BMJ

RESEARCH

CHRISTMAS 2010: THE LIVES OF DOCTORS

Urine output on an intensive care unit: case-control study

Anthony W Solomon, specialist registrar,[1,2,3] Christopher J Kirwan, specialist registrar,[1,4] Neal D E Alexander, reader,[5] Kofi Nimako, specialist registrar,[1,6] Angela Jurukov, audit clerk,[1] Rebecca J Forth, research fellow,[7] Tony M Rahman, consultant[1,8] on behalf of the Prospective Analysis of Renal Compensation for Hypohydration in Exhausted Doctors (PARCHED) Investigators

[1]General Intensive Care Unit, St George's Hospital, London, UK

[2]Clinical Infection Unit, St George's Hospital, London

[3]Clinical Research Department, London School of Hygiene and Tropical Medicine, London

[4]Department of Renal Medicine, St George's Hospital, London

[5]Department of Infectious Disease Epidemiology, London School of Hygiene and Tropical Medicine, London

[6]Department of Chest Medicine, St George's Hospital, London

[7]Portex Anaesthesia, Intensive Therapy and Respiratory Unit, Institute of Child Health, London

[8]Department of Gastroenterology and Hepatology, St George's Hospital, London

Correspondence to: A W Solomon, Clinical Research Department, London School of Hygiene and Tropical Medicine, London WC1E 7HT
anthony.solomon@lshtm.ac.uk

Cite this as: *BMJ* 2010;341:c6761
doi:10.1136/bmj.c6761

ABSTRACT

Objective To compare urine output between junior doctors in an intensive care unit and the patients for whom they are responsible.

Design Case-control study.

Setting General intensive care unit in a tertiary referral hospital.

Participants 18 junior doctors responsible for clerking patients on weekday day shifts in the unit from 23 March to 23 April 2009 volunteered as "cases." Controls were the patients in the unit clerked by those doctors. Exclusion criteria (for both groups) were pregnancy, baseline estimated glomerular filtration rate <15 ml/min/1.73 m^2, and renal replacement therapy.

Main outcome measures Oliguria (defined as mean urine output <0.5 ml/kg/hour over six or more hours of measurement) and urine output (in ml/kg/hour) as a continuous variable.

Results Doctors were classed as oliguric and "at risk" of acute kidney injury on 19 (22%) of 87 shifts in which urine output was measured, and oliguric to the point of being "in injury" on one (1%) further shift. Data were available for 208 of 209 controls matched to cases in the data collection period; 13 of these were excluded because the control was receiving renal replacement therapy. Doctors were more likely to be oliguric than their patients (odds ratio 1.99, 95% confidence interval 1.08 to 3.68, P=0.03). For each additional 1 ml/kg/hour mean urine output, the odds ratio for being a case rather than a control was 0.27 (0.12 to 0.58, P=0.001). Mortality among doctors was astonishingly low, at 0% (0% to 18%).

Conclusions Managing our own fluid balance is more difficult than managing it in our patients. We should drink more water. Modifications to the criteria for acute kidney injury could be needed for the assessment of junior doctors in an intensive care unit.

INTRODUCTION

Assessing the intravascular fluid balance of critically ill patients is a crucial role of intensive care physicians. Adequate fluid resuscitation can optimise cardiac output and improve outcome, especially in sepsis or after major surgery.[1 2]

When intrinsic renal function is normal and the urinary tract is unobstructed, urine output is a key indicator of intravascular volume status. In critically ill patients, the routine use of indwelling urinary catheters allows accurate hourly measurement of urine output. Such data are closely followed by doctors in intensive care. In doing so alongside their other multitudinous responsibilities, however, doctors' own autologous hydration can be delayed; they might become "dry" (intravascularly deplete) as a result. We hypothesised that this should not occur to such an extent as to lower doctors' urine output below that of the patients in the unit, as the latter often have one or more reasons for developing oliguria (hypoperfusion, acute or chronic renal damage, urinary tract obstruction). In this prospective case-control study we compared the urine output of intensive care doctors and their patients.

METHODS

The study was performed in a 17 bed general intensive care unit in a tertiary referral hospital in south west London over 22 consecutive weekdays (excluding public holidays) from 23 March to 23 April 2009. The unit admits a mixture of trauma, elective and emergency post-surgical, and emergency medical admissions. There are separate neurological intensive care, cardiothoracic intensive care, and coronary care units in the trust.

All junior doctors working on the unit (ranging from foundation year 1 doctors to specialist registrars) who took responsibility for the daily clerking of one or more patients on day shifts during the study were fully informed of the objectives and were eligible to volunteer as cases. The weight of each doctor (wearing scrubs but no footwear, seated and still, having divested themselves of stethoscope, pager, and pocket contents) was determined with Marsden MPDC-250 professional weighing scales (Marsden, Henley, UK).

For each case, controls comprised the patients on the same unit clerked by the case that day. Each patient is routinely clerked on admission to the unit and again each morning by a nominated junior doctor, who might or might not have admitted or clerked the patient previously. On any day, a case can have been matched with more than one control. During data collection, patients (controls) were allocated to doctors (cases) by the specialist registrar in charge of the unit (based on multiple factors, including patients' diagnoses and overall complexity, and the interests and experience of the available doctors), as normal; whenever practical, doctors do not clerk the same patient two days in a row. We determined the patients' weights by self report or from relatives. If both of these sources were unavailable or thought to be unreliable, we recorded the most recent weight documented in the medical notes. If weight had not previously been documented, we recorded an estimated weight, with estimation performed jointly by nursing and medical staff.[3]

Pregnancy, estimated glomerular filtration rate <15 ml/min/1.73 m^2 (chronic kidney disease stage 5), and renal replacement therapy (including renal transplantation) were exclusion criteria for both cases and controls because urine output for individuals with these characteristics was likely to be artificially high or low. Those included once as cases were eligible for later inclusion as controls, and vice versa[4] (subject to the hospital's usual procedures for recruitment and allocation of medical staff, and criteria for patient admission to the intensive care unit).

On each data collection day, participating doctors emptied their bladders on arrival at work, noting the time at which they did so on anonymised charts fixed to the inside of the male and female staff changing rooms. On each subsequent occasion that they voided during the course of their working day, they measured the volume of urine voided using a wide mouthed 1l graduated plastic measuring jug (RML 200-003, Rochialle, Mountain Ash, Wales, UK) and recorded the amount on the appropriate chart. Regardless of whether or not they had the urge to do so, they voided once more at the conclusion of their shift, noting the volume of urine and the time at which it was passed.

Hourly urine volume passed by controls was recorded on flow charts, as normal. As day shifts for doctors start at 8 am and are scheduled to finish between noon and 6 pm (depending on rota) but occasionally overrun (because of emergencies or other unforeseen circumstances[5]), we included control data for the period 8 am to 8 pm. For patients admitted to or discharged from intensive care during these hours, we included data only for the period in which they were in the unit, regardless of whether or not urine output was continuously monitored in the source or destination environment.

We placed no restrictions on the use by either doctors or controls of fluids (whether oral or intravenous) or diuretics (including loop diuretics, thiazides, and foods and drinks containing caffeine) with the exception of alcohol, which was not used by either group. Each participating doctor was offered a single 300 ml cup of caffeinated coffee, made up to strengths that varied from day to day (as dictated by the consultant in charge), at the multidisciplinary team ward round each morning, but he or she was not obliged to drink it: its consumption and any subsequent fluid intake were at the discretion of the individual and not recorded. None of our cases or controls fasted during the period of the study for religious or other reasons.

Control data were entered into Microsoft Excel and transferred to Microsoft Access; case data were entered directly into Access.

Statistical analyses

The exposure of main interest was oliguria as a binary variable. A commonly accepted definition of oliguria is a urine output <0.5 ml/kg for each of six or more consecutive hours, which is thought to confer "risk" of renal injury; when urine output <0.5 ml/kg persists for 12 or more consecutive hours, the kidneys are designated to be "in injury."[6] Use of this definition of oliguria was possible for controls, as their urine output was measured hourly, but lack of routine catheterisation of doctors on shift meant that hourly output data were not available for cases. We therefore defined oliguria for both cases and controls as a mean urine output <0.5 ml/kg/hour over a period of six or more hours of measurement.

The sample size was calculated to allow detection of an association between being oliguric and being an intensive care unit doctor. Assuming three controls per case and a 25% prevalence of oliguria in controls, we anticipated requiring 410 case days to detect an odds ratio of 1.5.[4] The unit of analysis was a stratum consisting of one day's data from a case (doctor) and one day's data from each of one or more matched controls (patients). Oliguria was evaluated in terms of the odds ratio of being a case, relative to being a control, on any given day.[4] Our secondary analysis looked for a "dose response effect,"[7] investigating whether urine output analysed as a continuous variable tended to be lower in cases than in controls. Both analyses used conditional logistic regression, matching on stratum. To allow for the presence of some of the cases in multiple strata, we inflated standard errors using the "sandwich" estimator[8]; we did not, however, adjust for the presence of the same controls in multiple strata on different days. We performed our analyses in Stata version 11 (StataCorp, College Station, TX, USA).

RESULTS

Nineteen junior doctors (12 men, seven women) worked a total of 127 weekday day shifts during the 22 days of data collection; this period spanned a rota changeover, so the low mean number of shifts per doctor should not be interpreted as suggesting that the rota was light. No doctors were excluded on the basis of pregnancy, known stage 5 chronic kidney disease, or renal replacement therapy. On nine of these days, the specialist registrar in charge of the unit did not take primary responsibility for clerking any patients. There were therefore 118 eligible case days. Eighteen doctors (12 men, six women; 95%) volunteered for the study, contributing a total of 87 case days (range per case 1-13 days, median 5, 74% of eligible case days).

Non-participation on any day was invariably attributed to forgetfulness.

For case days, mean and median urine outputs were 0.77 ml/kg/hour and 0.68 ml/kg/hour respectively. In 22 (25%) of 87 case days, the mean shift long urine output was <0.5 ml/kg/hour. Twenty of these shifts lasted more than six hours, including one that lasted for more than 12 hours (mean shift length 9.2 (SD 1.9) hours, range 4.5-12.3 hours). If we assume that doctors' urine output was relatively constant throughout each shift, they were "at risk" of acute kidney injury (based on urine output criteria[6]) on 19 shifts (22%) and "in injury" on one further shift (1%). Ten (six men, four women; 55%) of 18 cases had at least one day (range 1-3 days) "at risk" of renal injury or worse over the course of the study.

For the 87 case days, there were 209 control days in which controls were matched to participating cases. We excluded 13 control days because the controls received renal replacement therapy on the day in question and one control day because of missing data on urine output. We therefore analysed data for 195 control days paired to case days in 87 strata; each stratum had an average of 2.2 control days. Controls had mean urine output <0.5 ml/kg/hour on 29 (15%) of these 195 control days.

Pooling 20 oliguric case days together with 29 oliguric control days and considering oliguria as a risk factor, the odds ratio for being a case rather than a control (given the presence of oliguria) was 1.99 (95% confidence interval 1.08 to 3.68, P=0.03). With output assessed as a continuous variable, for each additional 1 ml/kg/hour mean urine output, the odds ratio for being a case rather than a control was about one quarter (0.27, 0.12 to 0.58, P=0.001). For both primary and secondary analyses, being a doctor was associated with lower urine output.

Oliguria was significantly more frequent, and urine outputs significantly lower, in the doctors than in the patients they cared for. Our data monitoring committee therefore stopped the study early on safety grounds. (Several of us also reached the end of our intensive care unit attachment.)

DISCUSSION

The incidence of urine outputs equivalent to risk and injury in our prospective cohort of day shift doctors in intensive care units was startlingly high, at 22% and 1% respectively. Doctors were twice as likely as their patients to be oliguric. The RIFLE criteria, used widely to describe and classify acute kidney injury in critically ill patients, incorporate the assessment of urine output (measured hourly) adjusted for body weight.[6] Because hourly urine output data were not available for doctors in this study, we modified the RIFLE definitions so that we assessed mean hourly output rather than hour by hour output. Notwithstanding this change, the incidence of urine outputs equivalent to RIFLE risk and injury in our prospective cohort of dayshift intensive care doctors was startlingly high, at 22% and 1%, respectively. Doctors were twice as likely as their patients to be oliguric. We hope (and expect, given that most do not work as hard as us) that these results are not generalisable to the whole UK medical workforce.

A surprising lack of mortality

Ostermann and Chang determined the incidence of acute kidney injury for 41 972 admissions to 22 intensive care units in Germany and the UK between 1989 and 1999.[9] They determined that 7207 (17%) patients were "at risk" of acute kidney injury at some time during their stay in intensive care and 4613 (11%) had "injury." In that series, patients without acute kidney injury had mortality rates in hospital of 8%, while those with risk or injury had mortalities of 21% and 46%, respectively.[9] The cumulative 0% (95% confidence interval 0% to 18%) mortality in our series of (frequently oliguric) intensive care unit doctors seems nothing short of miraculous in comparison and is presumably attributable to the robust constitutions of doctors on our unit. We did not collect mortality data on controls.

The RIFLE criteria are a relatively recent innovation and are subject to ongoing debate and refinement.[10] In a recent systematic review, the relative risk of death conferred by risk, injury, or failure according to RIFLE was lower in studies that used both creatinine and urine output criteria, compared with studies using creatinine alone.[11] In other words, urine output might be a "softer" marker of acute kidney injury than changes in serum biochemistry. This could explain why, for each stratum of acute kidney injury, mortality was higher in the Ostermann and Chang series (in which the classification of acute kidney injury was based solely on serum creatinine values[9]) than in our cases (in which the analysis used only urine output data). An alternative explanation could be the need for separate acute kidney injury criteria in patients in intensive care units and their doctors.

In any event, mortality was not a prespecified outcome of our study, and our main finding— that intensive care unit doctors are twice as likely as their patients to be oliguric—remains striking. Of course, as already mentioned, all our controls had urine output monitored on an hourly basis by experienced intensive care nurses, 24 hours a day; such data are not merely recorded but acted on. Nursing and medical personnel working on the unit are trained to repeatedly assess patients for intravascular volume depletion and, whenever necessary, appropriately intervene to correct it. With such close and continuous supervision, we expected the incidence of prolonged periods of low urine output because of inadequate filling in controls to be low. Similar close monitoring of urine output with consequent appropriate intervention for doctors has been declined by our nursing staff, even after presentation of these results, and despite advice from the Royal College of Nurses that "looking after colleagues . . . helps to build trust and increase feelings of security" in the workplace.[12] This might be an important issue to address as our data suggest that auto-fluid balance management is more difficult than auto-appendectomy, which has been successful in 100% of published attempts during the past five decades.[13] An obvious parallel conclusion to be drawn here is that medicine is far more complex than surgery.

Accuracy of methods

Our keenness to involve nursing staff in measuring urine output in doctors and disappointment at their rebuff should not be interpreted as indicating a lack of confidence from the authors in the accuracy of doctors' measurement of urine volume. The common belief that timed urine self collections are inherently inaccurate is, in fact, a misconception. In a 2008 UK study of dietary sodium intake supported by the Medical Research Council and the National Centre for Social Research, 780 members of the general public were selected by random digit dialling of telephone numbers and asked to perform a 24 hour urine collection.[14] Completeness of collection was assessed through oral administration of three 80 mg para-amino-benzoic acid (PABA) tablets during the collection period; collections containing 85-110% of administered PABA were considered complete. Of 751 samples for which PABA results were available, urine collection was considered complete or near complete in 692 (92%). In comparison with that work, the circumstances of our study were far more conducive to accurate collection. Our urine was self collected by medically trained individuals in a single location to which participants, by virtue of their work commitments, were essentially confined for the duration of their shift; the unit had one male and one female washroom, and notices concerning the study were prominently displayed in both. The study was a common topic of conversation in the unit at the time it was conducted. Supplementary personal reminders of the importance of accurate collection were given to each participating doctor on a daily basis. In addition, all our collections were for considerably shorter periods than 24 hours and did not include normal hours of sleep, when complete collection is presumably more difficult to ensure.

Study weaknesses

There are, however, several limitations to our analysis. We did not prescribe or record the intake of fluids in cases, so did not attempt to analyse the association of fluid intake volume and urine output volume for either cases or controls. Caffeine intake was also not restricted or recorded. If caffeine consumption by doctors did have a diuretic effect, it would have resulted in a reduction in the observed difference between cases and controls, but the effect of caffeine on increasing urine output is probably generally overestimated. It had no impact on urine production during three hours of cycling at 60% VO_2max[15] or two hours of cycling at 60-75% VO_2max followed by 15 minutes of maximal effort cycling[16]: physiological work intensities that are virtually identical to our work intensities on the unit. More generally, chronic caffeine use at doses of 3-6 mg/kg/day has no impact on urine output, renal function, or fluid and electrolyte balance.[17] We were unable to record an objective measure of each doctor's stress each day without unduly disrupting clinical activity and can therefore not exclude an antidiuretic effect of stress induced vasopressin release. We also cannot rule out a Hawthorne effect (the tendency of study participants to positively modify behaviours that are under observation). Finally, we did not attempt to ultrasonographically exclude postmicturition urinary retention in our cases at the end of each shift.

Implications

Oligoanuria is usually acute renal success rather than failure, being a sophisticated response to tubular damage caused by renal hypoperfusion or nephrotoxins, preventing life threatening polyuria when reabsorption of glomerular filtrate is impaired.[18] Increased concentration of chloride at the macula densa, however caused, is interpreted as an imbalance between filtration and reabsorption and leads via multiple mechanisms to a reduction in glomerular filtration, conserving intravascular volume.[18] The frequency with which this response was manifest in our doctors could (as suggested by our renal and intensive care physician) be interpreted as a demonstration of the physiological superiority of doctors in intensive care units or merely show (as suggested by the rest of us) that we should try to drink more water while on shift. We need a functioning water fountain in the staff room and the sense to go and drink from it.

We thank the medical, nursing, administrative and cleaning staff of St George's general intensive care unit for their support and encouragement and all our cases for their careful and good humoured participation. The PARCHED Investigators are: Aleksandar Aleksic, Neal D E Alexander, Nawaf Al-Subai, Jonathan Ball, Maurizio Cecconi, Arup Chakraborty, Richard Dodds, Costandine Fakiris, James Fletcher, Rebecca J Forth, Tim Gatheral, Petrut Gogalniceanu, Michael Grounds, Mark Hamilton, Hooi-Ling Harrison, Eloise Helme, Robin Johns, Angela Jurukov, Christopher J Kirwan, Jane Kung, Greg McAnulty, Nighat Nadeem, Phil Newman, Kofi Nimako, Oluwakemi Okubote, Kayur Patel, Barbara Philips, Tony M Rahman, Andrew Rhodes, Rajnish Saha, Anthony W Solomon, Shelley Vamadevan, Jo Wilson, Mark Wyldbore.

Funding: This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Competing interests: Several authors have been surprised by the colour and particulate nature of the water that emerges from the water cooler in the intensive care unit staff room and would be keen to be able to drink

WHAT IS ALREADY KNOWN ON THIS TOPIC

Oliguria is a common occurrence in patients admitted to intensive care and is associated with a marked increase in morbidity and mortality

WHAT THIS STUDY ADDS

Oliguria occurs twice as frequently in junior doctors on an intensive care unit as in their patients

This oliguria was not associated with increased mortality

Markers of acute kidney injury in junior intensive care unit doctors might diverge from those for the intensive care unit population as a whole water that doesn't first require filtering through a shirt. All authors have completed the Unified Competing Interest form at www.icmje.org/coi_disclosure.pdf (available on request from the corresponding author) and declare that they have no other financial or non-financial interests that may be relevant to the submitted work.

Contributors: TMR had the original idea for the study. AWS prepared a draft study design, which was developed by all the authors. AWS, CJK, NDEA, and RJF carried out the analyses. AWS wrote the first draft of the paper. All authors contributed to further drafts and had full access to all data. TMR is guarantor.

Ethical approval: The study protocol was reviewed by the Wandsworth Research Ethics Committee, who ruled that the study was a survey and that therefore, under NHS research governance arrangements, did not require formal ethical approval (00105.09).

Data sharing: Anonymised data are available, on request, from AWS at anthony.solomon@lshtm.ac.uk.

1 Pearse R, Dawson D, Fawcett J, Rhodes A, Grounds RM, Bennett ED. Early goal-directed therapy after major surgery reduces complications and duration of hospital stay. A randomised, controlled trial. *Crit Care* 2005;9:R687-93.
2 Dellinger RP, Levy MM, Carlet JM, Bion J, Parker MM, Jaeschke R, et al. Surviving Sepsis Campaign: international guidelines for management of severe sepsis and septic shock: 2008. *Intensive Care Med* 2008;34:17-60.
3 Mathew D, Kirwan C, Dawson D, Philips B. In critically ill patients, how often is their weight estimated and how accurate is that estimate? *Crit Care* 2009;13(suppl 1):P460.
4 Rothman KJ, Greenland S. Modern epidemiology. 2nd ed. Lippincott-Raven, 1998.
5 NHS Employers. National Health Service hospital medical and dental staff and doctors in public health medicine (England and Wales): terms and conditions of service (version 9). 2008. www.nhsemployers.org/SiteCollectionDocuments/Hospital_Medical_and_Dental_Staff_TCS_March_08_cd_160209.pdf.
6 Bellomo R, Ronco C, Kellum JA, Mehta RL, Palevsky P. Acute renal failure—definition, outcome measures, animal models, fluid therapy and information technology needs: the Second International Consensus Conference of the Acute Dialysis Quality Initiative (ADQI) Group. *Crit Care* 2004;8:R204-12.
7 Collett D. Modelling binary data. Chapman and Hall, 1991.
8 Armitage P, Berry G, Matthews JNS. Statistical methods in medical research. 4th ed. Blackwell Scientific, 2001.
9 Ostermann M, Chang RW. Acute kidney injury in the intensive care unit according to RIFLE. *Crit Care Med* 2007;35:1837-43; quiz 52.
10 Ostermann M, Chang RW. Challenges of defining acute kidney injury. *QJM* 2010; epub ahead of print; http://qjmed.oxfordjournals.org/content/early/2010/10/08/qjmed.hcq185.full.pdf+html.
11 Ricci Z, Cruz D, Ronco C. The RIFLE criteria and mortality in acute kidney injury: A systematic review. *Kidney Int* 2008;73:538-46.
12 Royal College of Nurses. Working well: improving working relationships in health care. Royal College of Nurses, 2005.
13 Rogozov V, Bermel N. Auto-appendectomy in the Antarctic: case report. *BMJ* 2009;339:1420-2.
14 National Centre for Social Research/Medical Research Council. An assessment of dietary sodium levels among adults (aged 19-64) in the UK general population in 2008, based on analysis of dietary sodium in 24 hour urine samples. 2008. www.food.gov.uk/multimedia/pdfs/08sodiumreport.pdf.
15 Wemple RD, Lamb DR, McKeever KH. Caffeine vs caffeine-free sports drinks: effects on urine production at rest and during prolonged exercise. *Int J Sports Med* 1997;18:40-6.
16 Millard-Stafford ML, Cureton KJ, Wingo JE, Trilk J, Warren GL, Buyckx M. Hydration during exercise in warm, humid conditions: effect of a caffeinated sports drink. *Int J Sport Nutr Exerc Metab* 2007;17:163-77.
17 Armstrong LE, Pumerantz AC, Roti MW, Judelson DA, Watson G, Dias JC, et al. Fluid, electrolyte, and renal indices of hydration during 11 days of controlled caffeine consumption. *Int J Sport Nutr Exerc Metab* 2005;15:252-65.
18 Thurau K, Boylan JW. Acute renal success. The unexpected logic of oliguria in acute renal failure. *Am J Med* 1976;61:308-15.

Accepted: 19 November 2010