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A Nomogram Predicting the Need for Bleeding Interventions after High-Grade Renal Trauma: Results from the American Association for the Surgery of Trauma (AAST) Genitourinary Trauma Study

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Abstract

Background

The management of high-grade renal trauma (HGRT) and the indications for intervention are not well-defined. The American Association for the Surgery of Trauma (AAST) renal grading does not incorporate some important clinical and radiologic variables associated with increased risk of interventions. We aimed to use data from a multi-institutional contemporary cohort to develop a nomogram predicting risk of interventions for bleeding after HGRT.

Methods

From 2014 to 2017, data on adult HGRT (AAST grades III-V) were collected from 14 Level-1 trauma centers. Patients with both clinical and radiologic data were included. Data were gathered on demographics, injury characteristics, management, and outcomes. Clinical and radiologic parameters, obtained after trauma evaluation, were used to predict renal bleeding interventions. We developed a prediction model by applying backward model selection to a logistic regression model and built a nomogram using the selected model.

Results

A total of 326 patients met the inclusion criteria. Mechanism of injury was blunt in 81%. Median age and injury severity score were 28 years and 22, respectively. Injuries were reported as AAST grades III (60%), IV (33%), and V (7%). Overall, 47 (14%) underwent interventions for bleeding control including 19 renal angioembolizations, 16 nephrectomies, and 12 other procedures. Of the variables included in the nomogram, a hematoma size of 12 cm contributed the most points, followed by penetrating trauma mechanism, vascular contrast extravasation, para-renal hematoma extension, concomitant injuries, and shock. The area under the receiver operating characteristic curve was 0.83 (95% CI: 0.81–0.85).

Conclusion:

We developed a nomogram that integrates multiple clinical and radiologic factors readily available upon assessment of patients with HGRT and can provide predicted probability for bleeding interventions. This nomogram may help in guiding appropriate interventions and decreasing unnecessary interventions.

Level of Evidence:

Prognostic and Epidemiological Study, Level III

Keywords:

Renal trauma; nephrectomy; nomograms; conservative treatment; computed tomography; wounds and injuries; trauma centers; multicenter study.

Introduction

The organ injury scoring scale, developed by the American Association for the Surgery of Trauma (AAST), is the most widely used tool to grade traumatic renal injuries. [1] The AAST grading for renal trauma encompasses a spectrum of severity within each injury grade, especially for higher grade injuries. Despite being highly associated with outcomes such as nephrectomy [2-5], the AAST grading system does not incorporate some key clinical and radiologic findings pertinent to bleeding interventions.[6] For example, it does not account for hemodynamic instability and mechanism of trauma, which are important factors to consider in renal trauma management. Similarly, the AAST grading does not account for some radiologic findings such as the presence of active renal vascular bleeding, size of the peri-renal hematoma, and laceration characteristics, which have been shown to be highly associated with nephrectomy and other bleeding control interventions. [7-9] Revisions to the AAST grading have been proposed in order to address some ambiguities within grade IV and V injuries, [10] and to incorporate radiologic factors aimed at improving the discriminating power for higher risk injuries.[8] However, these studies are limited by retrospective design and the rarity of renal trauma and related interventions in single center studies.[8, 11, 12]

The majority of patients with high-grade renal trauma (HGRT) can be successfully managed without open surgery, as most renal injuries can heal with expectant management or use of more conservative endovascular interventions (i.e. selective angioembolization of bleeding vessels).[13] Despite this, the management of HGRT is variable between centers and nephrectomy remains the most common intervention, performed in as many as 28% of patients with grade IV-V injuries. [5, 14, 15] Timely and accurate identification of patients with renal trauma who would benefit from intervention, as well as those that are at low risk for bleeding is paramount to guiding appropriate management. Recognizing factors that predict bleeding risk from renal injury and using a data-driven tool to predict interventions is the first step in achieving this goal. Such a tool could help clinicians rapidly obtain an estimated probability that a renal trauma patient would benefit from interventions to control bleeding or if the patient can be safely managed non-operatively. In an effort to create such a tool, we used our multi-institutional prospective data to build a HGRT bleeding intervention nomogram using clinical and radiologic factors readily available at the time of trauma assessment.

Patients & Methods

The data used for this study were collected as part of the Genito-Urinary Trauma Study (full study sites and collaborators' information is available at: 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. [5] In brief, the study was a multi-institutional prospective collaborative effort of the American Association for the Surgery of Trauma (AAST), in conjunction with the Trauma and Urologic Reconstruction Network of Surgeons (TURNS) that involved 14 Level-1 trauma centers across the United States. From 2014 to 2017, clinical and radiologic data were collected from patients with HGRT (defined as AAST grades III-V) who were treated at the participating trauma centers. For this study, patients who underwent immediate surgery without imaging or those who died before undergoing diagnostic studies were excluded from the analysis. Thus, only patients who were stable enough to undergo diagnostic trauma CT scan after renal trauma were included.

Clinical variables included: age, sex, trauma mechanism (blunt vs. penetrating), side of renal injury (right, left, bilateral), injury severity score (ISS), hypotension/shock (defined as systolic blood pressure <90 mmHg anytime during the first 4 hours from admission), Glasgow Coma Scale (GCS), number and type of blood products received in the first 24 hours, admission laboratory values (hematocrit/hemoglobin, lactate), and presence of any concomitant injury (including solid organ, gastrointestinal, spinal cord, major vascular, and pelvic fracture).

Radiologic variables included: vascular contrast extravasation (VCE), hematoma rim distance (HRD, i.e. largest measure from the edge of the kidney to the hematoma rim), hematoma extension (none/subcapsular; peri-renal; para-renal), and laceration location (lateral, medial, complex [both types]). VCE was defined as presence of contrast accumulation outside of the renal parenchyma demonstrated on arterial or venous phase CT scan (Supplemental Figure 1, Supplemental Digital Content 1, http://links.lww.com/TA/B295).[7] HRD was measured at 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 upper and lower margins of the kidney (Supplemental Figure 2, Supplemental Digital Content 1, http://links.lww.com/TA/B295). Laceration location was defined in a manner similar to Dugi et al. using a perpendicular line to a plane through the renal hilum to define the medial and lateral halves of the kidney (Supplemental Figure 3, Supplemental Digital Content 1, http://links.lww.com/TA/B295). [8] Para-renal hematoma was defined as hematoma extending beyond the aorta on the left or inferior vena cava (IVC) on the right, or extending inferior to the aortic bifurcation into the pelvis (Supplemental Figure 4, Supplemental Digital Content 1, http://links.lww.com/TA/B295). Definition of bleeding interventions included: nephrectomy, partial nephrectomy, renorrhaphy, renal packing, and renal angioembolization. All de-identified radiologic studies were uploaded to a secure web-based Orthanc [16] server for central review. Two radiologists, blinded to the intervention data and patient outcomes, reviewed the CT scans to extract injury specifics.

Descriptive statistics were used to summarize baseline patient characteristics as well as clinical and radiologic variables. Data are presented as mean (standard deviation [SD]) or median (25th-75th interquartile range [IQR]) when appropriate. Comparisons were made between those who underwent interventions for renal bleeding control and those who did not. Independent samples t-test (or Wilcoxon rank-sum test) and chi-squared test (or Fisher's exact test when appropriate) were used to compare continuous and categorical variables between groups, respectively. Mixed effect univariable and multivariable logistic regression models, with clustering by facility, were developed to predict bleeding interventions using selected clinical and radiographic variables. Variables were selected based on clinical relevance and availability at the time of initial trauma evaluation. Candidate predictors included the following: hypotension/shock, concomitant injuries, trauma mechanism, hemoglobin at admission, VCE, HRD, hematoma extension, and laceration location. Factors such as ISS and number of blood products transfused were not included as they are not typically available at the initial assessment. Lactate levels were not included due to a considerable amount of missing data (~39%) and also concerns about selection bias towards patients presenting with lactic acidosis and more severe injuries. AAST grade was also not included, as there is significant variability and some ambiguity about grading of high grade injuries [8, 10], some injury patterns are not addressed in the current AAST grading system[17], decreasing the accuracy in predicting urgent bleeding interventions.[6] Additionally, since the radiographic appearance of the injuries was characterized in detail and included in the model and the intent of this study was to further characterize these risk factors separate from the AAST grade inclusion of the AAST grade would not be appropriate.

Odds ratios (ORs) and p-values from univariable mixed effect logistic models predicting bleeding interventions were reported for each candidate predictor. Stepwise regression evaluating Akaike information criterion (AIC) with backward elimination was used to develop our prediction model using the candidate variables. ORs and p-values for the selected model were reported, and a nomogram was created to describe the relative contributions of risk for renal bleeding interventions of each predictor. For internal validation, model fit was assessed using the Hosmer-Lemeshow goodness of fit test and a calibration plot. To protect against over-optimism, prediction accuracy was estimated using 100 random iterations of 10-fold cross-validation for the area under the receiver operating characteristic curve (AUC). [18] Statistical analyses were conducted in R v. 3.4.0.

The point values for each variable in the nomogram were assigned using the methodology outlined by Yang for building prognostic nomograms.[19] Briefly, the range for each predictor was calculated and multiplied by its beta coefficient to assess its predictive utility relative to the other predictors in the model. The predictor with the highest predictive strength, MaxX, was assigned 100 points, and then the point values for each other predictor, X_i, were calculated as 100*(predictive utility X_i)/(predictive utility MaxX). The nomogram can be read for a particular combination of patient characteristics by obtaining the corresponding points for each patient characteristic from the "Points" bar in the box and summing them. The sum of the points is then found on the “Total Points” bar below the box on the nomogram, and a straight line from the total points to the bottommost bar will provide the predicted probability of undergoing bleeding interventions. To assist with this process, we have provided the point values for categorical variables in parentheses. Point values for the continuous variable (i.e. hematoma rim distance) must be obtained manually by comparing the variable’s value to the points bar at the bottom (Figure-1).

Results

From a cohort of 431 patients, 326 had initial CT scans available for review and were included in this study. Median age was 28.0 (IQR: 22–46) years and median ISS was 25 (IQR: 16 –33). Mechanism of trauma was blunt in 263 patients (81%) and included motor vehicle collisions (140, 53%), pedestrian versus automobile (26, 10%), bicycle (11, 4%), falls (31, 12%), and other (e.g. sport-related, assault, not specified; 55, 21%). Patient characteristics, as well as clinical and radiologic findings at the time of admission, separated by need for bleeding interventions, are presented in Table-1.

Overall, 47 patients (14%) underwent bleeding interventions including 19 renal angioembolizations, 16 nephrectomies, 7 renorrhaphies, 3 partial nephrectomies, and 6 renal packing for bleeding control; some patients underwent more than one intervention (e.g. both angioembolization and renorrhaphy). Patients who underwent bleeding interventions had higher rates of penetrating injuries, and lower hemoglobin on admission; they also had higher grade renal injuries, higher rate of VCE, more complex lacerations, and larger hematomas around the injured kidney (Table-1).

Table-2 presents the results from the univariable and multivariable regression models for the selected clinical and radiologic factors to predict undergoing bleeding interventions. In the multivariable model, a penetrating mechanism of injury and presence of VCE were associated with 4.7-fold and 3.9-fold increases in odds of undergoing bleeding interventions; each 1 cm increase in HRD was also associated with 54% increase in odds of undergoing bleeding interventions.

The nomogram for our bleeding intervention prediction model is presented in Figure-1. Risk of bleeding interventions was calculated using the logistic regression model as "predicted probability=exp(Y)/(1+exp(Y)), where Y was estimated as follows:

Y = - 5.109 + 1.586*(trauma mechanism) + 0.749*(hypotension/shock) + 0.768* (concomitant injuries) + 1.355* (vascular contrast extravasation) + 0.927* (para-renal hematoma) +0.389* (hematoma rim distance in cm).

Both the calibration plot and Hosmer-Lemeshow goodness of fit test (Chi-squared: 3.6, p=0.31) indicated that the data fit the model reasonably well (Supplemental Figure 5, Supplemental Digital Content 1, http://links.lww.com/TA/B295). Of the clinical and radiologic variables entered in the model, only hemoglobin, and laceration location were not included in the final model. Having a HRD of 12 cm contributed the most points to the nomogram, followed by penetrating trauma mechanism, presence of VCE, para-renal hematoma extension, presence of concomitant injuries, and hypotension/shock. The AUC was 0.83 (95% CI: 0.81–0.85). Examples for reading the nomogram using hypothetical patient scenarios are provided in Supplemental Figure 6, Supplemental Digital Content 1, http://links.lww.com/TA/B295.

In order to determine if the nomogram predicted interventions better than AAST grade alone, a separate univariable analysis was performed. AAST grade was associated with 3.4-fold increase in odds of bleeding interventions (Odds Ratio: 3.41, 95% CI: 2.13 – 5.48) and the AUC for the univariable model was 0.69 (95% CI: 0.61–0.77). Additionally, adding the AAST grade to the multivariable model did not significantly increase the AUC of the nomogram (data not shown).

Discussion

We developed a nomogram to predict the risk of bleeding interventions after HGRT, which includes a combination of important clinical and radiologic factors, which are readily available during a trauma evaluation. This nomogram provides an evidence-based predictive tool that may help guide management decisions, especially in lower volume centers with limited experience with management of HGRT.

There is well-established evidence that conservative management of renal trauma is safe and effective and that most stable patients with high-grade injuries can be managed non-operatively.[13, 20] Nephrectomy is avoidable in most patients, except those in extremis or with renal bleeding that fails to respond to alternate less invasive approaches, such as angioembolization and renorrhaphy. According to the National Trauma Data Bank (NTDB), about 1 in every 3 patients with a grade IV renal injury, and more than half of patients with grade V injuries undergo nephrectomy during their acute management.[14] Similarly, in our recent multi-institutional study, 15% of grade IV and 62% of grade V renal injuries underwent nephrectomy in Level-1 trauma centers.[5] It has been shown that nephrectomy rates can be significantly lowered by implementing non-operative management protocols.[21] Non-operative strategies benefit from predictive tools, such as the proposed nomogram, in order to identify those patients at higher risk for failure of non-operative management so that interventions can be performed early, encouraging a systematic approach to management.

Evidence-based nomograms have higher predictive values when compared to conventional grading systems and can provide highly accurate risk estimates to facilitate management-related decisions in different areas of medicine.[20, 22] Additionally, multiple variables can be combined in a nomogram that can increase the predictive accuracy when applied to individual patients. Previous efforts have suggested that a nomogram can be highly accurate in the setting of renal trauma; [23, 24] however, these previous nomograms were limited by coming from single institutions, small sample size with very few bleeding interventions, and being based primarily upon the AAST grading rather than a combination of clinical and radiologic parameters.

The AAST grading system was initially designed to summarize the anatomy of the renal injury and does not provide specific information about factors directly related to higher risk of bleeding and for some injuries it may not be necessarily accurate in the initial trauma evaluation or at predicting bleeding interventions. Using AAST grading in a predictive nomogram is associated with several problems.[6] For example, subtleties in grading such as deep lacerations with segmental vascular injuries but without urinary extravasation can be interpreted as grade III instead of grade IV, dramatically changing the prediction of risk. On the other hand, a parenchymal injury with minimal bleeding risk but a minor urinary extravasation will be categorized as a grade IV injury, overestimating the risk of needing acute interventions. In addition, many patients do not undergo excretory imaging during their initial trauma CT and an

AAST grade cannot be determined in many cases without information about urinary extravasation from the kidney. [25] These situations will potentially obviate the power of a nomogram in predicting the bleeding risk if the nomogram is primarily dependent upon AAST grade. In addition, the incorporation of low grade injuries (grades I and II), which are seldom associated with significant bleeding, will artificially increase the predictive accuracy of a nomogram. This undermines the purpose of a predictive tool as the tool needs to be accurate for predicting bleeding interventions in relevant patients. In our study, using AAST grades in a univariable model to predict bleeding interventions resulted in an AUC of 0.69 in comparison to an AUC of 0.83 for our nomogram. This indicates that using the nomogram, based upon the combination of clinical and radiologic factors, is more predictive for bleeding interventions compared to the AAST grades alone.

Clinical factors need to be readily available if they are to be helpful in a nomogram. For instance, 24-hour blood and platelet transfusion have been previously suggested to predict intervention,[23, 24] however, these are not helpful in predicting critical interventions as most interventions will occur in the first few hours after patient arrival. All of the clinical factors in our nomogram can be obtained at the time of initial assessment or shortly thereafter, and the radiologic factors are based upon the initial CT scans. The radiologic parameters also are easily obtained and do not rely upon extensive knowledge about the subtleties of the AAST grading system. These considerations would clarify communication between the radiology, trauma, and urology teams about the renal injury severity. The high AUC from this proposed nomogram suggests that high predictive accuracy is obtainable without incorporating the AAST grades.

Several studies have assessed important radiologic factors that are associated with bleeding interventions and nephrectomy after renal trauma. [7-9, 11, 12] For example, Dugi et al. [8] found that VCE, HRD, and laceration location are all important factors that should be incorporated into predictive tools. Although renal vascular bleeding can be self-limiting due to the tamponade effect of the retroperitoneal space, presence of VCE signals active bleeding that may benefit from early interventions, such as selective angioembolization. In our study 16 of 19 patients (84%) who underwent renal angioembolization had VCE in their initial scans; however, it is unknown if the other 3 patients underwent prophylactic angioembolization or had signs of active bleeding at the time of angiography that was not evident in the initial scan. A large hematoma (as measured in the axial [transverse] plane of a CT scan) and a hematoma crossing the midline or extending beyond the aortic bifurcation into the pelvis may also suggests an active and expanding hematoma or lack of tamponade effect, which merit close monitoring and or earlier intervention. The predictive power for laceration location has been less consistent. Medial and complex (both medial and lateral) lacerations were suggested as significant factors predicting interventions by Dugi et al. [8] but the results were not reproduced in other studies.[9, 11, 12] In our models, only complex lacerations were significantly associated with bleeding interventions, and this did not improve the overall predictive accuracy of the nomogram. However, HRD and VCE, were strong predictors in our model. Para-renal extension of the hematoma (i.e. bleeding extending laterally beyond the abdominal aorta or IVC, or bleeding extending inferiorly to the aortic bifurcation), was also an important factor. Although highly correlated with HRD, para-renal extension of hematoma also independently increased the nomogram's accuracy. It provides additional information particularly in cases where there is massive lower pole bleeding that may not cause a hematoma extending in the axial plane (measured by HRD).

A major limitation of our study is the exclusion of 105 patients (24%) of the initial HGRT cohort from the Genito-Urinary Trauma Study due to a lack of initial imaging data. These patients had higher rates of shock, 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) and nephrectomy rates were also higher for these patients (39 nephrectomies [37%] vs. 16 nephrectomies [5%], P<0.001). The inability to include these patients limits our nomogram findings to patients who were hemodynamically stable enough to get an initial CT scan. However, these may be the patients where a predictive nomogram is most helpful, rather than those that are in extremis from hemorrhage when a nephrectomy may be life-saving. Another limitation, inherent to all studies on renal trauma management, is a lack of gold standard measure for who needs intervention for bleeding. We can only state that our nomogram will predict with a certain accuracy when trauma surgeons *felt intervention was needed* and not whether an intervention truly was needed or what the consequence would have been had the intervention not taken place. Also, management was not standardized in our multicenter study setting, and there are likely significant differences among these centers and providers in management of HGRT. However, our data reflect the real-world management from Level-1 trauma centers across the country, which by default have more experience in management of high grade traumas. Lack of long-term renal function data and consistent follow-up after patient discharge, is another weakness of the study, which limits discussion of our findings to the acute trauma period. The final limitation is lack of validation of the nomogram with external data. We are currently collecting these data from several high-volume centers, not involved in the initial phase of the study, in order to complete external validation of the nomogram. Despite these limitations, this is the first renal trauma nomogram, predicting bleeding risk and interventions for bleeding, which was developed using contemporary data in a multi-institutional setting, using clinical and imaging data targeted at renal injury management.

Conclusion

We developed a nomogram that integrates multiple clinical and radiologic factors readily available upon assessment of the trauma victim, which can provide predicted probability for risk of undergoing bleeding interventions after HGRT. This nomogram can be used to identify important factors for bleeding interventions, and may help decrease unnecessary interventions, especially at lower volume trauma centers with limited experience with high-grade renal injuries.

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, A.P.P., R.A.M., S. K., and J. B. M. participated in data analysis and interpretation. J.B.M., R.A.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., 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., J. M. H., and R.N. provided critical revisions for this article. All the authors read and approved the final submission.

DISCLOSURE:

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FIGURE LEGENDS

Figure-1: Nomogram for the regression model predicting bleeding interventions after high-grade renal trauma.

How to read the nomogram: For hematoma rim distance, take the size of hematoma in cm and draw a vertical line to the red bar labeled “Points” in the box to get the points. Then sum the points of the hematoma rim distance with the other 5 variables using the point values in the parentheses for each variable. Take the sum of the points and make a dot on the “Total Points” bar below the box on the nomogram. Connect this dot from the “Total points” bar to the bottommost bar to obtain the predicted probability of undergoing bleeding interventions.

Example 1*: A patient is presented to the Emergency Department with a normal and stable blood pressure (i.e. no hypotension/shock during the first 4 hours of admission; 0 points) and with isolated high-grade renal injury (i.e. no concomitant injuries; 0 points) after a knife injury (penetrating injury; 34 points) to the left kidney; in the initial trauma CT scan there is a 3 cm (HRD=3 cm; 25 points) hematoma confined to the peri-renal space (no para-renal; 0 points) without active vascular contrast extravasation (no VCE, 0 points). Total points are 59 (0+0+34+25+0+0) corresponding to an intervention probability of <10%. (Supplemental figure 6-A)*

Example 2*: A patient is transferred to the Emergency Department in shock (16 points) after high-speed motor vehicle accident (blunt injury: 0 points). After initial fluid resuscitation and hemodynamic stabilization, the patient undergoes trauma CT scan which shows liver and splenic lacerations without active bleeding (concomitant injuries; 16.5 points) and multiple deep* *lacerations in the right kidney with vascular contrast extravasation from renal vessels (VCE; 29 points) and a 9 cm hematoma (HRD=9 cm; 75 points) extending inferiorly into the pelvis (para-renal extension: 20 points). Total points are 156.5 (16+0+16.5+29+75+20) corresponding to an intervention probability of ~90% suggesting that it is highly likely that the patient would need early angiography with angioembolization or an open intervention. (Supplemental figure 6-B)*

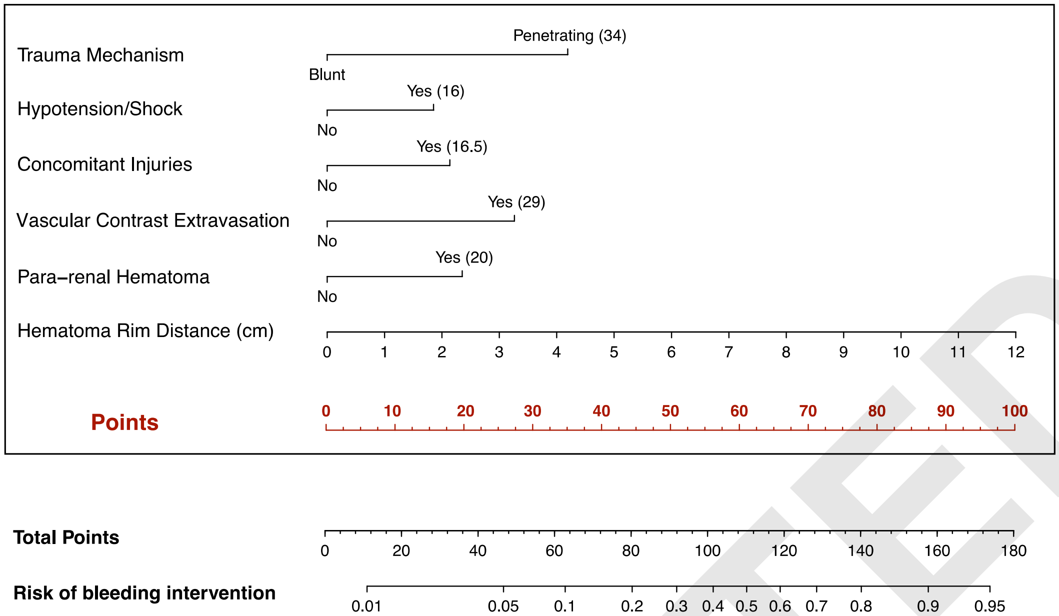


Figure-1: Nomogram for the regression model predicting bleeding interventions after high-grade renal trauma.

How to read the nomogram: For each patient characteristic obtain the corresponding points from the “Points” bar in the box and sum them. The sum of the points is then compared to the “Total Points” bar below the box on the nomogram, and a vertical line from the total points to the bottommost bar will provide the predicted probability of undergoing bleeding interventions. To assist with this process, we have provided the point values for categorical variables in parentheses. Point values for the continuous variable (i.e. hematoma rim distance) must be obtained manually by comparing the variable’s value to the points bar at the bottom.

***Example 1**: A patient is presented to the Emergency Department with a normal and stable blood pressure (i.e. no hypotension/shock during the first 4 hours of admission; 0 points) and with isolated high-grade renal injury (i.e. no concomitant injuries; 0 points) after a knife injury (penetrating injury; 34 points) to the left kidney; in the initial trauma CT scan there is a 3 cm*

(HRD=3 cm; 25 points) hematoma confined to the peri-renal space (no para-renal; 0 points) without active vascular contrast extravasation (no VCE, 0 points). Total points are 59 (0+0+34+25+0+0) corresponding to an intervention probability of <10%.

Example 2*: A patient is transferred to the Emergency Department in shock (16 points) after high-speed motor vehicle accident (blunt injury: 0 points). After initial fluid resuscitation and hemodynamic stabilization, the patient undergoes trauma CT scan which shows liver and splenic lacerations without active bleeding (concomitant injuries; 16.5 points) and multiple deep lacerations in the right kidney with vascular contrast extravasation from renal vessels (VCE; 29 points) and a 9 cm hematoma (HRD=9 cm; 75 points) extending inferiorly into the pelvis (para-renal extension: 20 points). Total points are 156.5 (16+0+16.5+29+75+20) corresponding to an intervention probability of ~90% suggesting that it is highly likely that the patient would need early angiography with angioembolization or an open intervention.*

Table-1: Demographics and clinical and radiologic variables in a cohort of patients with high-grade renal trauma (AAST III-V) split by bleeding intervention

	Total N= 326	No Intervention* N= 279	Intervention* N= 47	*P* **
Demographics				
Age, median (IQR), y	28 (22–46)	28 (22–44)	32 (23–47)	0.33
Body mass index, mean (SD), kg/m^2	27.4 (6.5)	27.4 (6.7)	27.1 (4.7)	0.74
Male sex, n (%)	248 (76%)	206 (75%)	42 (89%)	**0.02**
Injury specifics				
Injury severity score, median (IQR)	22 (16–33)	22 (16–33)	25 (18–35)	0.06
Trauma mechanism, n (%)				**0.01**
Blunt	263 (81%)	232 (83%)	31 (66%)	
Penetrating	63 (19%)	47 (17%)	16 (34%)	
HR on admission, mean (SD), beats/min	93.7 (22.5)	93.4 (22.6)	95.1 (22.4)	0.64
Tachycardia on admission, n (%)	123 (39%)	99 (35%)	24 (51%)	0.11
SBP on admission, mean (SD), mmHg	125.0 (25.3)	125.6 (25.1)	121.3 (26.4)	0.28
Hypotension/shock, n (%)	75 (23%)	59 (21%)	16 (34%)	0.12

Hemoglobin on admission, mean (SD), mg/dL	12.7 (1.9)	12.8 (2.0)	12.1 (1.7)	**0.04**
PRBC transfusion in the first 24h, n (%)	116 (35%)	81 (29%)	35 (74%)	**<0.001**
Lactate, median (IQR), mmol/L	2.7 (1.6 – 4.4)	1.5 (1.0 – 4.3)	2.5 (2.0 – 5.7)	0.17
GCS score, median (IQR)	15 (14–15)	15 (14–15)	15 (14–15)	0.92
Concomitant injuries, n (%) [†]	217 (66%)	184 (66%)	33 (70%)	0.57
Length of hospital stay, median (IQR), d	6 (3–12)	6 (3–11)	10 (6–17)	**<0.001**
Mortality	13 (4%)	10 (4%)	3 (6%)	0.36
Radiologic variables				
AAST grade, n (%)				**0.01**
III	195 (60%)	180 (64%)	15 (32%)	
IV	108 (33%)	88 (32%)	20 (43%)	
V	23 (7%)	11 (4%)	12 (25%)	
Vascular contrast extravasation, n (%)	73 (23%)	44 (16%)	29 (63%)	**<0.001**
Hematoma rim diameter, mean (SD), cm	2.1 (2.0)	1.7 (1.5)	4.3 (2.8)	**<0.001**
Hematoma extent, n (%)				**<0.001**
None/Subcapsular	43 (13%)	42 (15%)	1 (2%)	

Peri-Renal	160 (49%)	146 (52%)	14 (30%)	
Para-Renal	123 (38%)	91 (33%)	32 (68%)	
Laceration location, n (%)[††]				**<0.001**
Lateral	100 (31%)	89 (33%)	11 (24%)	
Medial	67 (21%)	65 (24%)	2 (4%)	
Both/Complex	151 (48%)	117 (43%)	34 (72%)	

* Bleeding interventions including nephrectomy, partial nephrectomy, renorrhaphy, renal packing, and renal-related angioembolization.

** Comparisons made between patients who underwent bleeding interventions and those who did not; bold numbers indicate statistically significant at *P*<0.05 level

[†] Defined as presence of any concomitant injury, including: solid organ, gastrointestinal, spinal cord, major vascular, and pelvic fracture.

AAST, The American Association for the Surgery of Trauma; SD, standard deviation; HR, heart rate; IQR, interquartile range; SBP, systolic blood pressure; PRBC, packed red blood cells; GCS, Glasgow coma scale

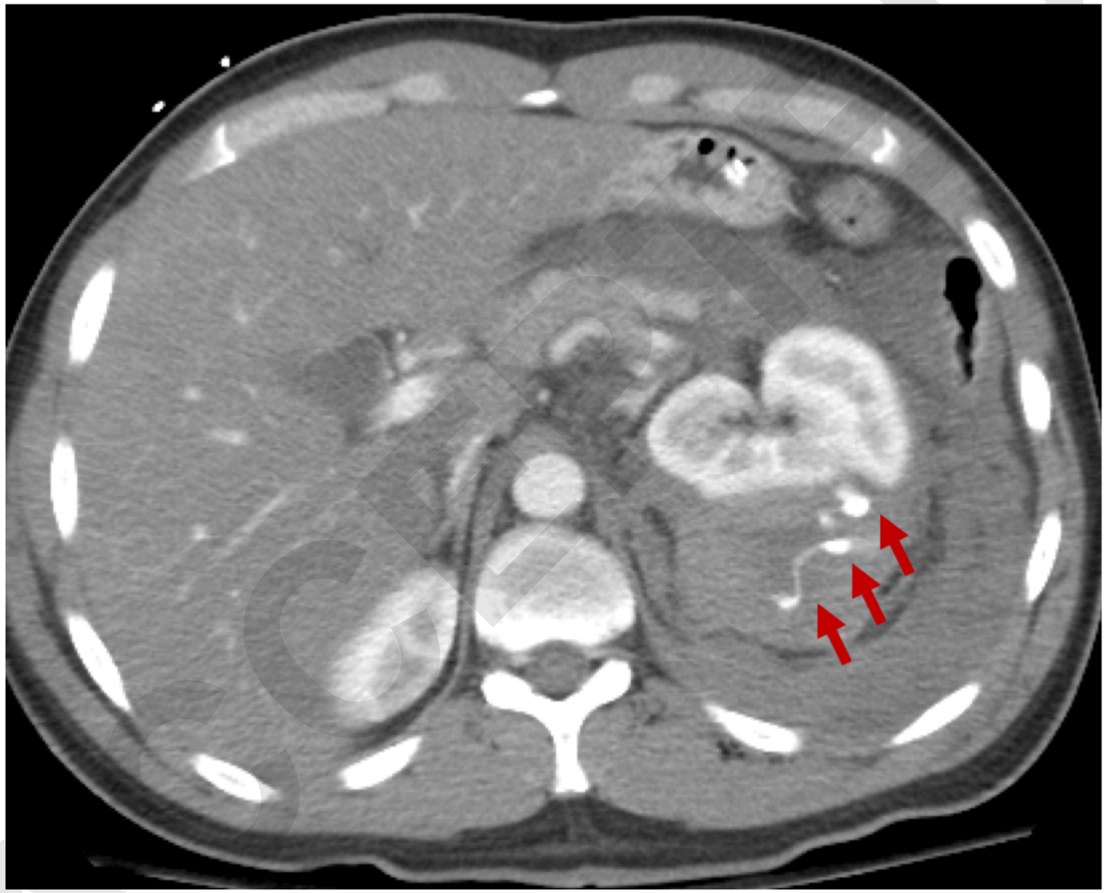
[††] 8 patients did not have parenchymal laceration

Table-2: Univariable and multivariable mixed effect logistic regression models for predicting bleeding interventions after high-grade renal trauma

	Univariable		Multivariable	
	Odds ratio (95% CI)	***P*-value**	**Odds ratio (95% CI)**	***P*-value**
Age (per year)	1.01 (0.9 – 1.03)	0.43	-----	
Sex (male vs. female)	3.05 (1.25 – 9.17)	0.03	-----	
Mechanism of injury (penetrating vs. blunt)	2.63 (1.28 – 5.33)	0.008	4.70 (1.76 – 13.06)	0.002
Hypotension/Shock (yes vs. no)	1.93 (0.95 – 3.84)	0.06	1.82 (0.74 – 4.41)	0.19
HGB at admission (per mg/dL)	0.86 (0.73 – 1.00)	0.05	-----	
Concomitant injuries (yes vs. no)	1.25 (0.64 – 2.56)	0.52	2.50 (0.98 – 7.02)	0.07
VCE (yes vs. no)	10.74 (5.23 – 23.22)	<0.001	3.88 (1.57 – 9.73)	0.003
Hematoma rim distance, (per cm)	1.85 (1.54 – 2.29)	<0.001	1.54 (1.20 – 2.04)	0.001
Para-Renal hematoma (yes vs. no)	4.57 (2.35 – 9.34)	<0.001	2.34 (0.83 – 6.73)	0.11
Laceration location (complex vs. lateral/medial)	3.38 (1.68 – 6.79)	<0.001	-----	

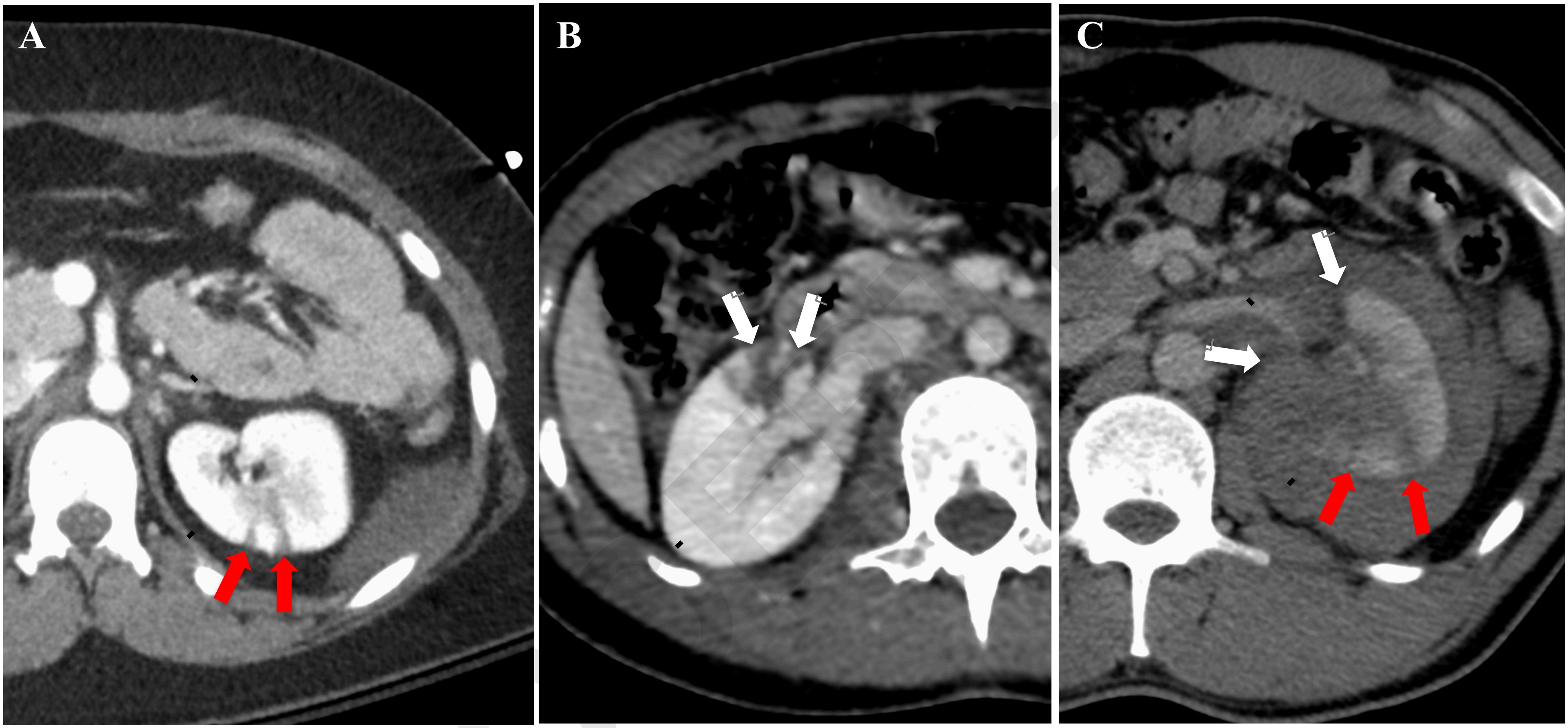
HGB, hemoglobin; VCE, vascular contrast extravasation; CI, confidence interval.

Supplemental figures:

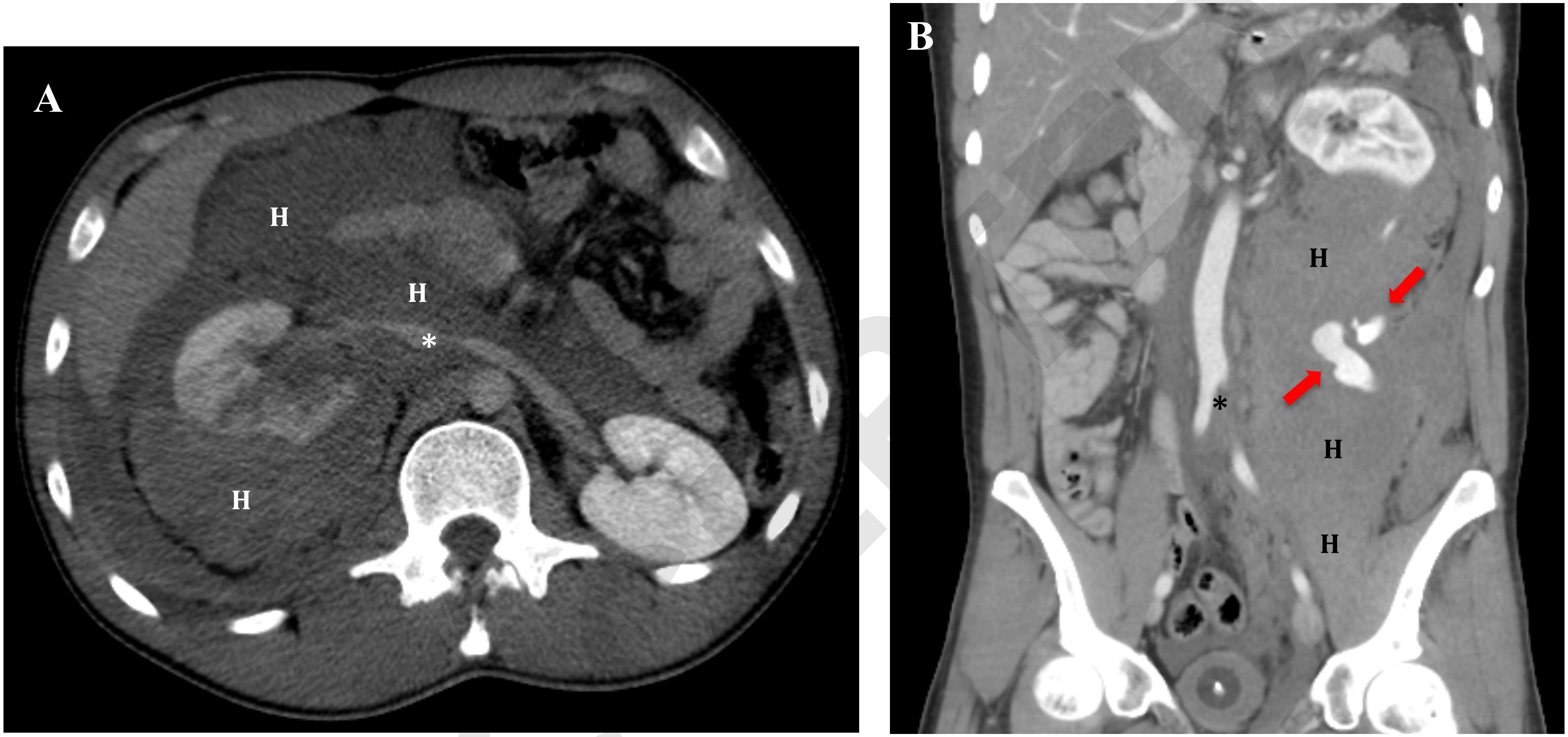


Supplemental Figure 1: Vascular contrast extravasation (VCE) from the lateral left kidney (red arrows), during the arterial phase of the CT scan, with associated peri-renal hematoma.

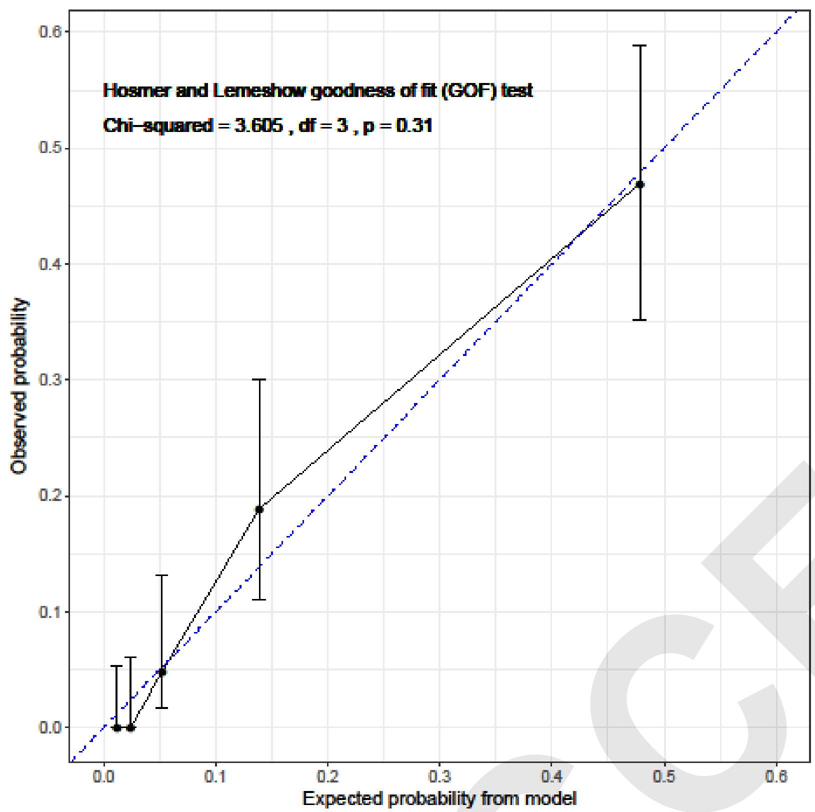
Supplemental Figure 2: Peri-renal hematoma rim distance (HRD) measuring 6 cm at the axial plane. Hematoma rim distance is measured in the axial CT images and is the maximum measurement anywhere from the lower to upper pole.



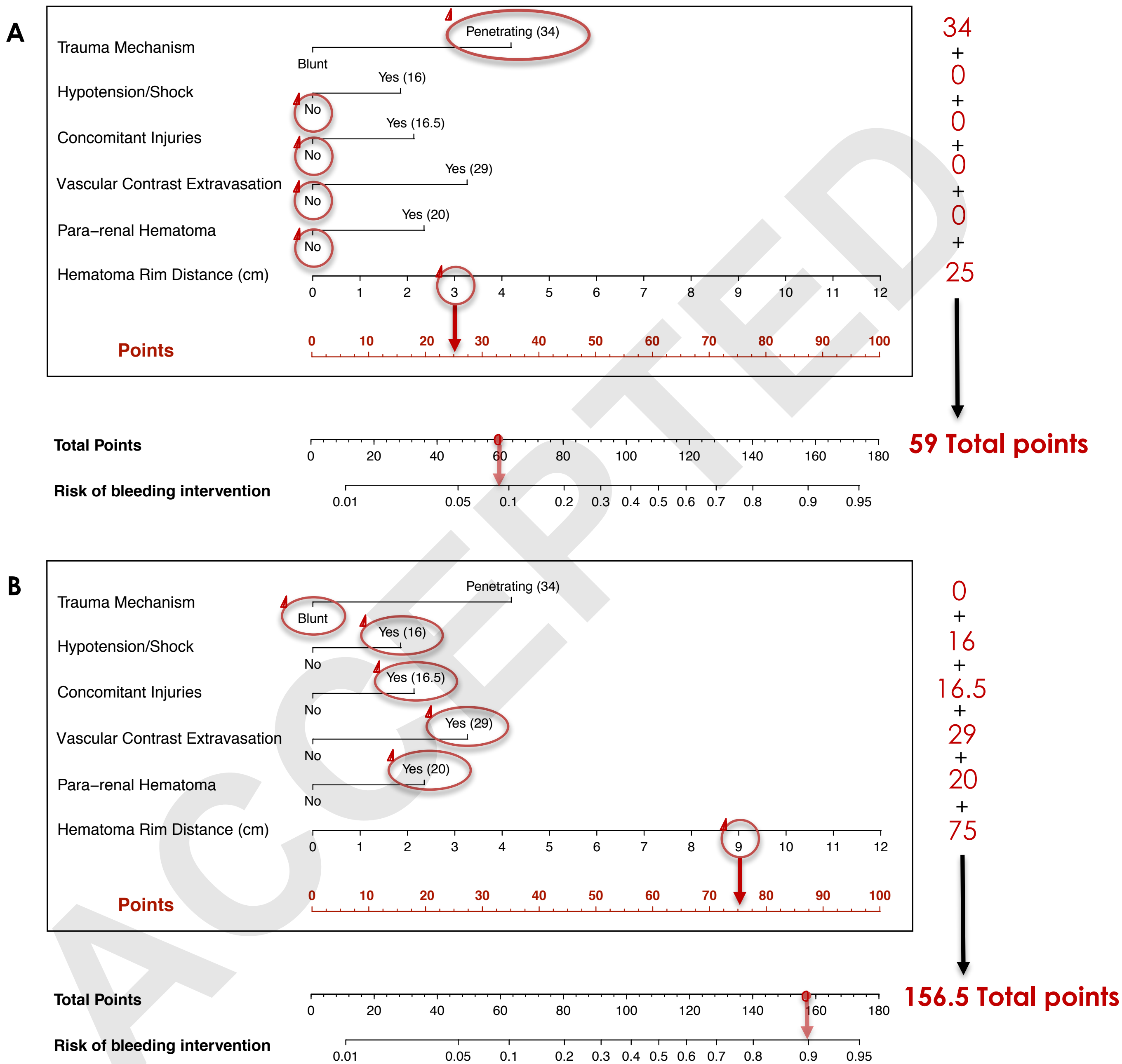
Supplemental Figure 3: Laceration location is defined using a perpendicular line to a plane through the renal hilum to define the medial and lateral halves of the kidney. A) Lateral laceration (red arrows); B) Medial laceration (white arrows); C) Complex laceration (both medial and lateral lacerations).



Supplemental Figure 4: A) Anterior para-renal extension of hematoma (letter H) beyond the inferior vena cava (asterisk) and adjacent to the pancreas; (B) Extension of hematoma (letter H) inferior to the aortic bifurcation (asterisk) into the pelvis associated with vascular contrast extravasation (red arrows).



Supplemental Figure 5: Calibration plot for the nomogram: Subjects were divided into 5 groups according to their percentile of predicted bleeding intervention risk. The observed bleeding intervention percentages for each of the groups was plotted against the average predicted risk of that group. Blue dashed line indicates the perfect prediction (observed = predicted). The p-value for the Hosmer and Lemeshow goodness of fit test was p=0.31, indicating no evidence of poor fit.


A
Trauma Mechanism
Penetrating (34)
Blunt
Hypotension/Shock
Yes (16)
No
Concomitant Injuries
Yes (16.5)
No
Vascular Contrast Extravasation
Yes (29)
No
Para−renal Hematoma
Yes (20)
No
Hematoma Rim Distance (cm)
0 1 2 3 4 5 6 7 8 9 10 11 12
Points
0 10 20 30 40 50 60 70 80 90 100
34 + 0 + 0 + 0 + 0 + 25
Total Points
0 20 40 60 80 100 120 140 160 180
59 Total points
Risk of bleeding intervention
0.01 0.05 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 0.95
B
Trauma Mechanism
Penetrating (34)
Blunt
Hypotension/Shock
Yes (16)
No
Concomitant Injuries
Yes (16.5)
No
Vascular Contrast Extravasation
Yes (29)
No
Para−renal Hematoma
Yes (20)
No
Hematoma Rim Distance (cm)
0 1 2 3 4 5 6 7 8 9 10 11 12
Points
0 10 20 30 40 50 60 70 80 90 100
0 + 16 + 16.5 + 29 + 20 + 75
Total Points
0 20 40 60 80 100 120 140 160 180
156.5 Total points
Risk of bleeding intervention
0.01 0.05 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 0.95

Supplemental Figure 6: Examples for reading the nomogram using patient scenarios.

A) A patient is presented to the Emergency Department with a normal and stable blood pressure (i.e. no hypotension/shock during the first 4 hours of admission; 0 points) and with isolated high-grade renal injury (i.e. no concomitant injuries; 0 points) after a knife injury (penetrating injury; 34 points) to the left kidney; in the initial trauma CT scan there is a 3 cm (HRD=3 cm; 25 points) hematoma confined to the peri-renal space (no para-renal; 0 points) without active vascular contrast extravasation (no VCE, 0 points). Total points are 59 (0+0+34+25+0+0) corresponding to an intervention probability of <10%.

Using regression formula: *- 5.109 + 1.586*1(penetrating trauma mechanism) + 0.749*0(hypotension/shock=no) + 0.768*0 (concomitant injuries=no) + 1.355*0 (vascular contrast extravasation=no) + 0.927*0 (para-renal hematoma=no) +0.389*3 (hematoma rim distance in cm=3) = -2.356. exp(-2.356)/(1+exp(-2.356))=* ***8.66%.***

B) A patient is transferred to the Emergency Department in shock (16 points) after high-speed motor vehicle accident (blunt injury: 0 points). After initial fluid resuscitation and hemodynamic stabilization, the patient undergoes trauma CT scan which shows liver and splenic lacerations without active bleeding (concomitant injuries; 16.5 points) and multiple deep lacerations in the right kidney with vascular contrast extravasation from renal vessels (VCE; 29 points) and a 9 cm hematoma (HRD=9 cm; 75 points) extending inferiorly into the pelvis (para-renal extension: 20 points). Total points are 156.5 (16+0+16.5+29+75+20) corresponding to an intervention probability of

~90% suggesting that it is highly likely that the patient would need early angiography with angioembolization or an open intervention.

Using regression formula: - *5.109 + 1.586*0(blunt trauma mechanism) + 0.749*1(hypotension/shock=yes) + 0.768*1 (concomitant injuries=yes) + 1.355*1 (vascular contrast extravasation=yes) + 0.927*1 (para-renal hematoma=yes) +0.389*9 (hematoma rim distance in cm=9) = 2.191. exp(2.191)/(1+exp(2.191))=* ***89.94%.***