The associations between initial radiographic findings and interventions for renal hemorrhage after high-grade renal trauma: Results from the Multi-Institutional Genitourinary Trauma Study

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BACKGROUND: Indications for intervention after high-grade renal trauma (HGRT) remain poorly defined. Certain radiographic findings can be used to guide the management of HGRT. We aimed to assess the associations between initial radiographic findings and interventions for hemorrhage after HGRT and to determine hematoma and laceration sizes predicting interventions.

METHODS: The Genitourinary Trauma Study is a multicenter study including HGRT patients from 14 Level I trauma centers from 2014 to 2017. Admission computed tomography scans were categorized based on multiple variables, including vascular contrast extravasation (VCE), hematoma rim distance (HRD), and size of the deepest laceration. Renal bleeding interventions included angioembolization, surgical packing, renorrhaphy, partial nephrectomy, and nephrectomy. Mixed-effect Poisson regression was used to assess the associations. Receiver operating characteristic analysis was used to define optimal cutoffs for HRD and laceration size.

RESULTS: In the 326 patients, injury mechanism was blunt in 81%. Forty-seven (14%) patients underwent 51 bleeding interventions, including 19 renal angioembolizations, 16 nephrectomies, and 16 other procedures. In univariable analysis, presence of VCE was associated with a 5.9-fold increase in risk of interventions, and each centimeter increase in HRD was associated with 30% increase in risk of bleeding interventions. An HRD of 3.5 cm or greater and renal laceration depth of 2.5 cm or greater were most predictive of interventions. In multivariable models, VCE and HRD were significantly associated with bleeding interventions.

CONCLUSION: Our findings support the importance of certain radiographic findings in prediction of bleeding interventions after HGRT. These factors can be used as adjuncts to renal injury grading to guide clinical decision making. (*J Trauma Acute Care Surg.* 2019;86: 974–982. Copyright © 2019 Wolters Kluwer Health, Inc. All rights reserved.)

LEVEL OF EVIDENCE: Prognostic and Epidemiological Study, Level III and Therapeutic/Care Management, Level IV.

KEY WORDS: Renal trauma; nephrectomy; conservative treatment; computed tomography; wounds and injuries; trauma centers; multicenter study.

Management of renal trauma has changed dramatically during the past two decades, and the majority of injuries are now managed nonoperatively.[1,2] This paradigm shift, and the widespread use of computed tomography (CT) scans for trauma evaluation, has led to investigation of radiographic findings that can guide decisions for management of severe injuries. Current evidence suggests that some CT findings, such as hematoma and laceration characteristics, are associated with bleeding control interventions.[2,3] For example, vascular contrast extravasation (VCE) and large perirenal hematomas have been shown to be highly associated with the need for endovascular or open procedures.[4–10] However, most data are from single-center studies with a small number of interventions. Validation of these findings in a multicenter setting with a larger cohort is needed.

The 1989 American Association for the Surgery of Trauma (AAST) organ injury scale is commonly used to grade renal injuries. However, it was initially developed based upon surgical findings in an era when open exploration was the standard of care for renal trauma management.[11] This grading system does not incorporate some important CT findings such as VCE and hematoma size and was not designed to predict the risk of bleeding control interventions. For instance, a laceration depth of 1 cm is used as a criterion in the AAST grading to separate grade II and III injuries, which has not been validated in studies as having prognostic importance.[11] Additionally, various hematoma size cutoffs from 2 cm to 6 cm[4–6,10] have been suggested to predict the need for bleeding intervention, but the optimal cutoff point remains unknown.

We hypothesize that specific radiographic findings, beyond the AAST renal injury grading system, are associated with bleeding interventions after high-grade renal trauma (HGRT). We aimed to use a multi-institutional database of HGRT to explore the associations between these CT findings and interventions. To improve the clinical application, we also aim to find the cutoff points for hematoma and laceration size that optimize prediction of undergoing bleeding control interventions.

PATIENTS AND METHODS

Study Design

From 2014 to 2017, data were collected from adult patients with HGRT as part of the Multi-institutional Genitourinary Trauma Study (MiGUTS, http://www.turnsresearch.org/page/aast-gu-trauma-study-group-author-list-renal-trauma). Details on the renal trauma study protocol and data collection have been previously published.[12] In brief, the study is a multi-institutional, prospective, collaborative effort supported by the AAST multi-institutional trials committee, in conjunction with

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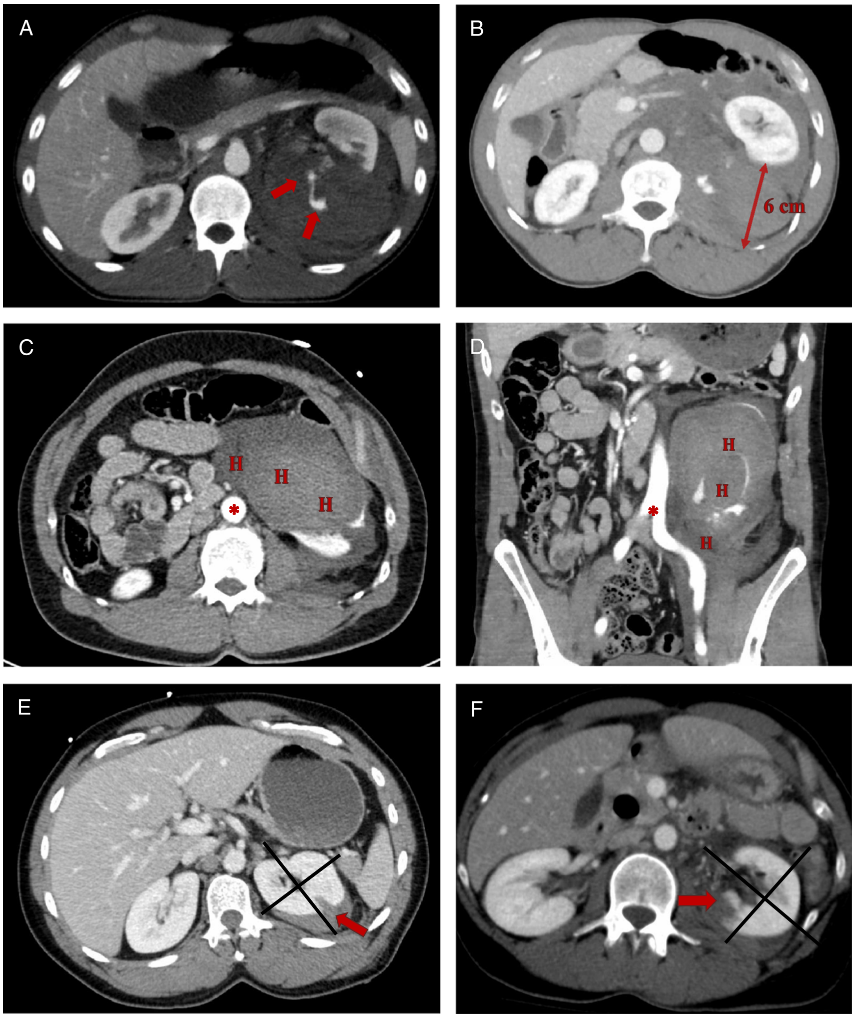

Figure 1. CT findings after high-grade renal trauma. (*A*) VCE from the left kidney (red arrows), during the arterial phase of the CT scan in the axial plane. (*B*) Perirenal HRD measuring 6 cm at the axial plane with associated VCE. (*C*) Anterior pararenal extension of hematoma (letter H) beyond aorta (red asterisk). (*D*) Extension of left kidney hemorrhage (letter H) inferior to the aortic bifurcation (red asterisk) into the pelvis in the coronal plane. (*E & F*) Laceration location is defined using a perpendicular line to a plane through the renal hilum to define the medial and lateral halves of the kidney; (*E*) lateral laceration (red arrow); (*F*) medial laceration (red arrow).

the Trauma and Urologic Reconstruction Network of Surgeons that involved 14 Level I trauma centers across the United States.

For this study, only HGRT patients (defined as AAST grades III-V) who underwent a diagnostic CT scan after renal trauma were included. Patients who underwent immediate surgery without prior imaging were excluded. Data were gathered on demographics, injury characteristics, radiologic variables, and management.[12]

Definitions

Management options were categorized as expectant, conservative/minimally invasive, and open operative.[12] Bleeding interventions included: nephrectomy, partial nephrectomy, renorrhaphy, renal packing, and renal angioembolization. Hypotension/shock was defined as systolic blood pressure less than 90 mmHg anytime during the first 4 hours from admission. Vascular contrast extravasation was defined as presence of contrast accumulation outside of the renal parenchyma demonstrated on arterial or venous phase CT scan (Fig. 1*A*).[4] Hematoma rim distance (HRD) was measured on the axial CT planes and was defined as the longest perpendicular distance from the renal parenchymal border to the hematoma border within the boundaries of superior and inferior kidney margins (Fig. 1*B*). Pararenal hematoma was defined as hematoma extending beyond the aorta on the left or inferior vena cava on the right, or extending inferior to the aortic bifurcation into the pelvis (Figs. 1*C and D*).[13,14] Laceration location was defined in a manner similar to Dugi et al.[5] using a perpendicular line to a plane through the renal hilum to define the medial and lateral halves of the kidney (Figs. 1*E and F*). Number of visible lacerations was counted in the axial plane and was dichotomized as less than three lacerations and three or more lacerations. Depth of laceration was measured as the length of the deepest laceration in the axial plane in centimeters. Percentage of parenchymal devascularization was estimated based on the extent of persistent parenchymal infarcts seen as segmental or global lack of enhancement on contrast trauma CT scans and was dichotomized as less than 25% or 25% or greater as suggested in previous studies.[15,16]

Radiologic Data Extraction

All deidentified CT scans were uploaded to a secure Web-based Orthanc[17] server for central review. Imaging data were collected and managed using Research Electronic Data Capture (REDCap) electronic database.[18] Radiographic variables included: VCE, HRD, hematoma extension (none/subcapsular; perirenal; pararenal), laceration location (lateral, medial, complex [both]), number of lacerations, depth of laceration, and parenchymal devascularization. For bilateral injuries, injury specifics from the side with higher injury grade were considered.

Two radiologists, blinded to the intervention data and patient outcomes, independently reviewed the CT scans to extract injury specifics. An initial training set of 20 CT scans from renal trauma patients was used to assure a common understanding of the study terminology and achieve substantial agreement between reviewers in test cases (kappa>0.6). Interrater reliability analyses were used to assess the agreement on radiologic measurements between the readers (Supplemental Digital Content, Table 1, http://links.lww.com/TA/B311). After measuring initial interradiologist agreements, the scans were rereviewed to reach a consensus on discordant findings. For continuous variables (e.g., HRD and laceration depth), the average of the two measurements was used. Input from a third reviewer was used to resolve the disagreements when needed.

Statistical Analysis

Values are reported as percentages for categorical variables and mean (standard deviation) or median (25th to 75th interquartile ranges [IQR]) for continuous variables as appropriate. Independent *t* test, χ^2 test, and Wilcoxon rank sum test were used to compare variables. Mixed-effect univariable Poisson regression models, with clustering by facility and robust estimator for error, were developed to assess the associations between radiologic variables and the outcome. Results from regression models are reported as risk ratios (RR) with 95% confidence intervals (CIs). Mixed effect Poisson regression was used to develop the multivariable model, which included HRD, laceration depth, VCE, and ≥3 lacerations. The AAST grade was not included as the radiographic appearance of the injuries was characterized in detail and the intent of this study was to characterize these risk factors separately; there is also significant variability and some ambiguity about the grading of HGRT.[5,19] For HRD and laceration depth, diagnostic accuracy was measured using the receiver operating characteristic (ROC) analysis, and the optimal cutoffs were chosen based on the F-1 score maximizing sensitivity and positive predictive value (PPV) simultaneously.[20] A second multivariable model was developed using the dichotomized values of HRD and laceration size based upon the cutoffs from the ROC analysis. Statistical analyses were conducted using STATA 15 (Stata Corp, College Station, TX).

RESULTS

From 431 patients with HGRT, 326 (76%) had CT scans on presentation and were included. Excluded patients (n = 105) had higher rates of shock, as well as penetrating and concomitant injuries, leading directly to surgical exploration. As expected, most these patients underwent immediate surgery without imaging studies and the rates of bleeding interventions were significantly higher for these patients compared to those who were included in the study (54% vs. 14%, $p < 0.001$).

Among the 326 patients with initial imaging, 47 (14.4%) underwent a total of 51 bleeding interventions including 19 renal angioembolization, 16 nephrectomies, 3 partial nephrectomies, 7 renorrhaphies, and 6 renal packings. Patient demographics, injury characteristics, radiographic variables, and injury management are summarized in Table 1.

Overall, 73 patients (22%) had VCE. In 123 patients (38%), the hematoma from renal injury expanded beyond the midline or into the pelvis (pararenal hematoma). Median HRD was 1.8 cm (IQR, 0.8–2.9) and was higher in those who underwent bleeding interventions compared to those who did not (3.8 cm; IQR, 2.1–5.0 vs. 1.4 cm; IQR, 0.8–2.3, $p < 0.001$). Median laceration depth was 1.9 (IQR, 1.4–2.5) and was also higher in patients who underwent bleeding interventions (2.8 cm, IQR, 2.3–3.5 vs. 1.8 cm, IQR, 1.4–2.3, $p < 0.001$).

In the univariable analyses, VCE, larger HRD, deeper lacerations, pararenal extent of hematoma, and three or more parenchymal lacerations were all associated with increased risk of bleeding interventions (Table 2). The rate of intervention was significantly higher for those with VCE compared to those without VCE (40% vs. 7%, $p < 0.001$).

In the multivariable regression (variables: HRD, laceration depth, VCE, and ≥3 lacerations), the presence of VCE was associated with a threefold increase in risk of interventions (RR, 3.03; 95% CI, 1.48–6.21; $p = 0.002$) and each centimeter increase in HRD was associated with a 15% increase in risk of bleeding interventions (RR, 1.15; 95% CI, 1.01–1.31; $p = 0.03$) (Table 3, model 1).

An HRD cutoff of 3.5 cm provided the best predictive accuracy for undergoing bleeding interventions (sensitivity, 0.62; specificity, 0.87; PPV, 0.44; F1 score, 0.51) (Fig. 2*A*). The intervention rate was higher for those with an HRD of 3.5 or greater compared to those with an HRD less than 3.5 cm (44% vs. 7%, $p < 0.001$). This cutoff (HRD ≥ 3.5 cm) was associated with a 6.3-fold increase in the risk of undergoing bleeding interventions in the univariable analysis (RR, 6.3; 95% CI, 3.5–11.4). For laceration depth, a cutoff of 2.5 cm provided the best predictive accuracy for undergoing bleeding interventions (sensitivity, 0.62; specificity, 0.80; PPV, 0.36; F1 score, 0.44) (Fig. 2*B*). The intervention rate was higher for those with laceration depth of 2.5 cm or greater compared with those with laceration depth less than 2.5 cm (34% vs. 7%, $p < 0.001$). A laceration depth of 2.5 cm or greater was associated with 4.4-fold increased risk of bleeding interventions in the univariable analysis (RR, 4.4; 95% CI, 2.5–8.0). In the multivariable regression model using the cutoffs from the ROC analysis, an HRD of 3.5 cm or greater was associated with 2.5-fold increased risk of bleeding interventions when controlling for laceration depth, VCE, and number of lacerations (Table 3, model 2).

DISCUSSION

This study confirms the critical associations of radiographic findings with bleeding control interventions after HGRT. Our results show that the presence of VCE and size of

TABLE 1. Patient Demographics, Injury Characteristics, Radiologic Variables, and Management in HGRT Cohort

Demographics	Total	Intervention	No Intervention	*p* value
No. HGRT patients	326	47	279	—
Age, median (IQR), y	28 (22–46)	32 (23–47)	28 (22–48)	0.33
Body mass index, mean (SD), kg/m^2	27.4 (6.5)	27.1 (4.7)	27.4 (6.7)	0.74
Sex, n (%)				0.02
Male	248 (76%)	42 (89%)	206 (74%)	
Female	78 (24%)	5 (11%)	73 (26%)	
Injury characteristics				
Injury severity score, median (IQR)	22 (16–33)	25 (18–35)	22 (16–33)	0.06
Trauma mechanism, n (%)				0.01
Blunt	263 (81%)	31 (66%)	232 (83%)	
Penetrating	63 (19%)	16 (34%)	47 (17%)	
Hypotension/shock at admission, n (%)	75 (23%)	16 (34%)	59 (21%)	0.05
Concomitant injuries, n (%)*	217 (66%)	33 (70%)	184 (66%)	0.57
Side of renal injury, n (%)				0.58
Left	156 (48%)	25 (53%)	131 (47%)	
Right	144 (44%)	20 (43%)	124 (44%)	
Bilateral	26 (8%)	2 (4%)	24 (9%)	
Renal AAST grade, n (%)				<0.001
III	195 (60%)	15 (32%)	180 (64%)	
IV	108 (33%)	20 (43%)	88 (32%)	
V	23 (7%)	12 (25%)	11 (4%)	
Radiologic variables				
VCE, n (%)	73 (22%)	29 (63%)	44 (16%)	<0.001
Hematoma rim diameter, median (IQR), cm	1.8 (0.8–2.9)	3.8 (2.1–5.0)	1.4 (0.8–2.3)	<0.001
Hematoma extent, n (%)				<0.001
None/subcapsular	43 (13%)	1 (2%)	42 (15%)	
Perirenal	160 (49%)	14 (30%)	146 (52%)	
Pararenal	123 (38%)	32 (68%)	91 (33%)	
Laceration depth, median (IQR), cm	1.9 (1.4–2.5)	2.8 (2.3–3.5)	1.8 (1.4–2.3)	<0.001
Laceration location, n (%)**				<0.001
Lateral	100 (31%)	11 (24%)	89 (33%)	
Medial	67 (21%)	2 (4%)	65 (24%)	
Both/complex	151 (48%)	34 (72%)	117 (43%)	
No. laceration, n (%)				<0.001
<3	197 (60%)	15 (32%)	182 (65%)	
≥3	129 (40%)	32 (68%)	97 (35%)	
Parenchymal devascularization, n (%)				0.79
<25	301 (92%)	43 (91%)	258 (92%)	
≥25	25 (8%)	4 (9%)	21 (8%)	
Renal trauma management				
Management, n (%)				<0.001
Expectant	254 (78%)	0 (0%)	254 (91%)	
Conservative/minimally invasive	40 (12%)	15 (32%)	25 (9%)	
Open operative	32 (10%)	32 (68%)	0 (0%)	
Bleeding control interventions, n (%)†				
Renal angioembolization	19 (6%)	19 (40%)	0 (0%)	—
Nephrectomy	16 (5%)	16 (34%)	0 (0%)	—
Partial nephrectomy	3 (1%)	3 (6%)	0 (0%)	—
Renorrhaphy	7 (2%)	7 (15%)	0 (0%)	—
Renal packing	6 (2%)	6 (13%)	0 (0%)	—
Length of hospital stay, median (IQR), d	6 (3–12)	10 (6–17)	6 (3–11)	0.41
Mortality, n (%)	13 (4%)	3 (6%)	10 (4%)	<0.001

*Defined as presence of any concomitant injury, including: solid organ, gastrointestinal, spinal cord, major vascular, and pelvic fracture.
**n = 318, excluding 8 patients who did not have parenchymal laceration.
†Total of 51 interventions in 47 patients; some patients underwent more than one intervention. Denominator for the percentages is total number of patients, hence percentages not tallying up to 100%.
SD, standard deviation; HR, heart rate; SBP, systolic blood pressure; PRBC, packed red blood cells; GCS, Glasgow coma scale.

TABLE 2. Univariable Regression Analysis of Radiologic Factors and Associations With Bleeding Interventions

Radiologic Variables	RR (95% CI)	*p* value
Hematoma rim diameter (per cm)	1.3 (1.2–1.5)	**<0.001**
Laceration depth (per cm)	1.9 (1.5–2.5)	**<0.001**
VCE		
No	1.00 (Reference)	
Yes	5.9 (3.2–10.9)	**<0.001**
Hematoma extent		
None/subcapsular	1.00 (Reference)	
Perirenal	3.5 (0.5–27.1)	0.22
Pararenal	10.5 (1.4–77.6)	**0.02**
Laceration location		
Lateral	1.00 (Reference)	
Medial	0.3 (0.1–1.2)	0.08
Both/complex	1.9 (0.9–3.9)	0.06
No. laceration		
<3	1.00 (Reference)	
≥3	3.4 (1.8–6.3)	**<0.001**
Parenchymal devascularization		
<25%	1.00 (Reference)	
≥25%	1.1 (0.4–2.9)	0.92

Bold values shows statistically significant at p<0.05.

hematoma are important CT findings that can be used to guide clinical management of renal trauma patients. Additionally, an HRD cutoff of 3.5 cm or greater and a laceration depth of 2.5 cm or greater can be used as clinically useful cutoffs to indicate the need for closer observation and/or endovascular or surgical interventions.

Vascular Contrast Extravasation

First described in 1989 by Sivit et al.,[21] VCE usually appears as a focal irregular high-density area surrounded by a lower-attenuation hematoma collection in CT. The extravasated blood usually has an attenuation of 80 to 370 Hounsfield Units, typically within 10 to 15 units of the aorta or adjacent major arterial structures.[22,23] Presence of VCE indicates active bleeding and may herald hemodynamic deterioration even in initially stable patients.[24] For example, in an early study of blunt abdominal organ injuries, 38% of patients with VCE developed hypotension during or immediately after imaging.[25] The incidence of VCE after renal trauma is difficult to estimate and ranges from 1.5% to 22% in different series.[4–6,8,10,26,27] In our study, 22% (73/326) of patients were diagnosed with VCE, which is similar to the rates reported by others after HGRT.[6,8]

Presence of VCE after renal trauma is associated with the need for angioembolization[4,6] or surgical interventions.[5,7,8] In our study, VCE was a significant predictor for bleeding interventions, and 40% of patients with VCE (29 of 73) underwent interventions. We consider it to be an important imaging finding, which should prompt close follow-up and potentially endovascular intervention. The majority of patients with the initial diagnosis of VCE will not need angioembolization. However, superselective embolization of distal renal arteries may allow bleeding control with minimal parenchymal loss in stable patients.[28,29] Risk of rebleeding, need for successive interventions, and also overuse of angiography and angioembolization for lower grade renal injuries are some considerations with more widespread use of endovascular procedures for conservative management of renal trauma.[30,31] Recognizing the radiologic factors associated with needing interventions (such as VCE) is an important step toward minimizing inappropriate use of angioembolization.

Hematoma Characteristics

Different hematoma characteristics have been used as predictors for bleeding interventions. In addition to HRD, previous studies have suggested measuring hematoma to kidney ratio,[4] hematoma area,[4,10] or hematoma volume.[32] We used HRD because it provides the simplest and most reproducible measurement of the hematoma size compared with more complex calculations. We also compared pararenal vs. perirenal hematoma extent using anatomic landmarks because HRD may be small even though there is an extension of the hematoma into the pelvis or across the midline.[13,33] A large hematoma that expands across the midline or into the pelvis, especially when accompanied by VCE, indicates ongoing bleeding and merits closer attention. A potential limitation of hematoma measurements is their dependence on the time elapsed from injury to diagnostic imaging. Hematoma size does not reflect whether bleeding is ongoing at the time of assessment as it reflects the amount of accumulated blood while bleeding might have already stopped.[21,34] However, we believe HRD and hematoma extent are important adjuncts to VCE and a large hematoma can be a sign of more severe injury patterns and a higher probability of needing interventions.

Previous studies have suggested HRD cutoffs that maximize the predictive accuracy for bleeding interventions, although most had a small number of interventions (between 4 and 18).[4–8,10] Nuss et al.[4] suggested that VCE in combination with an HRD greater than 4 cm can be used to guide the need for angioembolization; this value was merely based on the median HRD in four patients who underwent embolization. In a follow-up study, the same group suggested an HRD cutoff of 3.5 cm, reporting a 10-fold increase in odds of undergoing bleeding interventions.[5] These findings were externally validated in two separate studies that reported 8.4-fold[8] and 7.2-fold[7] increases in odds of intervention with HRD greater than 3.5 cm. More recently, Zemp et al.[10]

TABLE 3. Multivariable Regression Analysis of Radiologic Factors and Associations With Bleeding Interventions

	RR (95% CI)	*p* value
Model 1		
HRD (per cm)	1.15 (1.01–1.31)	**0.03**
Laceration depth (per cm)	1.16 (0.83–1.61)	0.38
VCE	3.03 (1.48–6.21)	**0.002**
No. laceration (≥3 vs. <3)	1.90 (0.94–3.82)	0.07
Model 2		
HRD ≥3.5 cm	2.47 (1.17–5.19)	**0.02**
Laceration depth ≥ 2.5 cm	1.88 (0.93–3.79)	0.08
VCE	2.72 (1.31–5.63)	**0.007**
No. laceration (≥3 vs. <3)	1.64 (0.81–3.35)	0.17

Bold values shows statistically significant at p<0.05.

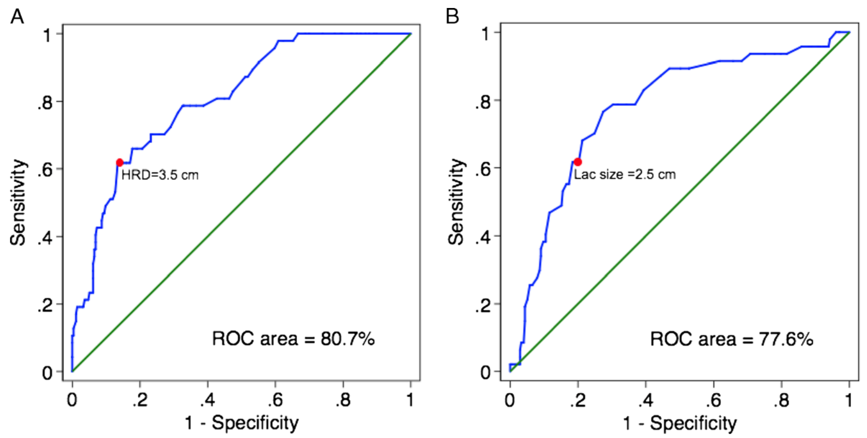

Figure 2. Receiver operating characteristic curves to find the best cutoffs for HRD (panel *A*) and laceration size (panel *B*).

performed descriptive analysis for 2 cm increments of HRD and suggested that a 6-cm cutoff provides a better distinction for undergoing interventions in comparison to a 4-cm cutoff. This finding was based on 31 urological interventions with 18 of them for bleeding control. We found that an HRD cutoff of 3.5 cm optimized the predictive accuracy for clinical practice. This translated to a 6.3-fold increase in the risk of bleeding interventions in the univariable analysis and 2.5-fold increase in risk in the multivariable model controlling for VCE and laceration depth and number.

Laceration Location, Depth, and Number

In some studies, laceration characteristics were also associated with bleeding interventions. For example, Dugi et al. reported that a medial laceration was associated with higher intervention rates compared to a lateral location.[5] This finding was not reproduced in two later studies,[8,10] or our current study. Although a medial laceration is more likely to involve major vascular structures, many vascular injuries are the result of deceleration injuries that tear the intimal layer of the renal artery and may not be associated with medial parenchymal lacerations. Additionally, deep lateral lacerations can involve multiple branching arteries and be associated with severe bleeding. It is intuitive that complex lacerations (involving both the medial and lateral sides) represent a more severe injury pattern and are associated with higher intervention rates. However; the results were not statistically significant in our univariable analysis ($p = 0.06$).

Depth of laceration may provide more clinically useful information as deeper lacerations are more likely to be associated with vascular injuries and will also have implications for diagnosis and management of urinary extravasation after renal trauma. Similar to Zemp et al.,[10] depth of laceration was a significant predictor in our univariable but not the multivariable analysis. Thus, addition of laceration characteristics may not add further information when hematoma characteristics, such as HRD, and VCE are being concurrently assessed, as was shown in our multivariable model. Depth of laceration has been a consistent criterion in the AAST organ injury scale originally published in 1989 and also in its most recent revision published in 2018.[11,35] According to the AAST criteria, a laceration greater than 1 cm upgrades the injury to grade III or higher.[11,35] However, this recommendation is probably based on anatomic findings during surgical assessment of renal trauma and does not reflect the risk of bleeding interventions or collecting system injuries. In our analysis, the optimal cutoff for laceration depth predicting bleeding interventions was 2.5 cm; this cutoff was associated with a 4.4-fold increase in the risk of bleeding intervention. In the future, with further iterations of renal grading systems, using a laceration depth, such as 2.5 cm, that correlates to increased intervention risk might improve the prognostic ability of a hypothetical grading system. Lacerations from blunt trauma and gunshot injuries can have complex patterns and usually do not extend in a single horizontal or coronal plane; thus measuring the deepest laceration in one plane might not provide an accurate estimate of the actual laceration depth.

We also included the number of lacerations as a potential surrogate for severity of renal trauma. However, in our experience, counting the exact number of lacerations is challenging and time-consuming so it may not be a suitable variable to use in practice. Additionally, number of lacerations per se does not provide enough clinically useful information as many patients with blunt abdominal trauma can have several shallow lacerations with minimal risk of bleeding. Supporting the concept that laceration number is not an independent predictor of bleeding risk, we did not find that three or more lacerations were associated with an increased risk of bleeding in our adjusted analysis.

Parenchymal Devascularization

Percentage of renal parenchymal devascularization has been suggested as a predictor for interventions in some previous studies.[36,37] Estimating the exact amount of devascularization can be challenging in the presence of multiple lacerations and intra-parenchymal bleeding and hematomas. Also, the degree of devascularization does not necessarily correlate with risk of bleeding; intimal injuries and arterial clots can cause wedge-shaped segmental devascularization of renal parenchyma without active bleeding. Similarly, a completely devascularized kidney due to an intimal flap in the main renal artery is not associated with significant bleeding risk, in contrast to renal hilar avulsion, which can lead to rapid exsanguination. Similar to Zemp et al.,[10] in our study, the degree of devitalized segment (≥25%) was not associated with increased interventions for renal bleeding.

Our study has some limitations. Given the lack of clear guidelines for intervention after HGRT, management was not standardized in our multicenter study setting, and thresholds for intervention and overall care among these centers are likely different. However, our data reflect the real-world management from Level I trauma centers across the country, which have the most experience in the management of HGRT. Lack of follow-up after patient discharge is another weakness of the study, which limits the discussion of our findings to the acute trauma period. In addition, these radiologic parameters only apply to patients who are stable enough to undergo a CT scan, and many interventions were performed on patients who were taken directly to the operating room for management of their injuries. However, the patients that are stable enough to get a CT scan are the population that would benefit the most from clinical tools predicting the need to intervene for hemorrhage. There is also a potential for bias as the presence of these radiographic findings could have impacted the decision for intervention in the clinical setting but not necessarily reflect the need for intervention or collate with outcomes. Despite these limitations, this is the first study that validates these radiologic findings and assesses the cutoffs in a multi-institutional setting and with a large enough sample size allowing for multivariable analysis. Also, all the images were reviewed by two radiologists, blinded to the outcomes, which increases the validity and reproducibility of our results.

CONCLUSION

Presence of VCE and the size of hematoma around the kidney are two important radiologic findings that can be used to guide the need for bleeding control interventions after HGRT. An HRD of 3.5 cm or greater and a laceration depth of 2.5 cm or greater can be used as surrogates for severity of injury and risk of bleeding and patients with these characteristics may need closer observation or early endovascular and/or surgical interventions. These radiologic factors can be used as adjuncts to the AAST renal grading to guide clinical decision making and could be incorporated in future predictive tools and renal trauma management algorithms.

AUTHORSHIP

J.B.M. and S.K. designed the study. B.E.P., D.M.R., M.E.H., and S.K. reviewed the imaging data and interpreted the results. C.Z., S. K., and J. B. M. participated in data analysis and interpretation. J.B.M. and S.K. drafted the article. X.L., K.M., B.J.M., S.M., J.P., C.M.D., I.S., S.P.E., E.S.D., S.Z., B.G.S., B.A.E., N.B., B.N.B., C.N.F., B.P.S., B.U.O., R.A., B.M., R.A.S., M.M.C., J.F.K., T.H., F.N.B., S. K., and J. B. M. participated in the data collection and revisions for this article. J. B. M., D.M.R., B.N.B., B.A.E., S.Z., and R.N. provided critical revisions for this article. All the authors read and approved the final submission.

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