Urinary catheter blockage depends on urine pH, calcium and rate of flow

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Urinary catheters tend to block when biofilm from urease-producing organisms build up on the catheter surface. This is a locally-occurring process that influences and is influenced by the composition of the urine. In this work we relate urine pH and calcium to catheter blockage and suggest how to reduce the rate of encrustation. Sixty patients with indwelling urinary catheters were studied, 26 of them being troubled by frequent blockage of their catheters, 34 of them not. A series of small urine samples were collected during a 24 h period. Urinary pH and calcium concentration were combined into discriminant functions designed to separate Blockers from Non-blockers and achieved a 95% correct classification. The results indicate that a high and uniform rate of fluid intake is mandatory for the patient with a tendency for catheter blockage. Excessive total fluid intake may be avoided by attention to uniformity. Other avoidable risk factors include: excess dietary calcium from certain protein supplements and antacids; excess dietary magnesium from certain beverages and antacids; alkali from effervescent tablets; excess dietary citrate from some fruit juices and cordials; intermittent dehydration from alcohol ingestion. Less tractable risk factors include infection of the urinary tract with urease-positive organisms, hypercalciuria of immobilisation, hyperhydrosis and postural oliguria. The processes involved in catheter encrustation and blockage provide a model for the formation of calculi in spinal cord injured patients. Therefore the above considerations may also be relevant to the management of stone disease in paraplegic and tetraplegic patients.

Keywords: calcium; pH; urinary catheterization; urine

Introduction

The indwelling urinary catheter remains a regrettable necessity for many patients, recent advances in the management of the paralysed bladder notwithstanding. The formation of encrustations and eventual blockage is a common problem.¹ This process occurs much more rapidly in some patients than in others, suggesting a useful distinction between 'blockers' and 'non-blockers'.²

Present data suggest the following view. A urinary catheter left *in situ* rapidly acquires a surface biofilm.³ This consists initially of bacterial cells in a matrix of bacterial exopolysaccharide. When organisms are present that are capable of producing the enzyme urease, local increases in pH and ammonium concentration result in the formation of crystals of calcium phosphate and magnesium ammonium phosphate.⁴ Visible encrustation and eventual occlusion of the catheter lumen result from increasing thickness of the biofilm, particularly due to the accumulation of these phosphate particles. This is a locally occurring process that is accelerated when urine composition is

particularly favourable. Urinary pH and ammonium concentrations will increase if urease-producing organisms are present in the urine as well as by diffusion of ammonium and hydroxyl ions from the biofilm.

Different strains of bacteria differ in their ability to adhere to catheter surfaces, in their potency as urease producers and in the quantity and properties of the exopolysaccharide they produce. It is probable that, while bacterial cells and exopolysaccharide are always present and influence the system, growth in thickness of biofilm is dependent largely on the rate of accretion of mineral phosphates.

The aim of this communication is to confirm and extend previous observations^{5,6} and to discuss how present knowledge can be applied to prevent or reduce the rate of encrustation and so to lengthen the intervals between catheter blockages.

Patients and methods

There were 60 spinal cord injured patients with indwelling urinary catheters (Table 1). 'Blockers' (Group B) had catheters that blocked within 7 days. 'Non-blockers' (Group NB) had catheters that lasted at least 6 weeks without blocking. Most patients were using Bard Biocath catheters, except that when

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blockage was frequent the cheaper Bard teflon-coated Foley catheter was used. Argyle All Silicone or Dow Corning Silastic were used occasionally. Where blockage occurred it was by a solid chalky substance, shown by quantitative wet chemical analysis⁷ to consist of calcium, magnesium, ammonium and phosphate.

All urine passed during 24 h was collected in 2–4 h lots. Urinary pH was measured by glass electrode either immediately or after storage in ice for up to 14 h. In our experience urinary pH does not alter significantly when urine is stored in ice for 14 h. The urine was acidified (HCl) and analyzed for calcium.⁸

Stepwise multiple analysis of variance or regression (MANOVA) was used to determine when variables were significant predictors of catheter blockage. Student's *t*-test, the Mann-Whitney U-test and the χ^2 -test were used as appropriate to test for differences between different groups of data. Discriminant analysis was used to classify urine samples from patients as B or NB on the basis of their pH and Ca data and to further classify patients as B or NB on the basis of maximum, mean and minimum and the range and variance of discriminant values.

Table 1 Clinical details of the patients

	<i>Non-blockers</i>	<i>Blockers</i>
Numbers of patients:		
Total	34	26
Male, female	27, 7	15, 11
Tetraplegia, paraplegia	17, 17	14, 12
Age: range (median)	19–69 (41) y	15–72 (27) y
Duration of cord lesion:		
range (median)	2 m–38 y (2 y)	2 m–19 y (1 y)

m: months; y: years

Results

Group B patients were younger and more recently injured and comprised fewer males than Group NB (Table 1). Recently injured patients were hypercalcaemic. MANOVA, however, showed that the only data significantly related to catheter blockage were urinary pH and Ca concentration. None of the following showed a statistically significant effect on catheter blockage: age, gender, level of spinal cord lesion, duration of spinal cord lesion, catheter site (urethral or suprapubic), catheter material, catheter size. Mean 24 h urine volume was lower and mean 24 h Ca excretion higher in Group B than in Group NB but these differences were not statistically significant (Table 2). Volume was not significantly related to any other variable.

Mean and maximal circadian pH and Ca were significantly higher in Group B than in Group NB (Table 2). Maximal values gave greater levels of significance than mean values. Variance of Ca concentration was greater in Group B than in Group NB. Variance of pH did not differ between the two groups.

The pH and Ca concentration of all urine samples from both groups of patients were submitted to discriminant analysis. This yielded a discriminant function value (DU) for each urine sample, that represented the propensity for the sample to have been derived from a 'Blocker' or from a 'Non-blocker', as follows:

$$DU = 1.4244586 \cdot \text{pH} + 2.6677706 \cdot \log_{10} \text{Ca} - 10.6622992$$

By this means 289 of the 382 urine samples (75.6%) were correctly classified as B or NB.

The maximum, mean and minimum DU value for each patient and the range and variance of values of DU for the patient were then submitted to a second (stepwise) discriminant analysis. Only mean and maximum values contributed significantly. Within-

Table 2 Analysis of multiple small urine samples through 24 hours

<i>Catheters</i>	<i>Not-blocking</i> <i>n</i> = 34		<i>Blocking</i> <i>n</i> = 26		<i>T</i>	<i>P</i>
	<i>m</i>	<i>SD</i>	<i>m</i>	<i>SD</i>		
Volume (litre/24 h)	3.08	1.74	2.49	0.90	1.52	>0.05
Ca(mmol/24 h)	5.87	4.05	6.94	2.90	1.11	>0.05
pH _{mean}	6.41	0.509	7.11	0.782	4.12	<0.001
pH _{maximum}	6.91	0.504	7.80	0.731	5.51	<0.001
pH _{variance} *	0.196	0.225	0.248	0.203	0.91	>0.05
Ca _{mean}	2.67	1.903	4.43	2.704	2.94	<0.01
Ca _{maximum}	5.02	4.30	9.28	5.93	3.20	<0.01
Ca _{variance} *	0.795	11.45	4.44	4.59	3.10	<0.01
DU _{mean}	−0.90	0.985	0.88	0.822	7.44	<0.001
DU _{maximum}	0.08	1.033	2.08	1.084	7.24	<0.001
DP	−1.23	1.320	1.30	1.159	7.76	<0.001

Ca_{mean}, Ca_{maximum}, Ca_{variance} in mmol/l. DU calculated from urine pH and Ca – see text. DP calculated from DU_{mean} and DU_{maximum} – see text. *logarithms used in the calculation

group correlation between the discriminating variable and the canonical discriminant function was 0.932 for mean values and 0.901 for maximum values. (Discrimination was 50/58 and 53/58 respectively, and $X^2=48.0$ and 45.9.) This yielded a discriminant function value (DP) for each patient, represented by

$$DP = 0.5702991.DU_{\max} + 0.7856851.DU_{\text{mean}} - 0.5674960$$

By this means 56 of the 58 patients (96.6%) were correctly classified as B or NB ($X^2=52.2$).

The data from one outlier (patient X, an NB patient with dilute acid urine) were omitted from both discriminant analyses and the data on another patient (patient Y, a B patient with anomalously low DU values) were omitted from the second discriminant analysis. When the data on patients X and Y were included in the final data set, 57 of the 60 patients (95.0%) were classified correctly, the three misclassified patients being B patients wrongly classified as NB.

Urine samples were collected from patient Y for a second 24 h period. The DP values were -1.60 for the first period and $+0.50$ for the second, thus data from the second period of urine collection, but not from the first, yielded correct classification. In all, 30 patients had a second 24 h period of urine samples collected. In 26 there was no significant difference in DU values between the two periods. In four patients, who were all group B, DU values differed significantly (Students' unpaired *t*-test). During the first 24 h period of urine collection, two patients were correctly classified and two were incorrectly classified on the basis of their DP values. During the second period all four patients were correctly classified.

Discussion

The distribution of different types of catheter among the patients was not such as to permit recognition of an effect on catheter encrustation if it existed. Some *in vitro* data suggest such effects are small.^{9,10} Hedelin's group, however, reported reduced encrustation with silicone catheters.¹¹ With small bore catheters (Ch 14 or less) there may be a further advantage in the use of all-silicone catheters because they have a larger internal lumen than catheters made of other materials.^{2,5}

The results obtained in a study of this kind will be influenced by the frequency and duration of urine sampling. Urine composition from an individual subject varies widely from time to time. Continuous sampling of urine composition, if it could be carried out, would permit recognition of possibly brief episodes when urine is either very concentrated or very dilute, that might be missed if sampling is infrequent. Patients' activities, diet, fluid intake, ambient temperature, etc, may vary from day to day, affecting urine composition. The single 24 h period of 2–4 h monitoring used in this study was a practically feasible protocol that was less than ideal but which is considered to have yielded useful

information. The data on the 30 patients for whom samples for a second 24 h period are available illustrate this.

The patients whose catheters blocked frequently differed from those not so troubled by higher urine pH and Ca concentrations. This association has been noted by others.^{12–14} Improved separation between the two groups was obtained by combining pH and Ca values into a single discriminant function, DU. This gave a spread of values of DU for each patient that depended on variation in pH and Ca concentration during the 24 h period. The mean DU for each patient made it possible to predict which group the patient belonged to (correct in 51/60). The patients' maximal DU also permitted this prediction (correct in 54/60). Stepwise discriminant analysis showed that both mean and maximal DU contributed significantly to improved prediction, calculation of DP permitting 57 of the 60 patients (95%) to be classified correctly as B or NB.

It follows that catheter blockage was related both to the average levels of urinary pH and Ca concentration as well as to the highest levels of urinary pH and Ca occurring during the 24 h period. In other words blockage occurred either if there was small variation about a high mean or if high maximal values occurred with a lower mean.

The implications of this are important. Total fluid intake must be distinguished from variation in the rate of intake. Some patients responded to exhortations to increase their fluid intake by a dramatic increase in 24 h urine volume. This did not prevent them producing very concentrated urine. Urine was very dilute for much of the day while a large volume of urine was being produced. For a short period the urine was very concentrated. It seems likely that this was when deposit growth occurred.

Table 3 lists items that may be important in patient management. It should be emphasised that unless catheter blockage actually occurs in a patient manipulation of the diet may be unwarranted.

The most important single factor is fluid intake, which may need to be increased in hot weather or if the patient sweats excessively for any other reason. As emphasised above, variation in fluid intake at different times of the day should be minimised. Alcohol should be consumed in moderation on account of its influence on vasopressin release. Any period when concentrated urine is produced greatly increases the rate of catheter encrustation. Diuresis lowers urinary Ca concentration and dilutes bacterial nutrients and, possibly, removes organisms mechanically. Grossly elevated pH associated with oliguria can be lowered by dilution.⁵ It has been suggested that excessive fluid intake may lead to hyponatraemia,¹⁵ but no figure was suggested as to what is a maximum safe level of fluid intake, and the occurrence of hyponatraemia appeared also to involve the presence of sepsis and low sodium intake.¹⁵ The present data show no difference in

Table 3 Urinary factors that may influence the rate of catheter encrustation

Volume	
– total:	fluid intake patient compliance sweating – high environmental temperature – autonomic disturbance
– variation:	erratic fluid intake patient compliance postural oliguria alcohol intake vasopressin release (pain, anxiety, nausea)
pH	urease-producing organisms rate of urine flow bladder debris medication: effervescent tablets antacids (except alumina alone) diet (beverages containing much citrate) The role of citrate is uncertain; oral citrates raise urine pH & citrate and lower urine Ca
Calcium	immobilisation fluid intake diet: Ca (milk, cheese, yogurt, some high protein supplements) sodium, sucrose, protein (increase urine Ca) fibre (Ca adsorbing) veganism (Ca retaining, but alkaline ash) medication: some antacids contain much Ca acidifying therapy may raise urine Ca
Magnesium	fluid intake diet: some beverages contain much Mg medication: some antacids (especially magnesium trisilicate) acidifying therapy may raise urine Mg

24 h volume but greater variance of Ca concentration between B and NB patients suggesting that reduced catheter encrustation requires constancy of fluid throughput and avoidance of concentrated urine. Thus excessive total fluid intake is unnecessary. Some tetraplegics have oliguria while seated followed by diuresis when horizontal.

Apart from ensuring adequacy of fluid intake, it may not be possible to reduce urine pH when the urine contains urea-splitting organisms.¹⁶ Large local variations in pH may occur in different parts of the urinary tract.¹⁷ Effervescent tablets as well as antacids may contain much alkali and if taken in quantity may raise urine pH.^{9,18} This effect is accompanied by reduced urine Ca and increased citrate, the relative effects of which deserve further study.

The issue of citrate is controversial. *In vitro*, citrate reduces encrustation.⁹ Others have advocated citrate therapy for reducing catheter blockage.¹⁹ Available therapies that increase urine citrate have the effects of reducing urine Ca, but of increasing urine pH, an effect that is undesirable. Our data in patients do not indicate a beneficial role for citrate therapy. Beverages may contain a high concentration of citrate naturally (citrous fruits), or a large amount of citrate may be added by the producer (many cordials and other fruit juices). The citrate content of specific dietary items may only be important when consumed in exceptional quantity. Occasionally one encounters a patient whose entire fluid intake comprises one particular high citrate juice.

Following spinal cord injury urine Ca increases and alimentary Ca absorption is inhibited.²⁰ At this time changes in Ca intake have negligible influence on urine Ca²¹ and urine Ca concentration can be lowered only by increasing the intake of fluid. If urine Ca remains high in a paraplegic after 9 months or in a tetraplegic more than 18 months after onset of the cord lesion consideration may be given to reducing Ca intake. Some high protein dietary supplements and antacids contain much Ca. However, except in a few absorptive hypercalciuric individuals changes in dietary Ca intake have only a small influence on urine Ca excretion. Urine Ca is increased by high dietary sodium, sucrose or protein and reduced by fibre.²² Acidifying therapy may raise urine Ca without lowering urinary pH if urease-positive organisms are present.²³

In vitro studies have indicated that magnesium promotes the growth of deposits on catheters,⁹ this finding has not been confirmed *in vivo*⁵ and may only be significant at high pH. However, in some Blockers urine magnesium is elevated, frequently traceable to medication with a magnesium-containing antacid⁵ or to a dietary component. The occasional patient is encountered for whom a high-magnesium fruit juice or herbal tea is a major component of total fluid intake.

Conclusion

Blockage of a urinary catheter can almost wholly be explained in terms of the pH and Ca concentration of the patients' urine. Average values of pH and Ca are important, as also are their highest values. The evidence suggests that deposit forms on a catheter when the urine is concentrated and does not disappear when the urine is dilute. It follows that attention should be directed to avoiding any occasion when the urine is concentrated.

Infected urinary stones form by a process^{24,25} that is identical in important respects to that involved in the encrustation of catheters. The considerations presented in this paper may therefore also be relevant to the management of urinary stone disease in spinal cord patients.

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