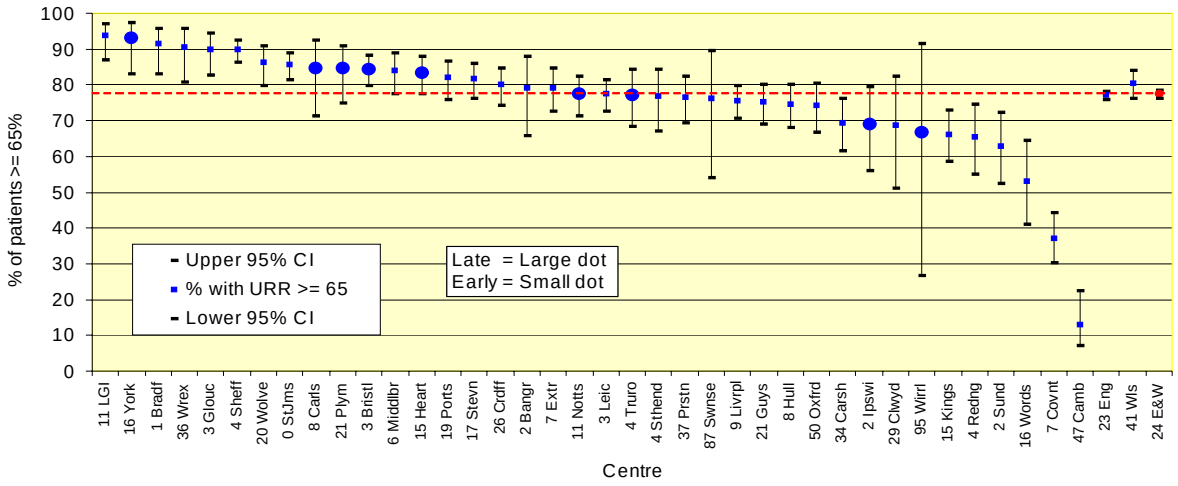

Figure 6.3. % patients, by centre, with a URR of ≥ 65% in the last quarter of 2002

units in 2001 compared to 2002. Several of the lower values are associated with incomplete returns, as shown by a high percentage of missing data (Cambridge, Newcastle, Oxford, Plymouth, Swansea, Wirral, Wordsley, and Wrexham). The URR calculation by the Registry relies on extraction of paired urea values (two measured on the same day) from renal IT systems which is not dependent on pre/ post identifiers being held in the system. At Swansea a local software error was identified in the storage of URR within the IT system and Wirral lacks an automated laboratory system link to Liverpool renal system. Whether through lack of measurement or lack of data logging, little progress has been made in improving the returns in some units.

Change in meeting the URR Standard during 2002

Within the first quarter of 2002 to the end quarter the achievement of the URR standard in England & Wales increased from 75% (95%CI 74%–76%) to 78% (95% CI 76%–79%).

It was not possible in 2002 to acquire reliable demographic data from Derby, so that URRs are not available to allow comparison of their late sampling method with previous and other data. The results from Coventry are improved but remain at the lower margin, despite implementation of changes in methodology highlighted in the 2002 Report. Cambridge is the only renal unit showing a significant drop in URR during 2002.

Change in achievement of dialysis adequacy

Since 1997 the percentage of patients achieving a URR >65% has risen from 56% to 78% in England and Wales (Figure 6.5). The median URR of 71% in 2002 is associated with 22% nationally falling below 65%. The trend to increasing URR values has been sustained, having risen at 1-2% per annum over the past six years.

The change by centre is shown in Figures 6.6 and 6.7. These data suggest that there has been greater compliance from Bradford, Coventry, King's and Sunderland, and something of a deterioration in performance at Cambridge, Carlisle, Plymouth and Preston. It seems unlikely that policies have changed in the latter group, so case-mix or other unexplained factors may be involved, as well as the incompleteness of data noted above. In the absence of data on dialysis duration, blood flow and dialyser size, it is

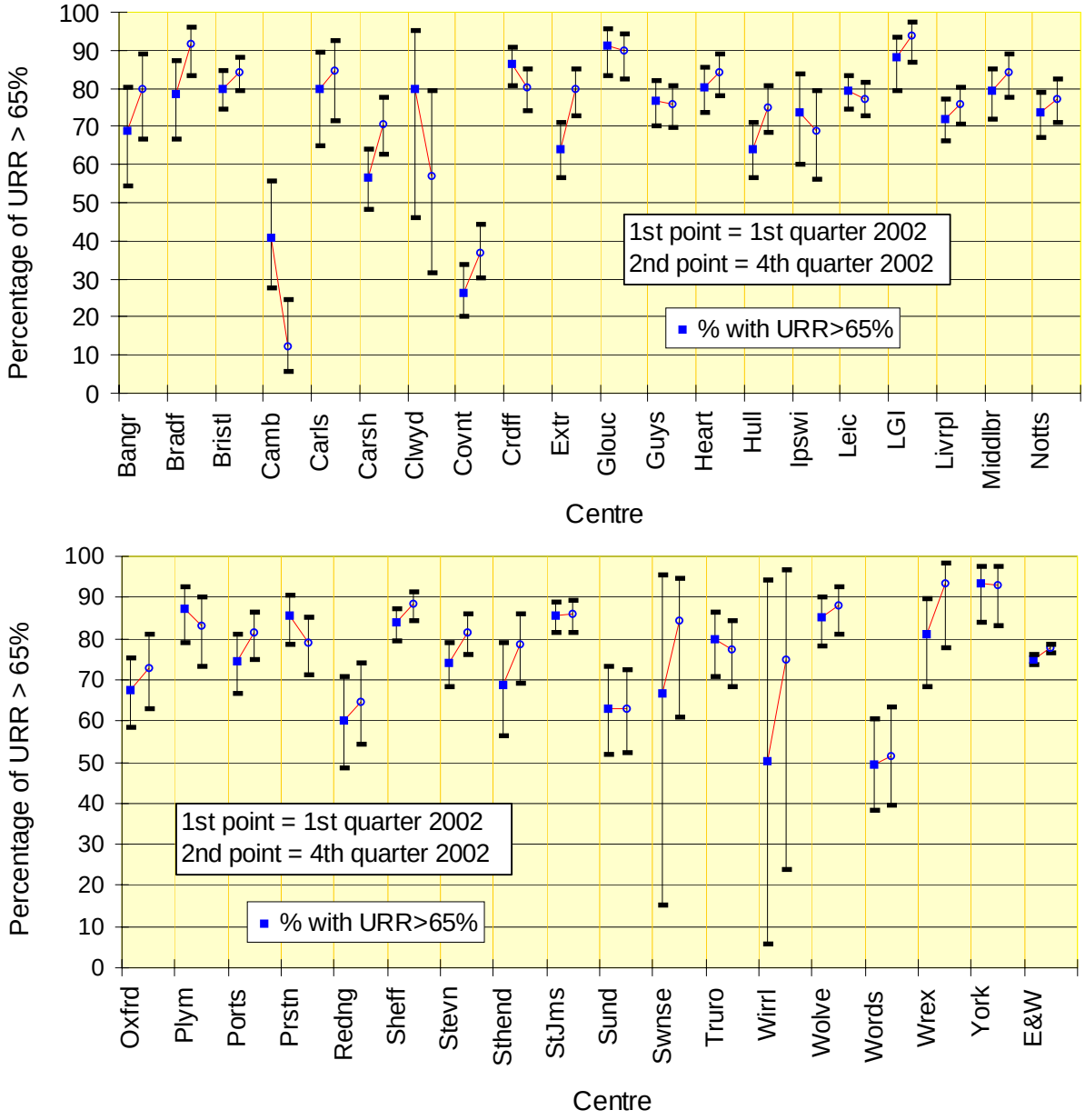

Figure 6.4. Change in meeting the URR Standard in 2002

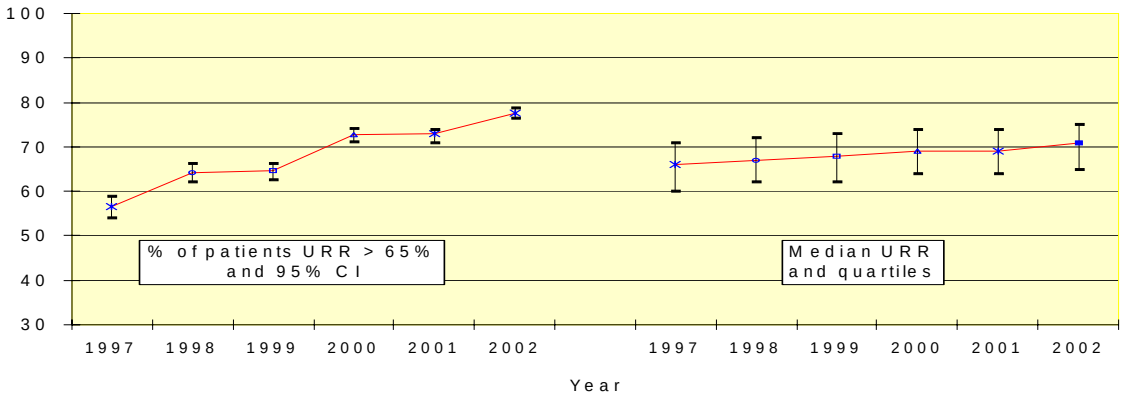

Figure 6.5. % URR over 65% and change in median URR 1997–2002, England & Wales

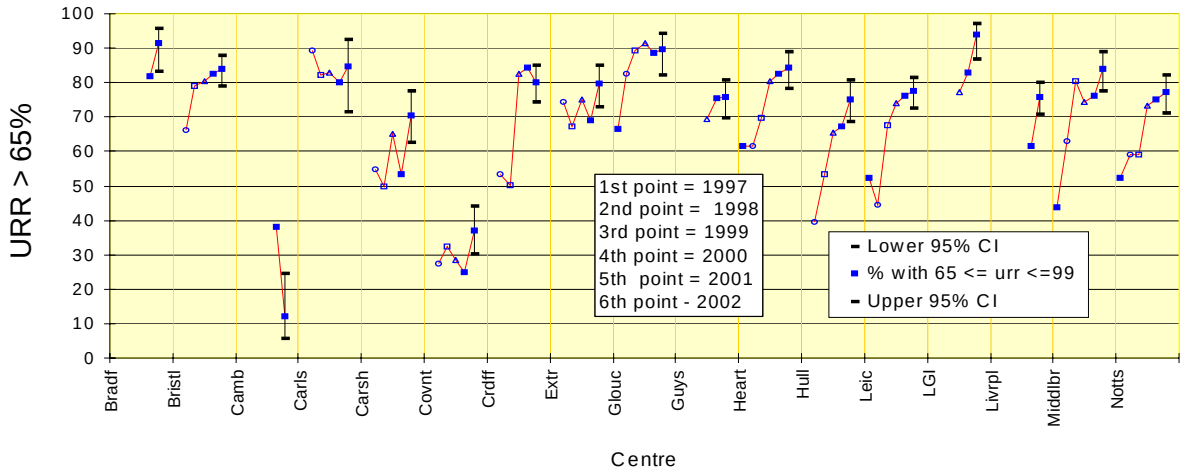

Figure 6.6. Change in meeting the URR Standard in 1997–2002

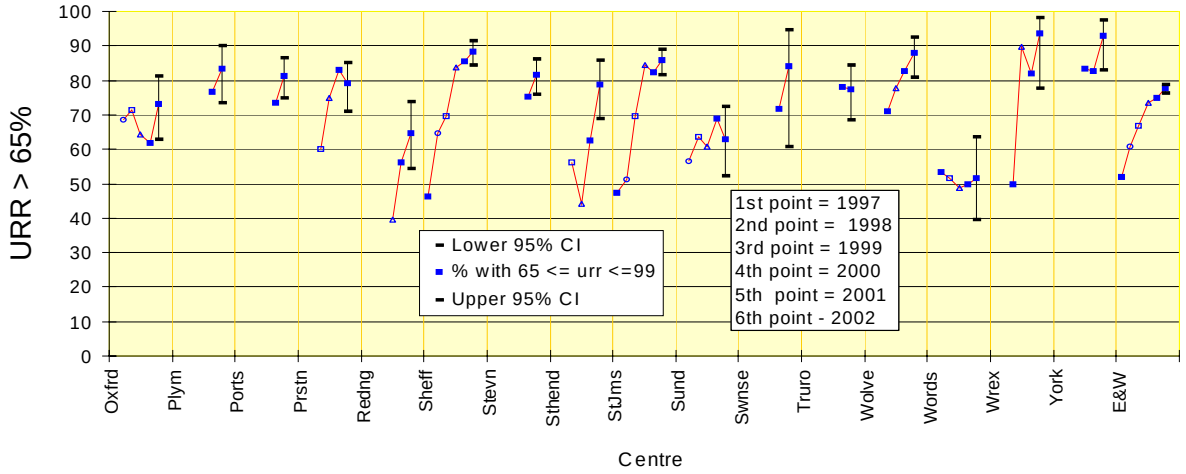

Figure 6.7. Change in meeting the URR Standard in 1997–2002

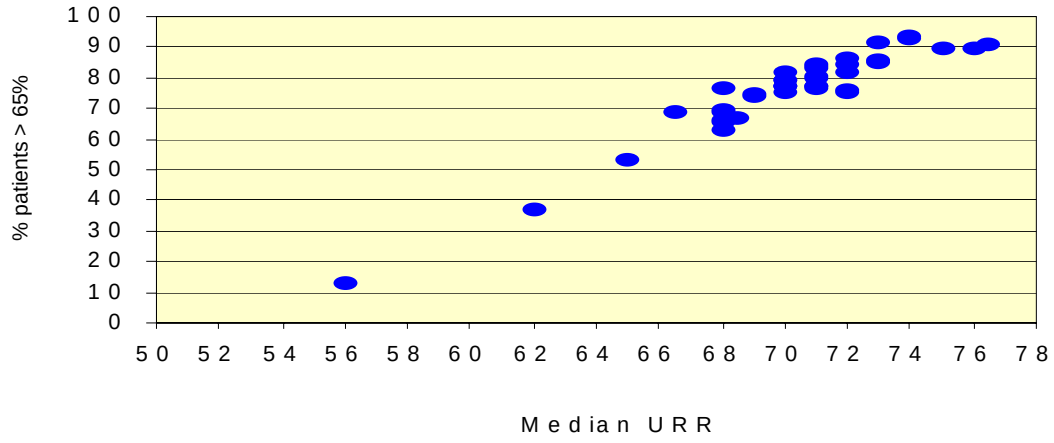

Figure 6.8. URR achievement and median URR at each renal unit

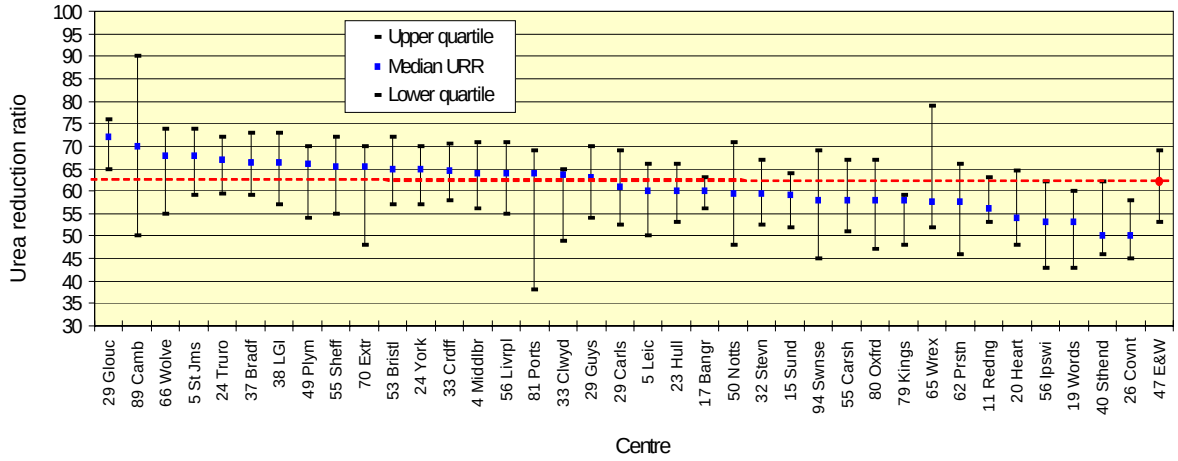

Figure 6.9. URR achievement in new patients within first 3 months

not possible to explain the results in terms of the determinants of dialysis dose.

These data show a modest improvement in Unit URR performance, with a 2% increase in median URR from 69% to 71%. Analysed by renal unit, this changes ranges from +4 to –3%. It would be of interest to be able to assess the effect of body weight on these changes.

Distribution of URR

Figure 6.8 shows the relationship of Unit median URR and the percent of values falling above the 65% standard (Rose–Day plot). The progressive improvement of compliance at the 65% level is demonstrated again, with some 'flattening' of the curve at the upper end of the graph. The need for centre median URR to be at or near 73% for even 85% compliance is clear, given the dispersion of URR values that may be expected from a centre cohort measured on one occasion (i.e. the dispersion would be reduced if the 4 quarter's results were averaged).

URR in the 2002 incident patient cohort

As in previous years the patients starting haemodialysis (within the first 3 months) show lower URR values than the established prevalent group (Figure 6.9). This is partly due to residual renal function being excluded from this calculation. The iDopps data has shown that in the UK it takes much longer than other European countries to establish permanent vascular access. This also accounts for the low dialysis adequacy achieved within the first 3 months. The data from the US Centre for Medicare and Medicaid Services indicate that mean blood pump flow rates were 345 ml/min for patients with catheters compared with 410 ml/min in those with a fistula. With the Renal NSF published, it is hoped that resources will now be targeted to reduce the waiting time required for access surgery and improvements in achievement of dialysis adequacy within the first 6 months will follow.

The cross-sectional analysis in Figure 6.10 implies that there has been some small improvement in early URR achievement with time.

International comparison

It is of interest to compare data with the US Centre for Medicare and Medicaid Services (CMMS) Report for 2002 published in July 2003.[4] Their reported population was a random sample of approximately 500 haemodialysis patients from each of the 18 US 'Networks' (n = 8,863 3.5% US HD popula-

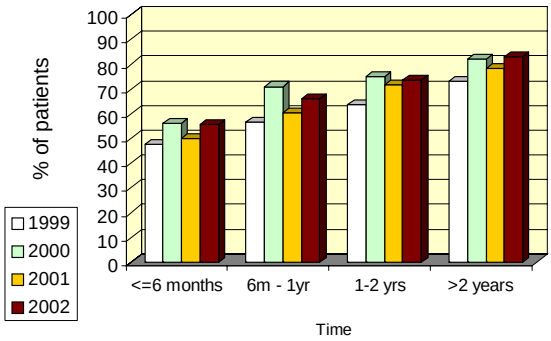

Figure 6.10. Change in URR by length of time on RRT 1999–2002

tion) with data from the last quarter of 2001.

Eighty two per cent of patients had monthly adequacy measurements, 11% measured twice and 5% only once. These individual results were averaged and this methodology (using the means of mean values) would be expected to give a narrower dispersion of results (s.d. 6.7%) than the current UKRR single quarterly sample system (s.d. 9.0%).

1. Mean URR was 70.9% to compare with 71% in this year's Registry Report.
2. For the 65% level of URR, 84% were compliant in the US data compared with 78% in the UK (post dialysis sampling in the US is largely by early methods, since Kt/V calculations based on best-fit formulae have required it).
3. Median dialysis session length was 212 minutes.
4. Median Kt/V was 1.49. The distribution of Kt/V (and hence mean KT/V) did not change for US data samples 1999-2001.
5. 29% of incident patients were dialysed using an AV fistula (AVF).
6. 31% of prevalent patients were dialysed using an AVF.
7. 19% of prevalent patients were dialysed with a chronic catheter continuously for 90 days or longer.
8. 51% of prevalent patients with an AV graft were routinely monitored for the presence of stenosis.

Independent analyses of the CMS data published in abstract form, of 2,500 US units, showed an average improvement in meeting URR guideline values of 1.6% per annum over the years 1998–2002, to compare with the data reported here for England and Wales (Figure 6.5). There was such variation that it 'suggests that some organisations were more effective than others in quality improvement'.[5] In addition, and perhaps more important, the changes in URR when related to Standardised Mortality Ratios suggested that improvements in URR (and anaemia) tended to be associated with greater improvements in mortality 1999–2002 at Unit level[6].

Discussion

URR and survival

The patient requiring renal replacement is at risk from many factors, particularly vascular and infective co-morbidity. The desire to minimise the effects of the renal failure has been the motive to find an adequate dose of dialysis, above which there would be no further benefits in both mortality and morbidity.

URR, despite a relative lack of sophistication, has been associated with mortality in large studies of haemodialysis patients.[7,8] Current experience suggests that thrice-weekly dialysis of a practical duration is not at the beneficial limit and 2003 saw the publication of the HEMO Study, which could show no benefit for achievable changes in urea reduction using modern techniques, thrice weekly.[9] The reduction of urea at current best-practice levels is a relevant associated factor in overall mortality of dialysis patients, but one analysis suggests

that all the possible biochemical optimisations by dialysis will only account for 13 to 37% of the factors involved. URR is a much less potent associated factor than Serum Albumin.[10] Others have shown that when URR is standardised at best practice levels nutritional elements seem to dominate the potential moderators of mortality.[11] To that extent adequacy through URR may be achieved.

Quality improvement

The effort to increase URR in haemodialysis populations has had limited success internationally. The incentive value of collaborative audit must be assessed against a background of improving through intuitive clinical management. Within comparative audit there are important 'centre effects' (for example, the understandable reluctance to change established blood sampling protocols). Patterns of provision (for example, twice-weekly dialysis) take some time to resolve, when facilities are constantly stretched. Improvements in access provision of AV fistulae, will also take time to show benefit at centre level. Such improvements generally require a substantial change of policy in clinical management and previous Registry reports have shown that these changes are realistic.

There needs to be an improvement in local clinical informatics supporting the clinical IM&T and data retrieval infrastructure required to monitor this process. The renal NSF Information Strategy document (see Appendix E) highlights the importance of a renal unit's infrastructure for collection of data.

Methodology

The Registry use of single data points has some disadvantages, not least errors in estimating true URR.[15,16] The dispersion of these data would be smaller if the mean of the year's quarterly values were taken, since profiles change slowly within any given year (Figures 6.6 and 6.7). It is unlikely that this would significantly change the interpretation of data.

Sampling techniques for the post dialysis urea concentration remain controversial, although calibration of late sampling, in a limited range of treatment conditions, may yet allow derivation of Kt/V.[17]

Future role of URR

The results of the HEMO study were not encouraging for those who thought there was a linear relationship between increasing URR or Kt/V and reducing dialysis morbidity and mortality.[9] The negative findings of the HEMO study were rationalised to have reflected too narrow a range of dialysis dose, on a 'flat' section of the dialysis dose-response curve. Other data linking mortality with URR, however, are not compromised, simply unexplained. It is clear that dialysis at any dose level has a parallel effect on many metabolites, volume control/blood pressure etc., which are very relevant to 'adequate' dosing and effective reversal of the uraemic state. Others have claimed that the inevitable relationship of URR to Kt/V means that it is flawed as a guide to dose, since the implicit standardisation to body water content is confounding.[18] The relative risk of mortality appears independently associated with dialysis dose *and* body weight so that measures that combine them are complicated composites.[19]

One study suggested that from 1994 to 1997, the threshold for mortality benefit with URR had increased from 61% to 71%. The explanation given for this was that improved URR may only have been achieved through a change in dialysis procedure or blood sampling favouring a higher measurement of URR![20] The attempts in some patients to increase URR to very high levels may have negative benefits.[21] This is assumed to be related to the relative ease of achieving a high URR dose in lighter, possibly less healthy, individuals, when greater body mass is associated with better dialysis

outcomes. By contrast, body size over 81kg in one study militated against 'adequate' URR.[22] Without renal units electronically storing data on body weight, the Registry is unable to contribute to this debate.

In so far that URR >65% may be used to reflect adequate dialysis dosing, with all its related benefits, it continues to be an appropriate surrogate outcome indicator. The annual UK improvement in achievement of URR appears that in time, it will plateau and come to be accepted as a readily achievable norm. The focus of attention to dialysis 'adequacy' may then shift to other indicators of outcome, carried in nutritional, inflammatory and cardiovascular variables.

Recommended post dialysis sampling techniques

The following three methods are recommended in 3rd Standards document.

A. Simplified stop blood flow sampling technique

- When you are ready to take the sample, turn the blood pump slowly down to 50 mls/min.
- **Start counting to 5**; if the venous pressure alarm has not already stopped the blood pump when you get to 5, stop the pump manually.
- Disconnect the arterial line and take a sample from the needle tubing (or the arterial connector of the catheter) **within 20 seconds** of slowing the blood pump to 50 ml/min.
- If more than one sample is required, the urea sample should be the first one taken, wash back blood, take patient off as normal.

Guidelines developed by EJ Lindley, V Osborne, S Sanasy, D Swales and M Wright, The Leeds Teaching Hospitals NHS Trust.

Timing is **important** in this technique.

B. Slow blood flow sampling technique

- At the end of dialysis, turn the blood pump down to 100 ml/min.
- Override the alarms to keep the blood flowing.
- **Wait 15–30 seconds** and take samples from the 'A' line sampling post.
- If more than one sample required, the urea should be the first one taken, wash back blood, take patient off as normal.

Guidelines developed by F Gotch and M Keen, Davis Medical Centre, San Francisco, and used since 1990 by the Lister Renal Unit, East & North Herts NHS Trust.

Timing is **important** in this technique.

C. Stop dialysate – continue blood flow method

- Turn off the dialysate flow, leaving the blood flow unchanged.
- Sample 5 minutes after this from any point in the extracorporeal circuit.

Developed by Drs Mactier, Geddes and Traynor at Stobhill Hospital Glasgow.

Timing is less critical in this technique. It is acceptable to stop the blood flow at 5 minutes and then sample immediately from the 'A' line.

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