Urinary Stone Formation After Spinal Cord Injury: Risk and Risk Factors

Yuying Chen, Michael J. DeVivo, and L. Keith Lloyd

Presumably because of immobilization and susceptibility to urinary tract infection, persons after spinal cord injury (SCI) are at increased risk for urinary stones. Analyzing data from the Model SCI Care Systems, a series of studies has been conducted to document the incidence and recurrence rate of kidney and bladder stones and to identify potential contributing factors, with an emphasis on environmental exposures. This article reviews these reports in comparison with general population data and discusses the plausibility of these findings in light of current knowledge about causal pathways to stone formation. The need for an effective prevention program is also addressed. Key words: *bladder, calculi, epidemiology, kidney, spinal cord injury*

Urinary stone disease is one of the common and serious complications after spinal cord injury (SCI); it occurs in almost 25% of patients within 10 years of injury.[1–4] Bladder stones are about four times more common than kidney stones. In the absence of adequate treatment, calculi can lead to sepsis, renal failure, and even death. To alleviate this health burden, a prevention program that appropriately intervenes to control risk factors for urinary stones is needed.

Characteristic geographic distribution of kidney stones and contributing factors have been addressed in the general population.[5] There are limited studies of potential environmental risk factors for SCI-related stones. More than 90% of urinary calculi in persons with SCI are struvite (magnesium ammonium phosphate),[6] whereas more than 70% of stones in the general population contain calcium oxalate, calcium phosphate, or both.[7] It is unknown whether risk factors identified in the general population can be applied to people with SCI. Any prophylactic strategy based on findings in able-bodied persons may be inappropriate for individuals with SCI.

Our institution has maintained a computerized database over the last three decades and possesses a large amount of longitudinal data on persons with SCI. This article reviews our data on the frequency of and determinants for kidney and bladder stones.[1–4,8–12] Potential risk factors as reported in the general population are reviewed when they appear relevant to struvite stones and people

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Top Spinal Cord Inj Rehabil 2003;8(3):8–19

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with SCI. The limitations of available data are also addressed.

Definition

In a series of investigations, we define urinary stone disease as an abnormal concretion in the kidney, ureter, or bladder documented by radiographs or cystoscopy. Stones that are reported by participants that pass spontaneously before radiographic evidence can be obtained are classified as bladder stones, even though they might have been renal in origin. Stones documented as first occurring after injury are assigned as initial stones. Recurrence of kidney stones is defined as kidney stone disease after the resolution of the initial stones by passage or surgical removal, irrespective of composition, localization, or the period intervening since the first stone episode.

Frequency (Incidence, Recurrence, Prevalence)

The high occurrence of calculi in the SCI population has been demonstrated over the last five decades by various case series[13,14] and follow-up studies.[1–4] In a longitudinal cohort of patients with SCI (**Table 1**), we observe a peak incidence of urinary stones during the first 3 months after injury. This incidence quickly declines and tends to level off after the first year. It is estimated that within 10 years, approximately 7% of patients injured after 1985 will develop kidney stones, whereas 15% of patients will have bladder stones. This incidence figure is considerably higher than that in the general population where an annual incidence of 0.4 to 2.0 per 1,000 population is reported.[15–17]

The overall recurrence of kidney stones is estimated to be 34% within 5 years after the resolution of the initial stones,[12] which is similar to previous reports in the general population.[17,18] Spinal cord–injured persons may be susceptible to stone formation early after injury; however, with appropriate management and close follow-up, their risk of stone recurrence becomes essentially the same as in the general stone-forming population.

The presentation of upper urinary tract stones, first or recurrent, ranges from 1.9% to 9.4% at annual surveillance.[19] The recur-

Table 1. Incidence of initial kidney and bladder stones in persons with spinal cord injury, stratified by injury cohorts

	Kidney stones		**Bladder stones**	
	1973–82 (*n* = 5,850)	**1986–99 (*n* = 8,314)**	**1973–84 (*n* = 720)**	**1985–96 (*n* = 616)**
Incidence (per 1000 person-years)				
Within 3 months after injury	38	31	400	140
Year 2 and later	10	8	15	10
Cumulative incidence (%)				
Within 8 years after injury	8.1	6.8	29.2	11.7
Within 10 years after injury	—	7.3	30.5	15.2

rence and prevalence of bladder stones have never been addressed.

A continuous decreasing trend is demonstrated in bladder stone incidence[4] but not in kidney stone incidence.[3] Because methods of urinary drainage do not appear to impact the development of kidney stones as strongly as that of bladder stones, contemporary bladder management techniques may have little influence on the current trend in kidney stones.

Risk Factors for Urinary Stones

Two main factors have been described to explain the high stone risk in the SCI population: immobilization hypercalciuria and increased susceptibility to urinary tract infection (UTI). The risk of stone formation varies by years since injury, therefore it is biologically plausible that different causal pathways may be involved at the different risk periods. Dysfunction of mineral metabolism, such as hypercalciuria, that is present during the acute phase of cord injury parallels and, perhaps, produces the peak incidence of urinary stones during the initial period after injury.[20] In the later years, as physical activity improves and urologic instrumentation increases, infection might play a more important role in stone causation. This hypothesis is supported by a finding that the chemical composition of SCI-related urinary stones is predominantly nonoxalate calcium (carbonate apatite) during the early years and consists of a higher proportion of magnesium (struvite) in the later years.[6]

Because UTI is much more common than urinary stones, infection may be a necessary component of, but may not be sufficient to cause, stone formation. It is possible that other factors interact with hypercalciuria and UTI in stone formation. Because stone risk differs before and after the first year postinjury, potential risk factors for stones are addressed separately for the two risk periods.

Age

During the first year after injury, older persons have an increased risk of kidney stones but a decreased risk of bladder stones (**Table 2**). Age plays no significant role in stone formation during the later years after injury or in the recurrence of kidney stones.[12]

In the general population, the peak age at onset of kidney stones is around 30 years. On account of the high recurrence, however, the presentation of kidney stones seems to come between 40 and 60 years of age.[7,16,17] Kidney stones are uncommon in children and the elderly. The relatively low urinary excretion of calcium and oxalate as a result of low levels of hormones has been hypothesized as the reason for the decreased risk in these age groups. It is unknown whether this etiologic mechanism is shared with SCI-related stones, especially during the initial period after injury when immobilization hypercalciuria is a concern.

Race

In the general population, kidney stone risk is approximately 2-fold higher for Caucasians than for African Americans and Asians.[16,21] This might be partly attributable to the difference in access to care that produces the underreporting of stone incidence in the non-Caucasian population. With respect to struvite stones, African Americans have a greater risk than Caucasians, perhaps as a result of higher susceptibility to UTI.[21]

Among persons with SCI, the risk of initial kidney or bladder stones is reported to be up to two times higher for Caucasians than for Af-

Table 2. Demographic risk factors for initial kidney and bladder stones in persons with spinal cord injury, stratified by years since injury

	Kidney stones[a]		Bladder stones[b]	
	1986–99 (n = 8,314)		1973–96 (n = 1,336)	
Factors	**Year 1**	**Year 2 & later**	**Year 1**	**Year 2 & later**
Gender				
Women	1.0	1.0	1.0	1.0
Men	1.5 (0.9-2.5)	1.4 (0.9-2.2)	1.6 (1.0-2.7)	1.9 (1.1-3.5)
Race				
African American	1.0	1.0	1.0	1.0
Caucasian	2.1 (1.3-3.3)	1.3 (0.8-1.9)	2.1 (1.4-3.2)	1.6 (0.9-2.7)
Current age (years)[c]				
15–24	1.5 (0.9-2.3)	1.3 (0.8-2.0)	1.0	1.0
25–34	1.0	1.0	0.6 (0.4-0.9)	0.9 (0.5-1.7)
35–44	1.5 (0.9-2.6)	1.1 (0.7-1.8)	0.5 (0.3-0.9)	0.9 (0.4-1.8)
45–54	1.8 (1.0-3.5)	0.9 (0.4-1.7)	0.3 (0.1-0.7)	0.8 (0.3-2.0)
> 54	2.0 (1.1-3.5)	1.5 (0.9-2.6)	1.2 (0.4-3.3)	1.0 (0.4-2.4)

Note: Data presented as risk ratio (95% confidence interval).

[a]Multivariable Cox regression models adjusted for neurologic deficit, bladder management, and listed variables.

[b]Multivariable Cox regression model adjusted for neurologic deficit, bladder management, injury cohort, symptomatic urinary tract infection, and listed variables.

[c]Time-variant measurement.

rican Americans, particularly during the first year after injury (**Table 2**). A similar, but not significant, trend is also found in the recurrence of kidney stones (5-year recurrence: 44% vs. 19%, p = .46). This observation appears contrary to a slightly higher incidence of UTI, an important risk factor for struvite stones, among African Americans.[22] It is possible that in addition to UTI, race might be an indicator of other stone determinants such as microbiologic characteristics of infection, diet, fluid intake, and other host factors.

Gender

Several investigations in the general population observe that men are two to three times more likely to develop stones than women.[15–17] Hormonal effects on urinary excretion of calcium and oxalate have been described as a potential causal mechanism. Struvite stones, nevertheless, seem to be more common in women than men, perhaps as a result of increased susceptibility of women to UTI.[23]

In the SCI population, the risk of initial stones is greater for men than women for both risk periods (**Table 2**). The 5-year recurrence of kidney stones tends to be higher for men than women, but not significantly (38% vs. 14%, p = .66). The increased risk of struvite stones observed in able-bodied women is not observed in the SCI population. One possible explanation is that the neurogenic bladder dysfunction and urinary drainage in men with SCIs overcomes the negative impact of

Table 3. Injury-related risk factors for initial kidney and bladder stones in persons with spinal cord injury, stratified by years since injury

	Kidney stones[a]		Bladder stones[b]	
	1986–99 (n = 8,314)		1973–96 (n = 1,336)	
Factors	**Year 1**	**Year 2 & later**	**Year 1**	**Year 2 & later**
Neurologic deficit				
ASIA D	1.0	1.0	1.0	1.0
Paraplegic, ASIA A, B, or C	1.1 (0.6-1.9)	1.4 (0.8-2.7)	0.9 (0.4-1.7)	1.2 (0.2-6.2)
Tetraplegic, ASIA A, B, or C	1.6 (1.0-2.8)	1.9 (1.0-3.6)	1.1 (0.5-2.1)	2.3 (0.4-12.8)
Bladder management[c]				
Catheter free	1.0	1.0	1.0	1.0
Intermittent catheter	1.2 (0.6-2.1)	2.4 (1.2-5.2)	4.7 (1.8-12.2)	6.2 (1.1-35.7)
Condom catheter	1.3 (0.6-2.8)	2.0 (0.9-4.6)	4.6 (1.8-11.6)	2.5 (0.4-13.4)
Indwelling catheter	1.3 (0.6-2.7)	2.5 (1.1-5.7)	8.8 (3.4-22.9)	18.8 (3.5-101.5)

Note: Data presented as risk ratio (95% confidence interval). ASIA = American Spinal Injury Association Impairment Scale.

[a] Multivariable Cox regression models adjusted for gender, race, age, and listed variables.

[b] Multivariable Cox regression model adjusted for gender, race, age, injury cohort, symptomatic urinary tract infection, and listed variables.

[c] Time-variant measurement.

a shorter urethra or other factors on UTI in non-SCI women.

Severity of injury

Persons with abnormal reflexes or minimal neurologic deficit are reported to remain free of kidney stones for up to 8 years after injury. Increased severity of neurologic damage is associated with an increasing risk of initial stones, particularly during the later years (**Table 3**). The recurrence of kidney stones, however, tends to relate to the level of injury only (5-year recurrence, paraplegic vs. tetraplegic: 23% vs. 45%, $p = .09$) and not to the completeness of injury (5-year recurrence, incomplete vs. complete: 34% vs. 35%, $p = .47$).

A direct relation between severity of injury and mineral metabolism dysfunction might contribute to the increased stone risk among persons with severe injury.[13,20] Another possible explanation is that the severity of injury impacts renal excretory function differently.[13]

Methods of urinary drainage

For persons who were injured after 1985 and who could void satisfactorily using any method of reflex stimulation or any form of extrinsic pressure at discharge, less than 2% were estimated to have kidney or bladder stones within 5 years. The impact of other methods of urinary drainage on stone formation varies by stone type and risk periods (**Table 3**).

Kidney stones are not significantly associated with bladder management during the initial period, but there is a stronger relation in

the later years. For people using indwelling urethral or suprapubic, intermittent, and condom catheterization, the likelihood of developing kidney stones seems not to be significantly different ($p > .35$); it is about 2.5 times higher than in those with satisfactory bladder control. The findings agree with most previous investigations.[1,8,24,25] The recurrence of kidney stones is not influenced by the method of urinary drainage; the 5-year recurrence for indwelling catheterization and other methods (predominantly condom catheterization) is 22% versus 39% ($p = .46$).

Bladder management tends to impact bladder stones more than kidney stones. Compared with patients who are free of a catheter and external collection system, the risk of bladder stones for the users of an indwelling catheter is 9-fold and 19-fold increased during the first year and in the later years, respectively. Over the last 25 years, the influence of methods of urinary drainage on bladder stones has decreased, although it is still substantial.[4]

Despite less susceptibility to UTI,[22] persons with intermittent catheterization have a higher risk of bladder stones than persons with condom catheterization during the later years after injury. This may partly be explained by the fact that persons using intermittent catheterization tend to limit fluid intake to reduce the frequency of catheterization, which leads to concentrated urine and subsequent stone formation. Also, an inappropriate self-catheterization technique might increase the likelihood of introducing a foreign body (i.e., pubic hair) into the bladder during the process, which could initiate the formation of stones around a foreign-body nidus.

Urinary tract infection

Previous studies carried out in the SCI population have confirmed a direct, but weak, relation between UTI and stone occurrence.[2,8,24] For the bacteria profile, most of the urea-splitting bacteria (proteus, pseudomonas, klebsiella, and staphylococcus) have been shown to increase the risk of urinary stones, although statistical significance is not usually achieved, perhaps because of a small sample size.[2,8] Whether the observed UTI is a cause or a consequence of stone formation has not been carefully examined because the majority of previous investigations evaluated UTI at the time of stone diagnosis, at admission, or at discharge, which might not be relevant to the time of stone onset.

To account for the time-variant nature of UTI, we consider the information on UTI obtained at the previous visit as a factor preceding stone formation. Between 63 stone cases (31 kidney, 27 bladder, and 5 both) and 289 stone-free controls, the frequency of symptomatic UTI (17% vs. 18%, $p = .89$) and presentation of significant bacteriuria (79% vs. 75%, $p = .41$) did not differ significantly.[10] In a longitudinal cohort of 1,336 patients with SCI, the presence of preceding symptomatic UTI had no significant influence on the formation of bladder stones.[4]

It is difficult to investigate the causal relationship of UTI to stone formation because bacteriuria is very common among spinal cord–injured patients, and many factors are believed to interplay with infection to lead to the development of stones. Because UTI tends to occur after stone formation, it is crucial to address the temporal relation and induction period between UTI and stone formation.

Urologic complications

Kidney stones have been known to cause the deterioration of renal function in persons

with SCI.[26] Decreased total effective renal plasma flow (ERPF) is shown to precede stone formation in our investigation; this association remains relatively consistent for kidney, bladder, initial, and recurrent stones.[10] It is possible that factors associated with decreased ERPF, such as previous procedures on the kidneys, promote urinary stasis and subsequent stone formation; this supposition needs further confirmation.

Vesicoureteral reflux, which enhances susceptibility to upper UTI, has been found to increase the risk of kidney stones by up to 3-fold,[8,14,24] but not significantly. Patients with a history of bladder stones seem to be at an increased risk for kidney stones[1,8]; this is particularly important for persons who are free of vesicoureteral reflux.[14] It is biologically plausible that kidney and bladder stones share similar risk factors, because the main chemical composition of both stones contains struvite.

Urine composition

Burr and associates have conducted a series of biochemical studies to delineate the characteristic urine composition in patients with SCI and to assess its potential on stone formation. Urine pH and ammonium are shown to be consistently higher for patients with kidney stones or catheter blockage.[27,28] Urinary calcium, magnesium, and phosphate are also slightly higher, but the statistical significance varies by studies. Biochemical risk factors for bladder stones or recurrent stones have seldom been addressed in the literature. Results of limited published studies indicate that urine pH and calcium have no impact on bladder stones.[2,29]

The major problem of these studies is that most of the laboratory tests were performed at, or even after, the diagnosis of stones or catheter blockage. Differences in particular urine composition might be a consequence, rather than a cause, of stone disease because biochemical factors vary by diet, fluid intake, and renal function, which is likely to change after stone diagnosis. To clarify the temporal relation, we obtained the data on urine pH before stone diagnosis and did not find a direct association between urine pH and stone presentation.[10]

Although the chemical composition of the debris from a catheter with blockage is identical to the composition of struvite stones, the relation between catheter blockage and stone formation has not been documented. Thus, the generality of risk factors for catheter blockage to urinary stones, especially among patients free of a catheter, is uncertain. Furthermore, potential confounding and interaction by other risk factors (such as UTI) are not justified in most of the previous analyses.

Possible environmental determinants

Various nationwide surveys report that persons living in the southeastern region of the United States have a higher stone occurrence than persons in other regions.[30] Analyzing data from 21 SCI centers, we found a remarkable geographic variation in kidney stones,[9] which is generally in agreement with reports in the general population. The characteristic geographic distribution suggests that environmental factors might play a part in stone formation, and the increased risk among spinal cord–injured persons may be preventable by intervening in environmental exposures. In the general population, various potential environmental determinants of urinary stones have been identified. Investigations of this issue among spinal cord–injured persons, however, are sparse.

Temperature, latitude, and sunlight index

In a nationwide survey in the United States, the prevalence of kidney stones is reported to increase from the north to the south, with increasing mean air temperature and sunlight index.[30] Among persons with SCI who enrolled in the National SCI Database, we observe an increasing incidence of initial kidney stones with decreasing latitude and increasing average annual temperature regardless of risk periods.[9] There is, however, no consistent trend of sunlight index with SCI-related stone formation. Water loss as a result of warm climates, along with inadequate fluid intake, is a possible contributor to a higher stone incidence in the South.

Water hardness

There is controversy regarding the relation between urinary stones and water hardness. Similar to the findings in the general population,[31,32] a study conducted on an aggregate level in the SCI population observes a higher incidence of kidney stones in areas with decreasing water hardness and calcium and magnesium content.[9] In a study of individuals, the water hardness and concentrations of calcium and magnesium in a community water supply are reported to be similar between stone cases and stone-free controls, regardless of adjustment for the amount of water intake.[10,11] This discrepancy may be caused by a small variation of drinking water hardness in the study areas of case-control studies, which is not sufficiently important to affect differentially the risk of stone formation.

Water hardness is caused primarily by compounds of calcium and magnesium. Increased calcium intake has been reported to decrease stone incidence in the general population.[33] It is hypothesized that dietary calcium decreases urinary excretion of oxalate by binding with oxalate in the gastrointestinal tract. Another hypothesis is that lower calcium intake may induce 1,25-vitamin D-mediated bone resorption that, consequently, increases urinary calcium. Moreover, magnesium competes with calcium for binding and prevents the formation of calcium salt. Experimental studies have provided evidence that mineral water, high in calcium and magnesium, favorably alters urinary concentration and relative supersaturations of stone salts.[34] In addition, the taste difference between soft and hard drinking water might affect the amount of water intake.

Fluid intake and beverage type

High fluid intake should reduce the likelihood of stone formation, because of increased urine volume and diluted stone constituents in urine. Direct evidence of a protective association between high fluid intake and urinary stones has been provided by some studies,[35] but not our study[11] or others.[36]

Among healthy adults in the steady state, total fluid intake might solely determine urinary dilution status. For spinal cord–injured persons, several other factors (such as impairment of renal function and heavy sweating as a result of autonomic disturbance) have the potential to influence urine volume and concentration. Urine specific gravity measures urinary density function and may be a better indicator of urinary dilution in persons with SCI. After potential confounding factors are adjusted for, increased urine specific gravity is shown to be significantly related to a higher frequency of stone presentation.[10]

The effects of different beverages on the development of stones have been examined

in the general population.[5,35–37] Beer and coffee are consistently associated with decreased stone risk. This protective effect is presumably mediated through the interference of the secretion of antidiuretic hormone (ADH), leading to increased urine flow and diluted urine. Prospective follow-up studies show that stone incidence is increased by the consumption of grapefruit juice, but not other fruit juices.[35] The mechanism of this observed effect is not described by previous investigators.

Among spinal cord–injured persons, we observe that fluid choice is important in influencing stone formation, independent of the effect of total fluid intake.[11] A greater intake of juice, primarily cranberry and orange juices, is associated with reduced frequency of stone presentation. An interesting, but not significant, increased risk for stone formation caused by coffee consumption is also noted in the SCI population. There is no evidence that milk consumption increases stone risk.

Cranberry juice has been known for decades to reduce UTI; perhaps it decreases the risk of stone formation as the result of urine acidification, the inhibition of bacterial adhesion, or both.[38] Orange juice has not been recommended for patients with SCI because of its potential to increase urine pH and related stone formation. Recent studies, however, suggest that citrate provided by orange juice favorably inhibits the urease-induced crystallization,[39] probably mediated by the citrate complexation of magnesium.

Coffee has a potential to increase urinary excretion of calcium, which may overcome its effect on increasing urine output, that leads to stone formation.[40] Other unknown components of coffee and uncontrolled confounding factors may have also contributed to this direct, but marginally significant, relation between coffee consumption and urinary stones in this patient population.

Persons with SCI have been advised to limit milk intake because of its high calcium content and related risk of stone formation. Nevertheless, similar to a previous study in the general population,[5] milk consumption shows a tendency to reduce stone occurrence in our population. Because spinal cord–injured individuals are also at risk for osteoporosis, calcium intake should not be routinely restricted.

Summary and Conclusion

This article mainly summarizes our 30-year experience in the Model SCI Care Systems on the risk and risk factors for urinary stones in persons with SCI. Over the last three decades, bladder stone rates have declined consistently for various ages, genders, races, severity of injury, and methods of urinary drainage. Despite this promising news, bladder stones are more common than kidney stones, and spinal cord-injured persons with certain characteristics are still at substantially increased risk of urinary stones.

Demographic factors appear to be more strongly associated with urinary stones during the first year, whereas injury-related variables (severity of injury and methods of urinary drainage) are more important factors in the later years. Both kidney and bladder stone formers are more likely than stone-free patients to be male and Caucasian, have more severe injury, and need instrumentation for urinary drainage. The type of bladder management (such as indwelling urethral or suprapubic, intermittent, and condom catheterization) differentially impacts bladder stone formation; however, it does not appear to be

an important factor in determining kidney stone incidence or recurrence.

Kidney stone incidence is greater in the southeast United States and tends to increase with decreasing latitude, which is similar to the geographic association with kidney stones in the general population. Decreasing water hardness could well explain this geographic variability during the first year after injury, whereas increasing air temperature is an important contributor in the later years. Sunlight index has no relation with kidney stone incidence in the SCI population.

Analyzing data from 63 stone cases and 289 age- and duration-matched controls, we observe a continuously increasing trend in stone occurrence with increasing urine specific gravity. A greater intake of juice, primarily orange and cranberry juices, significantly reduces stone formation.

Because of constraints with our existing database, several limitations are inevitable. We lack detailed information on the microbiological characteristics of UTI and prophylactic antibiotic use. This error, if any, is likely to be minimal because methods of urinary drainage (a strong predictor of UTI) are adjusted for in the analyses, and prophylactic antibiotics are not routinely recommended for patients with SCI by most of the collaborating centers.

Our data are unable to address the influence of several factors, including bladder characteristics and metabolic features, on stone formation. The stone composition is not available in the database for further clarification of stone etiologies. Nonetheless, because more than 90% of stones have been reported to be struvite in the SCI population and a significant association between injury-related characteristics and stone occurrence was shown in these reports, we believe that the majority of stones under study are struvite, perhaps mixed with various amounts of calcium components.

Differential loss to follow-up by various characteristics cannot be ruled out as biasing study findings if the baseline risk of stones is different between lost and compliant participants. Likewise, the study results might not be generalizable to persons with minimal neurologic deficit, normal bladder control, and lost to the system care, who are underrepresented in our database.

Information on fluid intake and beverage type as reported by study participants during telephone interview might be subject to recall errors or bias. The validity of the self-reported data, however, is assessed in several aspects. It reveals that our data are consistent with common practices and the experiences in the general population.

These studies provide evidence of geographic variability and environmental risk factors for stones. They imply that the high risk of urinary calculi in the SCI population is potentially preventable by intervening in environmental factors (i.e., water hardness) and modifying life style (i.e., decreased exposure to high temperature and adequate beverage use). The urine specific gravity test strip may be a useful tool as a self-feedback mechanism to monitor urinary dilution and modify fluid intake and beverage type for maintaining specific gravity below a certain level (e.g., 1.010). Compared with oral prophylactic medicines that have achieved limited success and have adverse side effects, use of a test strip to develop an individualized fluid regimen may be more cost-effective in the control of stone occurrence and recurrence.

Although most urinary stones can be managed successfully by surgical modalities, an effective prevention program will have a

tremendous benefit on reducing economic impact, preserving renal function, and improving quality of life for persons with SCI. Because the etiologic pathways seem to differ by years postinjury, any intervention programs need to be specific for each risk period. Because the greatest risk of urinary stones occurs soon after injury, any strategy against stone formation should be commenced immediately after injury.

The causality of stone formation is multifactorial. We believe that there are additional risk factors to explain the increased rate of stone formation. This review might serve to help investigators generate causal hypotheses and develop further research to examine how these factors influence stone formation and how they can be modified to reduce stone formation in this patient population. For example, an experimental study that assesses the effects of particular beverages on urine specific gravity and UTI may help elucidate causal pathways to stone formation. The potential effect of certain fruit juices against stone formation and related etiologic mechanisms also need confirmation, thus possibly leading to an effective fluid regimen for stone prevention.

Acknowledgments

This work was supported in part by grants H133N50009-96A and H133B980016A from the National Institute on Disability and Rehabilitation Research, Office of Special Education and Rehabilitation Services, US Department of Education, Washington DC.

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