National Trends in CT Utilization and Estimated CT-related Radiation Exposure in the Evaluation and Follow-up of Stone Patients

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OBJECTIVE To describe trends in computed tomography (CT) use and estimate the radiation exposure among stone formers using a national insurance claims database.

METHODS Within MarketScan, adult stone patients from 2007 to 2013 were identified using International Classification of Diseases-Revision 9, International Classification of Diseases-Revision 10, and Current Procedural Terminology codes. Patients were classified as "active" (≥2 diagnosis codes for nephrolithiasis, or receipt of stone surgery) or "inactive" (1 stone diagnosis) and compared to age- and gender-matched controls. CT utilization was tracked over 3 years for each group. Annual CT-related radiation exposure was estimated using previously published dose values and compared using Kruskal-Wallis and χ^2 tests. Demographic factors associated with greater CT exposure were identified on multivariate logistic regression.

RESULTS Of active stone patients, 112,140 underwent surgery and 215,376 were managed nonoperatively. There were 175,228 inactive stone patients and 502,744 controls. On average, active stone patients received nearly 10 times as many CTs as controls at 3 years (P <.001), and more acute imaging (P <.001). About 25% and 15% of operative and nonoperative patients, respectively, received ≥3 CTs in 3 years. This was associated with female gender. For nonoperative patients, this was also associated with age, residence in the North-Central or South regions, and inversely associated with metropolitan residence (all P <.01). Over 10% of active stone patients are estimated to receive >20 mSv in the first year alone.

CONCLUSION CT use and nonsurgical radiation exposure for active stone patients is significant. Over 10% are estimated to exceed occupational limits in the first year. Judicious CT imaging and low-dose protocols are critical for stone patients. UROLOGY 133: 50−56, 2019.

With over 62 million studies obtained each year and an estimated annual growth rate of 7.8%, computed tomography (CT) use has rapidly grown since its initial development in the 1970's.[1,2] Consequently, the long-term effects of ionizing radiation have become a growing concern. Though current knowledge regarding the impact of CT-related radiation has been largely extrapolated from data on atomic bomb survivors and nuclear workers, studies in these populations suggest that even low doses of radiation from 0.5 to 20 mSv may increase risk of future cancers.[3,4] This stochastic effect is of significant concern for patients exposed to radiation from medical imaging; predictive models suggest that up to 2% of future cancers and as many as 29,000 new malignancies annually may be attributable to CT-related radiation.[1,5]

The International Commission on Radiological Protection recommends an occupational exposure dose limit of <20 mSv per year averaged over 5 years, with no single year's exposure exceeding 50 mSv.[6] However, there remains no well-defined limit for patients exposed to medical radiation. Due to its high sensitivity and specificity, CT has become the initial imaging study of choice for nephrolithiasis.[7] As patients with urinary stone disease are prone to recurrence, they receive repeated CT studies and are at particular risk for high lifetime cumulative radiation exposures. To date, the longitudinal exposure of stone patients to ionizing radiation from CT imaging remains poorly defined.

Using a national insurance claims database, we describe CT utilization among patients with active urinary stone disease and estimate the cumulative radiation exposure accrued from CT imaging during 3 years of follow-up. For

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comparison, CT utilization and CT-attributable radiation exposure was also evaluated in a control cohort of patients without known stone diagnoses.

MATERIALS AND METHODS

MarketScan is an administrative insurance claims database that includes billing claims from over 350 individual payers for over 43.6 million privately insured enrollees and their dependent spouses and children. Inpatient and outpatient data for a single individual is collated and verified in a standard fashion. The database captures entire episodes of care at the individual patient-level, as well as longitudinal follow-up of patients for the duration of insurance enrollment. All MarketScan enrollees and their claims are deidentified.[8]

We performed a retrospective cohort study of adult patients over age 18 enrolled in MarketScan between 2007 and 2013 with active urinary stone disease who were followed for 3 years out to 2016. A minimum of 6 months' prior enrollment and 3 years of continuous enrollment for follow-up was required. Patients over age 65 were excluded, as they could potentially have concomitant Medicare coverage resulting in imaging studies not captured within the database. Additional exclusion criteria included receipt of a previous surgical stone procedure in the 6 months preceding study entry. Institutional review board approval was not required for this study.

Active stone disease was defined as: (1) ≥ 2 primary diagnosis codes for nephrolithiasis without any surgical interventions during the study period ("non-operative") or (2) receipt of a stone procedure ("operative"), such as ureteroscopy , shockwave lithotripsy (SWL), or percutaneous nephrolithotomy. For comparison, age and gender-matched controls without nephrolithiasis diagnosis codes were identified, as well as a cohort of patients with inactive stone disease, defined by a single diagnosis code for nephrolithiasis without subsequent stone diagnoses over the study period. Patients were identified by review of International Classification of Diseases-Revision 9 (ICD-9) and Current Procedural Terminology codes for nephrolithiasis and stone-related procedures (Appendix 1A).

The cumulative number of CT; kidneys, ureter, and bladder x-ray (KUB); and ultrasound studies obtained for patients within each cohort was tracked annually over 3 years using ICD-9, ICD-10, and Current Procedural Terminology codes (Appendix 1B). Codes on claims for CT were classified as either noncontrast or contrast-enhanced CT study types. Multiple claims with codes for the same study type obtained on the same day were presumed duplicates and counted only once; however, if there were codes for both noncontrast and contrast-enhanced CT obtained the same day, these were counted as 2 studies. Imaging obtained within 6 months before study inclusion was included for analysis, as this was presumed to represent index diagnostic imaging. Both average number of studies and overall distribution of CT imaging were examined. Imaging utilization by imaging type was compared across groups at all time points using Kruskal-Wallis tests. Indication for and location of obtained imaging were also tracked across all groups.

To provide estimates of cumulative CT-related radiation exposure in each cohort, median effective radiation doses were selected from the range of reported exposures in previously published multi-institutional studies.[9,10] To account for differences in exposure for different study types, single phase, multi-phase, and anatomically restricted studies were assigned distinct doses. The respective effective radiation values assigned to each study type are listed in Appendix 2. All CTs were presumed to be standard dose, as low-dose CT could not be distinguished from standard CT in this database. Radiation related to KUB imaging was also determined for each group, using a previously reported median value of 0.7 mSv per KUB.[11] If there were multiple claims on a single day for the same imagining type, the code with the highest median dose was used.

The proportion of individuals in each group estimated to receive >20 mSv and >50 mSv annually in CT-related radiation was determined at each year and compared using χ^2 tests. A multivariate logistic regression analysis was used to identify demographic factors associated with the receipt of ≥3 CT over 3 years. To better contextualize our results using most conservative estimates, additional sensitivity analyses were performed assuming all CT studies used "low dose" protocols (3 mSv). All analyses were performed using SAS 9.4® (Cary, NC, 2017).

RESULTS

A total of 327,516 patients with active stone disease were identified. Of these, 112,140 were managed operatively and 215,376 were managed nonoperatively. There were 175,228 inactive stone patients and 502,744 age- and gender-matched controls. Patient characteristics for each group are listed in Table 1**.** For operative and nonoperative stone patients, 25.6% and 29.15% of CT imaging was ordered in the acute setting (urgent care or Emergency Department [ED]), compared to 27.1% of inactive stone patients and 13.4% of controls at study entry; these differences did not significantly change over time during the study period (*P* <.001). "Renal colic" and "stone" were indications for 75.3% and 68.2% of operative and nonoperative stone patients, respectively, compared to 0.45% of controls. The most common indication for CT imaging among controls were "abdominal pain" (34.8%).

Mean cumulative utilization of CT, KUB, and ultrasound over time is shown for each group in Appendix 3. In the first year of follow-up, active stone patients managed operatively receive a mean of 1.48 ± 1.13 CTs, while those managed nonoperatively receive a mean of 1.1 ± 0.97 CTs. On average, patients with active stone disease received significantly more CT studies as controls at all time points following study entry (*P* <.001). The overall trend of mean cumulative CT utilization over time (Fig. 1**)** suggests that inactive stone patients receive CT imaging at similar rates to control patients, whereas both nonoperative and operative active stone patients receive imaging at similarly higher rates over time. By the end of 3 years, nonoperatively managed patients received more than 9-fold and operatively managed patients received more than 12-fold the number of CT's as controls (1.53 ± 1.54 and 2.02 ± 1.83 vs 0.16 ± 0.63, respectively). KUB use was also significantly higher among active stone patients, with nonoperative patients receiving over twice the number of KUBs as controls, and operative patients receiving over 10 times more than controls by year 3 (*P* <.001).

Within the active stone group, CT utilization varied widely across patients. The relative frequency of cumulative CT counts for operative and nonoperative stone patients at year 3 are shown in Fig. 2A and B. Over 3 years, 25% and 15% respectively received ≥3 CT scans during the study period in the operative and nonoperative groups, respectively. Notably, 675 (0.6%) operative and 741 (0.34%) of nonoperative stone patients received 10-15 CTs over 3 years; 144 (0.13%) and 204 (0.09%) in each group, respectively, received >15 CTs (Fig. 2C). In

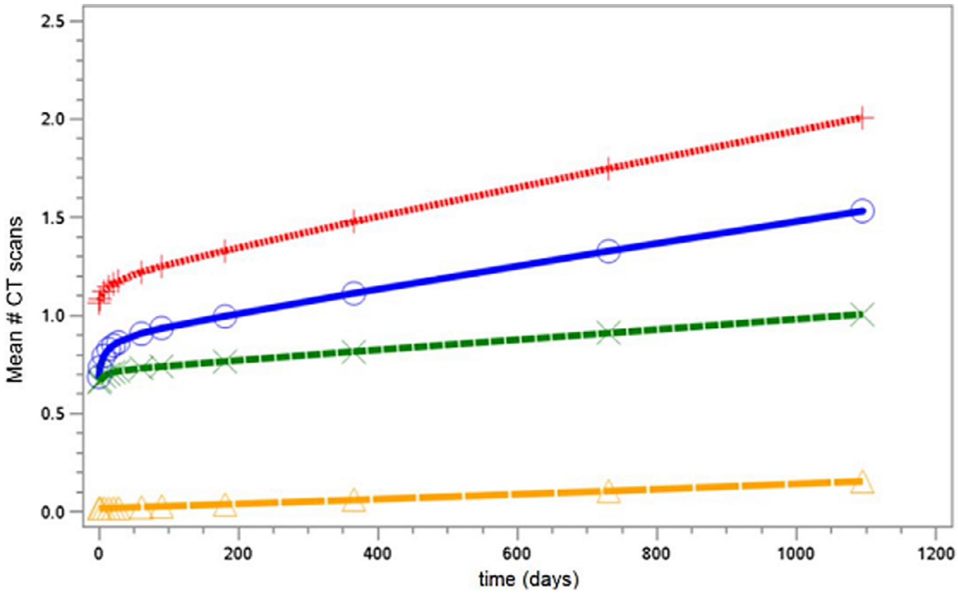
Table 1. Demographic characteristics of study patients, by group

	Active Urinary Stone Disease			
	Surgical Management	Nonoperative Management	Inactive Urinary Stone Disease	No Urinary Stone Disease
Total number	112,140	215,376	175,228	502,744
Gender				
Male	63,392 (56.5%)	122,594 (56.9%)	90,040 (51.4%)	276,026 (54.9%)
Female	48,748 (43.5%)	92,782 (43.1%)	85,188 (48.6%)	226,718 (45.1%)
Age				
18-39	25,340 (22.6%)	58,957 (27.4%)	49,191 (28.1%)	133,488 (26.6%)
40-49	31,611 (28.2%)	61,717 (28.7%)	50,451 (28.8%)	143,779 (28.6%)
50-59	45,313 (40.4%)	78,469 (36.4%)	61,876 (35.3%)	185,658 (36.9%)
60-65	9876 (8.8%)	16,223 (7.5%)	13,710 (7.8%)	39,819 (7.9%)
Location				
Northeast	15,369 (13.7%)	36,099 (16.8%)	28,157 (16.1%)	45,111 (9.0%)
North-Central	26,998 (24.1%)	47,384 (22.0%)	37,888 (21.6%)	140,142 (27.9%)
South	52,560 (46.9%)	91,565 (42.5%)	76,897 (43.9%)	275,067 (54.7%)
West	14,477 (12.9%)	34,362 (15.0%)	27,469 (15.7%)	41,367 (8.2%)
Unknown	2736 (2.4%)	5966 (2.8%)	4817 (2.8%)	1057 (0.2%)
HMO				
Yes	17,633 (15.7%)	36,535 (17.0%)	28,992 (16.6%)	74,450 (14.8%)
No	92,157 (82.2%)	174,330 (80.9%)	142,602 (81.4%)	427,852 (85.1%)
Unknown	2350 (2.1%)	4511 (2.1%)	3634 (2.1%)	442 (0.1%)
Metropolitan statistical area				
Yes	109,481 (97.6%)	209,619 (97.3%)	170,672 (97.4%)	501,832 (99.8%)
No	2659 (2.4%)	5757 (2.7%)	4556 (2.6%)	912 (0.2%)

All categories significant across groups *P* <.01.

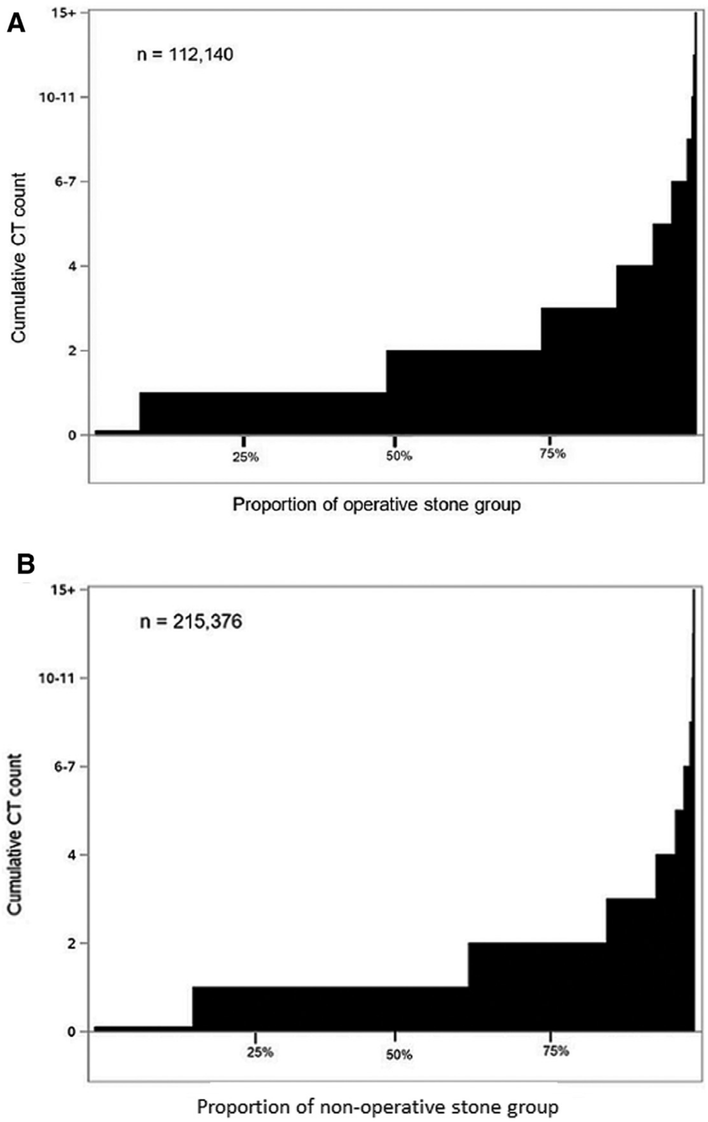
contrast, (0.05%) patients in the control group received 10-15 CTs and only 32 (0.01%) received >15 over 3 years. On multivariate logistic regression analysis, receipt of ≥3 CTs over 3 years was significantly associated with female gender (OR1.3, 95% CI 1.27−1.34, *P* <.01) for operative patients. For nonoperative patients, this was associated with age (OR 1.004, 95% CI 1.003-1.005, *P* <.001), female gender (OR 1.5, 95% CI 1.47-1.54, *P* <.01), and also residence in the North-Central (OR 1.2, 95% CI 1.20-1.29, *P* <.01) or South (OR 1.2, 95% CI 1.17-1.25, *P* <.01) regions. Nonoperative patients residing in metropolitan areas were less likely to receive ≥3 CTs (OR 0.6, 95% CI 0.37-0.93, *P* <.01).

For active stone patients, mean 3-year estimated cumulative CT-related radiation was 28.3 ± 28.5 mSv for operative patients



CT = computed tomography; Dx = disease

Figure 1. Mean number of cumulative CT scans per patient over time, by study group. Active stone patients appear to receive CT imaging at higher rate than both inactive stone patients and controls who have no known stone history, which have similar rates of CT exposure. (Color version available online.)



C

Cumulative CT count at 3 years	# of patients (operative)	# of patients (non-operative)
10	235	227
11	142	180
12	127	121
13	68	101
14	62	70
15	41	42
16	35	36
17	14	24
18	21	22
19	11	24
20	11	16
21	11	11
22	7	13
23	6	14
24	4	6
25	6	6
26	0	4
27	0	1
28	1	2
29	2	5
30	1	4
30+	14	16

Figure 2. Relative frequency of cumulative CT imaging received over 3 years among patients with active urinary stone disease managed (**A**) operatively and (**B**) nonoperatively. (**C**) Numerical distribution of patients in both groups receiving over 10 CT scans over the 3-year study period.

and 22.0 ± 24.4 mSv for nonoperative patients. In contrast, mean exposure estimates over 3 years were 14.9 ± 19.3 mSv for those with inactive stone disease and 2.4 ± 10.0 mSv for controls. The change in estimated effective CT-related radiation exposure over time is shown in Appendix 4. Sensitivity analyses performed assuming all low-dose CT studies were obtained revealed mean cumulative dose of 6.12 ± 5.56 mSv and 4.66 ± 4.71 mSv for operative and nonoperative groups, compared to 3.06 ± 3.59 mSV and 0.47 ± 1.92 mSv in the inactive stone and control groups, respectively. In contrast, the mean estimated radiation from KUB at 3 years was 2.3 ± 2.1 mSv for operative stone patients, 0.57 ± 0.97 mSv for nonoperative stone patients, 0.2 ± 0.6 mSv for inactive stone patients, and 0.04 ± 0.29 mSv for controls.

After just 1 year of follow-up, an estimated 10.4% of operative stone patients and 9.3% of nonoperative stone patients received 20-50 mSv in CT-related radiation, compared to 4.7% of inactive stone patients and 1.1% of controls (P <.001). The proportion of active stone patients estimated to receive >50 mSv during the first year was over double the inactive stone group, and over 10 times greater than the control cohort (Table 2). In all groups, the proportion of patients estimated to have CT-related radiation exposures of >20 mSv and >50 mSv declined following the first year. However, 6.4%-6.8% of operative and 5.2%-5.5% of nonoperative stone patients still continued to receive >20 mSv exposure from CT in the subsequent years of follow-up. Sensitivity analyses performed assuming all studies were low dose reveals that the proportion of subjects receiving >20 mSv at 3 years was 2.6% in the operative group, 1.3% in the nonoperative group, 0.6% in the inactive stone group, and 0.2% of controls.

DISCUSSION

This study demonstrates that despite debate about the risks of CT-related radiation, overall CT utilization remains

Table 2. Proportion of patients estimated to receive annual CT-related radiation exposure of >20 mSv and >50 mSv in each group, over time, based on median of effective radiation dose ranges reported in the literature.[9,10] The groups were significantly different at each time point (*P* <.001)

	Exposure	% During Year 1 (*n*)	% During Year 2 (*n*)	% During Year 3 (*n*)
Active stone disease, operative	20-50 mSv	9.34 (10,478)	6.10 (6,836)	5.67 (6,357)
	>50 mSv	1.24 (1,386)	0.73 (819)	0.76 (853)
Active stone disease, nonoperative	20-50 mSv	10.40 (22,408)	5.01 (10,797)	4.57 (9,840)
	>50 mSv	0.91 (1,954)	0.52 (1,122)	0.57 (1,236)
Inactive stone disease	20-50 mSv	4.67 (8,188)	2.35 (4,110)	2.26 (3,961)
	>50 mSv	0.40 (694)	0.26 (451)	0.28 (491)
Controls	20-50 mSv	1.13 (5,657)	1.17 (5,879)	1.18 (4,865)
	>50 mSv	0.09 (472)	0.14 (705)	0.14 (597)

high among patients with active stone disease. Over 3 years of follow-up, these patients received significantly more CT imaging than those with inactive stone disease and controls. Moreover, a considerable number received over 10 CT scans over a 3-year period (819 operative and 945 nonoperative active stone patients). This has implications on cumulative radiation exposure over time, as 10.6%-11.3% of active stone patients received an estimated exposure of >20 mSv in the first year of follow-up alone, with over 6.4% of operative and 5.2% of nonoperative patients exceeding this dose in the following years.

Our results expand upon previous work characterizing radiation exposure associated with acute stone episodes, which has been based largely on institutional data. Prior studies described less contemporaneous cohorts, many of which are now over a decade old.[12-14] Though some have reported lower average CT utilization in the year following an acute stone episode or stone treatment, our findings remain consistent with a multi-institutional study by Ferrandino et al, who estimated an average of 1.7 CT scans per patient in the year following an acute stone episode.[13-15] Notably, we find that the number of active stone patients receiving ≥3 CTs in follow-up (25% operative, 15% nonoperative over 3 years) is considerably higher than previously published rates by Katz et al (4% over 6 years).[12] Though this may be partly explained by differences between institutional and national-level practice patterns, these findings may also reflect an overall trend toward even greater CT utilization for stone patients since these earlier studies were published.

The estimated average CT-related radiation exposure for active stone patients accrued by the first year of this study (20.1 mSv operative and 15.3 mSv nonoperative) patients is similar to prior reports. Based on both estimates as well as direct calculations from CT dose length products, exposures as high as 34 mSv in the year following an acute stone episode and 13.32-27.02 mSv in the year following SWL have been described.[13,15] In contrast to those studies, our study relies on more contemporary dose data and accounted for differences in single- and multiphase studies as well as anatomically restricted CT imaging in dose estimates.[9,10] However, the finding that estimated average CT-related radiation exposure declines after the first year of treatment or diagnosis is consistent with previously published findings.[14]

Several factors may contribute to higher rates of CT imaging among patients with active stone disease. Such patients are prone to recurrence and are likely more closely followed with repeated imaging studies to assess for interval growth or de novo stones.[16] Even when patients are presumably rendered stone-free after ureteroscopy/SWL or percutaneous nephrolithotomy, about 25% and 50%, respectively, receive at least 1 CT scan within 1 year.[17,18] Increasing stone complexity or large stone burden also informs CT use. Kaynar et al showed that among patients undergoing SWL, those with multiple stones received 1.38 CTs on average in the year following treatment, compared to 0.51-0.59 CTs among those with isolated renal or ureteral stones.[15] Such practice patterns may drive additional radiation exposure among operative stone patients.

Another potential source of repeated CT imaging for active stone patients is in the ED. Our study supports this, as patients with stone diagnoses receive a significantly greater proportion of CT's in the acute setting, compared to controls. Despite best practice guidelines from the American College of Emergency Physicians recommending against routine initial CT for stone patients with renal colic, a recent study by Shah et al reveals that 77.9% still undergo CT imaging in the ED.[19] Moreover, such patients may represent for the same stone episode, often at a different ED, and nearly 40% undergo a duplicate CT.[19] Notably, for patients who have had surgical intervention, the 30-day representation and readmission rate has been reported as high as 13%.[20] Presumably, many of these patients also undergo CT imaging at the time of representation. This therefore remains a potential area for continued improvement in stewardship of CT use.

Over the past decade, CT imaging techniques have been refined to minimize the radiation delivered from each study. Modification to CT protocols such as reducing tube current, decreasing slice thickness, or increasing pitch, along with automatic dose-modulation protocols, have resulted in "low-dose" CTs with effective radiation doses <3-4 mSv[21,22,23] Moreover, novel image reconstruction techniques such as iterative reconstruction, have facilitated "ultra low-dose" CTs with even lower effective radiation doses <1 mSv.[24] Split-bolus protocols and digital unenhanced CT are additional strategies by which radiation can be minimized while still preserving imaging quality.[25] Though such advances may minimize CT-related radiation, the adoption of low-dose and ultra low-dose CT has remained slow. Only about 20% of institutions contributing to the American College of Radiology CT Dose Index Registry in 2014 provided low-dose CT data.[22] More recent studies further indicate that <8% of CTs are currently performed with a low-dose protocol.[23,26] Sensitivity analyses performed in our study suggest that routine use of low dose CT could dramatically reduce the cumulative radiation exposure risk to stone patients over time, though further research remains to be performed in this area.

While it may not be unexpected that older patients and those living in more rural areas may be more likely to receive CT imaging, it was somewhat surprising that female gender was significantly associated with greater CT utilization at 3 years. Prior studies utilizing national insurance databases have found that females appear more likely to undergo CT imaging than men, but sparse clinical data in such administrative databases limits further evaluation of patient or provider-level factors underlying this finding.[5,18] Yet, other retrospective studies have found male gender to be independently associated with higher radiation dose exposures for abdominopelvic CTs.[27] One potential explanation may lie in differences of study protocol, which may be adjusted for patient habitus or gender. Further research is warranted to determine specific factors associated with greater CT utilization and higher levels of radiation exposure.

Our study has several limitations. Within the MarketScan database, specific indications for CT imaging were not identifiable. Thus, some studies may have been ordered for reasons unrelated to nephrolithiasis. However, a control group was included to account for this possibility. We were also unable to determine the specific clinical context in which a CT was ordered, and therefore could not differentiate between planned follow-up imaging and unplanned imaging that may have been obtained in the ED at the time of a symptomatic presentation. Lastly, the MarketScan database includes only those with commercial insurance. Thus, these findings may not be generalizable to the greater United States population, which includes those who are insured through Medicare, Medicaid, or are uninsured.

CONCLUSION

Acknowledging the limitations of our study, patients with active urinary stone disease receive between 9 and 12 times the number of CTs as age- and gender-matched controls over 3 years of follow-up, with the greatest number of CTs received by those who require surgical intervention. Based on median-range radiation dose exposures, over 10% are estimated to exceed occupational hazard limits in the first year and over 5% in the subsequent years, without considering the additional exposure received during operative procedures. Judicious CT imaging and use of low-dose CT protocols should be considered to minimize future risk to stone patients.

SUPPLEMENTARY MATERIALS

Supplementary material associated with this article can be found in the online version at https://doi.org/10.1016/j.urology.2019.07.030.

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