ABSTRACT

Background. Percutaneous renal biopsy (PRB) of native kidneys (NKs) to better understand and treat acute kidney injury (AKI) is being advocated, but little is known about the risk of complications.

Methods. We performed a retrospective study of PRB of NKs in 955 adults from 1991 to 2015 at an academic medical center with real-time ultrasound and automated biopsy needles. Patients undergoing PRB for evaluation of AKI (n = 160) were compared with 795 patients biopsied for other reasons (not-AKI) for postbiopsy complications [need for transfusion of packed red blood cells (PRBCs), an interventional radiologic or surgical procedure, readmission or death].

Results. Patients biopsied for AKI were older (58 ± 16 versus 44 ± 16 years; P < 0.0001), with a higher serum creatinine (SCr) (4.5 ± 2.7 versus 1.8 ± 1.6 mg/dL; P < 0.0001) and lower hemoglobin (Hgb) (10.4 ± 1.7 versus 12.1 ± 2.1; P < 0.0001) and a greater proportion had an abnormal bleeding time (12.5% versus 7.4%, P 0.04), partial thromboplastin time (15.2% versus 5.3%, P < 0.0001) and/or prothrombin time (27.0% versus 12.8%; P < 0.0001) compared with not-AKI patients. Complications post-PRB were significantly greater in patients biopsied for AKI (11.3% versus 6.7%; P=0.04; odds ratio [OR] 1.78 [95% confidence interval (CI) 1.01–3.12]) with patients biopsied for AKI requiring more blood transfusions (10.0% versus 5.3%; P 0.02; OR 2.04 (95% CI 1.12–3.74)). By multivariate analysis, baseline features predictive of a complication were increased SCr and decreased Hgb level, as well as female gender and increased systolic blood pressure.

Conclusion. Patients biopsied for evaluation of AKI are at greater risk of complications due to increased risk factors.

Keywords: acute kidney injury, acute renal failure, complications, native kidney, percutaneous renal biopsy

INTRODUCTION

Acute kidney injury (AKI) was a primary indication for performing percutaneous renal biopsy (PRB) of native kidneys (NKs) when this procedure first became widely available in the 1950s [1–5]. At that time, the information obtained from the renal biopsy was of diagnostic, therapeutic and prognostic value and the risk of a biopsy-related complications was low. As a result, essentially all patients with AKI underwent PRB.

Over the course of the last 60 years, it has been recognized that the majority of cases of AKI can be diagnosed clinically, often as a result of conditions resulting from hypovolemia or ischemic or nephrotoxic AKI [6–10], with treatment limited to hydration and/or dialysis. As a result, in clinical practice, PRB of NKs has been reserved for patients in whom the etiology of AKI is of ‘unknown cause’ [11].

Given the increased morbidity, mortality, medical costs and lack of effective treatments in patients with AKI [6–10, 12, 13],...
there has been renewed interest in performing renal biopsies in patients with AKI [14–16]. The National Institute of Diabetes and Digestive and Kidney Diseases (NIDDK) launched the Kidney Precision Medicine Project [17] in the summer of 2017 with the goal of obtaining ‘research’ renal biopsies from AKI patients in order to identify pathways of AKI through the use of newer technologies (i.e. proteomics and genomics) that will enable the development of targeted therapies aimed at preventing and treating AKI in the future [14–16, 18, 19].

While PRB of NKs is safe with minimal risk, serious complications can occur [14–16, 20–24] and little is known regarding the complication risk in patients with AKI, many of whom are often quite ill with little likelihood of benefit from the procedure (20, 24–26). We evaluate our single-center experience in adult patients undergoing a PRB of NKs for the evaluation of AKI in order to better understand the risk in this patient population.

**MATERIALS AND METHODS**

PRB of NKs was performed in 955 adult (≥15 years) patients consecutively from 1991 to 2015 at Rush University Medical Center. We retrospectively compared 160 patients undergoing a PRB for evaluation of AKI (AKI group) with 795 patients undergoing renal biopsy for evaluation for other reasons (not-AKI group), including proteinuria, hematuria, chronic kidney disease or systemic disease with renal involvement (i.e. systemic lupus erythematosus and vasculitis). This study was approved by the institutional review board at Rush University Medical Center.

**Data collection and biopsy procedure**

Data was prospectively collected at the time of biopsy and up to 1 week postbiopsy. Information collected at the time of biopsy included the nephrologist’s primary reason(s) for the biopsy (i.e. AKI, proteinuria or chronic kidney disease), age, gender, race, systolic and diastolic blood pressures (BPs), serum creatinine (SCr), bleeding time (BT), activated partial thromboplastin time (PTT), prothrombin time (PT) and hemoglobin (Hgb) concentration. In general, it is our practice to perform percutaneous biopsies in ‘stable’ patients with a normal BT (≤9 min), normal PTT (≤33 s), normal PT (≤13.2 s or >65% of control) and stable BP. In patients with a prolonged BT, the use of desmopressin acetate (DDAVP) was at the discretion of the attending nephrologist.

An attending nephrologist or a fellow under the supervision of an attending nephrologist performed all biopsies. Imaging was performed by an experienced attending radiologist using real-time ultrasound as previously described [22, 27]. The lower pole of the kidney was identified for biopsy. A 14- or 16-gauge automated biopsy needle (Bard Biopty Gun, C. R. Bard, Covington, GA, USA) was used.

Following the procedure, patients lay in bed flat on their back for 4–6 h and then remained in bed for 23 h of observation. Patients were monitored postbiopsy for signs or symptoms of complications, such as gross hematuria, flank pain and hypotension. Vital signs were checked every 15 min for 2 h, every hour for 4 h, every 2 h for 6 h and then every 4 h thereafter. Each urine void was checked for hematuria. Hgb levels were checked at ~5–8 h, 10–13 h, and 18–20 h after the procedure and the lowest Hgb level postbiopsy was recorded. The need for additional studies (i.e. renal ultrasound and computed tomography [CT]) or treatment (i.e. transfusion and interventional radiology procedure/embolization) was determined by each nephrologist. All patients were reevaluated ~1 week after biopsy, after which a biopsy data form was completed and submitted.

**Definition of a biopsy-related complication**

A biopsy-related complication was defined by the need for an intervention such as a transfusion of packed red blood cells (PRBCs) or an interventional radiologic or surgical procedure and those resulting in readmission or death.

**STATISTICAL ANALYSIS**

Statistical analysis was performed using the Mann–Whitney test for continuous data or the Fisher’s exact test for categorical data using GraphPad InStat version 3.06 for Windows (GraphPad Software, La Jolla, CA, USA; www.graphpad.com). Multivariate analysis using logistic regression was performed using SAS software version 9.3 (SAS Institute, Cary, NC, USA) to determine which feature at baseline was predictive of a complication after renal biopsy. The baseline variables examined included race, gender, age, BT, systolic BP, diastolic BP, SCr, Hgb concentration, proteinuria, who performed the biopsy (attending or fellow) and reason for the biopsy (AKI versus not-AKI). Variables with a P-value < 0.05 were retained in the final model and reported as odds ratios (ORs) with 95% confidence intervals (CIs). Data are reported as mean ± standard deviation (SD) and a P-value < 0.05 was considered significant.

**RESULTS**

**Baseline demographic, clinical and laboratory features**

The baseline demographic and clinical features of the 160 patients biopsied for evaluation of AKI compared with not-AKI patients are shown in Table 1. Patients undergoing PRB for evaluation of AKI were significantly older (58 ± 16 versus 44 ± 16 years; P < 0.0001) with a significantly higher proportion >60 years of age (48% versus 21%; P < 0.0001) and >65 years of age (39% versus 14%; P < 0.0001) and they were more often male (54% versus 36%; P < 0.0001). There were no racial differences between the two groups and systolic and diastolic BPs were similar as well. The proportion of patients with a systolic BP > 140 mmHg was similar between patients whether biopsied for AKI or not (32.5% versus 29.4%; P = 0.45).

Baseline laboratory features are shown in Table 2. Patients with AKI had a significantly higher SCr at the time of biopsy (4.5 ± 2.7 versus 1.8 ± 1.6 mg/dL; P < 0.0001) and a significantly greater proportion of AKI patients had an SCr > 1.5 mg/dL (94% versus 37%; P < 0.0001), > 2.0 mg/dL (86% versus 25%; P < 0.0001) and > 3.0 mg/dL (65% versus 12%; P < 0.0001) at the time of biopsy. The level of proteinuria was significantly less in patients biopsied for evaluation of AKI compared with not-AKI patients.

| Table 1. Baseline demographic and clinical features |
|-----------------------------------------------|
| AKI | Not-AKI | P-value |
| --- | --- | --- |
| n (%) | 160 (17) | 795 (83) | <0.0001 |
| Age (years), mean ± SD | 58 ± 16 | 44 ± 16 | <0.0001 |
| Male, n (%) | 86 (54) | 284 (36) | <0.0001 |
| Race, n (%) | | | |
| White | 68 (43) | 276 (35) | 0.07 |
| Black | 69 (43) | 357 (45) | 0.73 |
| Other | 23 (14) | 162 (20) | 0.09 |
| BP | | | |
| Systolic (mmHg), mean ± SD | 136 ± 17 | 133 ± 19 | 0.11 |
| >140 mmHg, n (%) | 52 (32.5) | 233 (29.4) | 0.45 |
| Diastolic (mmHg), mean ± SD | 79 ± 12 | 80 ± 13 | 0.60 |
Table 2. Baseline laboratory data

|                      | AKI      | Not-AKI  | P-value |
|----------------------|----------|----------|---------|
| Patients, n (%)      | 160 (17) | 795 (83) | <0.0001 |
| Creatinine (mg/dL), mean ± SD | 4.5 ± 2.7 | 1.8 ± 1.6 | <0.0001 |
| PTT (sec), mean ± SD | 157 (60) | 788 (50) |         |
| n                    | 160      | 795      |         |
| UPro (g/g)           | 3.9 ± 5.6| 4.3 ± 4.7| 0.02    |
| n, mean ± SD         | 143      | 773      |         |
| PT (sec), mean ± SD  | 7.3 ± 1.9| 6.9 ± 1.9| 0.07    |
| n                    | 157      | 788      |         |
| BT (min), mean ± SD  | 20 (12.5)| 58 (7.4) | 0.03    |
| n                    | 158      | 787      |         |
| ADP (sec), mean ± SD | 24 (15.2)| 42 (5.3) | <0.0001 |
| n                    | 160      | 795      |         |

Table 3. Biopsy procedure

|                      | AKI      | Not-AKI  | P-value |
|----------------------|----------|----------|---------|
| n                    | 160      | 795      |         |
| Fellow biopsy, n (%)  | 141 (88) | 686 (86) | 0.61    |
| Needle gauge, n (%)   | 14       | 16       |         |
| 14                   | 133 (83.1)| 702 (88.3)| 0.08    |
| 16                   | 27 (16.9)| 93 (11.7)|         |
| Adequate tissue       | 157 (98.1)| 791 (99.5)| 0.09    |

Table 4. Diagnoses in biopsies for AKI

| Diagnosis                | n (%)     | Complications, n (%) | P-value |
|--------------------------|-----------|----------------------|---------|
| Glomerulonephritis/vasculitis | 75 (47)   | 5 (7)                | 0.13    |
| ATN                      | 19 (12)   | 3 (16)               | 0.45    |
| AIN                      | 18 (11)   | 1 (6)                | 0.69    |
| Cast nephropathy/AL amyloid | 14 (9)   | 6 (43)               | 0.01    |
| AED/TMA/Other/QNS        | 17 (5)    | 2 (12)               | 1.0     |
| Total                    | 160       | 18                   |         |

Table 5. Biopsy complication

|                      | AKI      | Not-AKI  | P-value |
|----------------------|----------|----------|---------|
| n                    | 160      | 795      |         |
| Gross hematuria, n (%) | 3 (1.9)  | 8 (1.0)  |         |
| Hematoma, n (%)       | 10 (6.3) | 32 (4.9)*|         |
| Both, n (%)           | 3 (1.9)  | 10 (1.3) |         |
| Drop in Hgb + pain, n (%) | 2 (1.3) | 2 (0.3)  |         |
| Sudden death, n (%)   | 0        | 1 (0.1)  |         |
| Total, n (%)          | 18 (11.3)| 53 (6.7) | 0.04    |

*One death.

Biopsy procedure

Biopsies performed for the evaluation of AKI were performed by fellows under nephrology attending supervision in a proportion similar to not-AKI patients (Table 3). There was no significant difference in the proportion of biopsies done with 14- versus 16-gauge needles between the two groups. Adequate tissue for a diagnosis was obtained in a similar proportion of patients. The most common lesion found in patients biopsied for AKI was glomerulonephritis, and this was found in 47% of biopsies (Table 4). Acute tubular necrosis alone or acute interstitial nephritis (AIN) alone was observed in 12% and 11% of biopsies, respectively.

Biopsy complications

A complication after renal biopsy (Table 5) occurred more frequently in patients biopsied for evaluation of AKI compared with those biopsied for other reasons (11.3% versus 6.7%; P = 0.04). The OR for a complication in AKI patients was 1.78 (95% CI 1.01–3.12) compared with not-AKI patients. In patients with a complication, the most common complication in both groups was a hematoma (identified by renal ultrasound or CT imaging), with or without gross hematuria, occurring in 13/18 patients (72.2%) biopsied for evaluation of AKI and in 42/53 (79.2%) of not-AKI patients. In four patients (two in each group) a decrease in Hgb associated with flank pain occurred and was likely the result of a perinephric hematoma, but no imaging study was done to confirm this (all required blood transfusions). There were no deaths in patients biopsied for AKI, whereas there were two deaths in not-AKI patients. One death was the result of hemorrhage post-PRB. The second death occurred suddenly the day after the biopsy and prior to discharge from the hospital in an elderly patient with diabetes mellitus. The biopsy had been uneventful with no signs or symptoms of complications or changes in Hgb after biopsy. At autopsy, there was no evidence of a biopsy-related complication (i.e. no subcapsular or perinephric hematoma). By multivariate analysis (Table 7), baseline features predictive of a complication were female gender, increased systolic BP, increased SCr level and decreased Hgb level. The reason for a PRB (i.e. AKI versus not-AKI) was not independently predictive of a complication.

In patients biopsied for evaluation of AKI, the complication rate was highest in patients found to have cast nephropathy or amyloid light-chain amyloidosis (Table 4), where 6/14 (43%) had a complication post-PRB. All six of the patients with a complication had an SCr >4.0 mg/dL and Hgb <10.0/dL and five had an abnormal BT, PTT or PT at the time of biopsy. All six patients had cast nephropathy and were ultimately diagnosed with multiple myeloma.

The most frequent intervention in patients with a complication was transfusion of PRBCs (Table 6). Overall, 10.0% of
patients biopsied for evaluation of AKI required a postbiopsy transfusion compared with 5.3% (P = 0.02) of not-AKI patients. The OR for requiring a transfusion postbiopsy in AKI patients was 2.04 (95% CI 1.12–3.74) compared with not-AKI patients. While the proportions were not significantly different, patients biopsied for AKI required an interventional radiology procedure due to underlying glomerulonephritis in 10.0% compared with 5.3% (P = 0.02) compared with those undergoing biopsy for other reasons (not-AKI). Patients undergoing biopsy for evaluation of AKI had a greater number of risk factors for a complication, as they were significantly older, had a higher SCR level, lower Hgb level and a greater proportion with a prolonged BT, prolonged PTT and/or an abnormal PT at the time of PRB compared with patients biopsied for other reasons (not-AKI patients). By multivariate analysis, AKI was not an independent risk factor for a complication, but increased SCR level and decreased Hgb level were predictive of both complications and the need for transfusions and explained the difference in complication rates between the AKI and not-AKI patient groups.

After the advent of a safe PRB procedure in the 1950s the evaluation of patients with AKI was a primary indication for renal biopsy [1–5]. The biopsy material provided new insight into the pathology of AKI. However, as it became evident that the primary cause for AKI in hospitalized patients was a result of easily treatable causes such as hypovolemia or due to ischemic or nephrotic AKI, for which the only therapy was supportive care or dialysis, it became apparent that there was limited prognostic or therapeutic value in doing a renal biopsy in the majority of patients with AKI [6, 8, 28, 29]. As a result, over the last 60 years, biopsy for AKI has been almost completely reserved for patients with otherwise ‘unexplained’ AKI [11].

Acute renal failure is the indication for performing a renal biopsy in 10–25% of biopsies, series [24, 30–34], similar to our study. In hospitalized patients with AKI <10–20% actually undergo a renal biopsy as the majority of cases can be explained by hypovolemia, obstruction, drug-induced AIN or a drug-induced nephrotic acute tubular necrosis [8, 28, 35, 36]. A study by Kazi et al. [57], in which 158 patients presenting to the emergency department with AKI were biopsied, found that almost 70% had an acute tubular or interstitial etiology for AKI. Since the cause of AKI is evident in many of these cases and the prognosis and therapy are known, biopsy has limited value in these circumstances. As a result, the majority of patients with AKI do not undergo a renal biopsy, as the risk outweighs any potential benefit.

In patients undergoing biopsy for otherwise unexplained AKI, it has been shown that the information obtained is highly valuable. We found that in AKI the biopsy was diagnostic in >98% of cases and that an underlying glomerulonephritis was the primary cause for the AKI with interstitial nephritis or acute tubular necrosis alone seen infrequently. Our findings are similar to the observations found in other biopsy studies for unexplained AKI where glomerulonephritis is the primary finding in >50% of cases [28, 30, 33–36, 38, 39]. Lopez-Gomez et al. [33], in the AKI cohort of the Spanish registry of glomerulonephritis, found that in 14 000 biopsies done over 12 years, 16.9% were done for the evaluation of AKI and glomerulonephritis (often a necrotizing or crescentic lesion) was seen in >60% of biopsies. Haas et al. [30] evaluated the cause of unexplained AKI in patients >60 years of age and found that glomerulonephritis was demonstrated in 46%, most often a pauci-immune glomerulonephritis, whereas acute tubular necrosis alone was observed in only 7% of biopsies. Thus renal biopsy in unexplained AKI has significant diagnostic, prognostic and therapeutic implications.

Since it has been clearly shown that patients with AKI have an increased risk of progressive renal disease, morbidity and mortality that result in increased medical costs [6–10, 13], there is renewed interest as demonstrated by the NIDDK Kidney Precision Medicine Project [17] in performing ‘research’ renal biopsies in patients with AKI [14–16]. It is hoped that through the use of newer diagnostic procedures, such as proteomics and genomics on biopsy material, a better understanding of the pathophysiology of AKI will be achieved, resulting in the development of therapies that may prevent or halt the progression of AKI and possibly lead to resolution of AKI [14, 15, 17–19]. Clearly, doing PRB in such patients, many of whom are acutely ill, will initially pose a greater risk than benefit to such patients and thus the NIDDK recognizes the importance of providing participating patients ‘with clear information about the risks associated with undergoing a kidney biopsy’ [17].

**DISCUSSION**

We found that patients undergoing PRB for evaluation of AKI had a significantly higher complication rate (11.3% versus 6.7%; P = 0.04) and were significantly more likely to receive a transfusion of PRBCs due to a postbiopsy complication (10.0% versus 5.3%; P = 0.02) compared with those undergoing biopsy for other reasons (not-AKI). Patients undergoing biopsy for evaluation of AKI had a greater number of risk factors for a complication, as they were significantly older, had a higher SCR level, lower Hgb level and a greater proportion with a prolonged BT, prolonged PTT and/or an abnormal PT at the time of PRB compared with patients biopsied for other reasons (not-AKI patients). By multivariate analysis, AKI was not an independent risk factor for a complication, but increased SCR level and decreased Hgb level were predictive of both complications and the need for

| Risk factor | Odds ratio | 95% CI | P-value |
|-------------|------------|--------|---------|
| Complication |            |        |         |
| Female gender | 2.01       | 1.2–3.6 | 0.02    |
| Systolic BP⁴ | 1.01       | 1.001–1.03 | 0.04      |
| SCR³       | 1.14       | 1.04–1.26 | 0.004 |
| Hgb²       | 1.31       | 1.13–1.51 | 0.0003 |
| Transfusion |            |        |         |
| Female gender | 2.12       | 1.08–4.10 | 0.029 |
| Systolic BP | 1.02       | 1.002–1.03 | 0.024 |
| SCR         | 1.17       | 1.06–1.29 | 0.002 |
| Hgb         | 1.48       | 1.25–1.75 | <0.0001 |

⁴For every increase of 1 mg/dL.
³For every increase of 1 mmHg.
²For every decrease of 1 g/dL.

**Table 6. Complication intervention**

| AKI | Not-AKI | P-value |
|-----|---------|---------|
| n   | Transfusion alone | n       | 160 | 795 |
|     | Transfusion alone | n       | 13  | 36  |
|     | Total transfusions | n (%)  | 16 (10.0) | 42 (5.3) | 0.02 |
|     | Cystoscopy, n (%)  | 0       | 2 (0.25) | 1.0 |
|     | Radiologic embolization | n | 3 (1.9) | 8 (1.0) | 0.41 |
|     | and transfusion, n | 6       | 3 |
|     | Hematuria with obstruction, n (%) | 0 | 1 (0.13) | 1.0 |
|     | Readmitted with hematoma, n (%) | 2 (1.25) | 5 (0.63) | 0.33 |

**Table 7. Baseline features predictive of a complication or need for transfusion post-PRB**

| Risk factor | Odds ratio | 95% CI | P-value |
|-------------|------------|--------|---------|
| Complication |            |        |         |
| Female gender | 2.01       | 1.2–3.6 | 0.02    |
| Systolic BP⁴ | 1.01       | 1.001–1.03 | 0.04      |
| SCR³       | 1.14       | 1.04–1.26 | 0.004 |
| Hgb²       | 1.31       | 1.13–1.51 | 0.0003 |
| Transfusion |            |        |         |
| Female gender | 2.12       | 1.08–4.10 | 0.029 |
| Systolic BP | 1.02       | 1.002–1.03 | 0.024 |
| SCR         | 1.17       | 1.06–1.29 | 0.002 |
| Hgb         | 1.48       | 1.25–1.75 | <0.0001 |

⁴For every increase of 1 mmHg.
³For every increase of 1 mg/dL.
²For every decrease of 1 g/dL.
PRB of NKS has generally been shown to be safe, with complications requiring an intervention such as transfusion or arterial embolization in <5% of cases and a biopsy-related death being extremely rare [20, 22–24]. It is well known that a number of features at baseline are significantly predictive of an increased risk of complications, including age >60 years, elevated BP, renal insufficiency, anemia and coagulopathy or thrombocytopenia [20–25, 31, 40, 41]. While patients undergoing biopsy for AKI have many of these risk factors, as demonstrated in our study, little has been published regarding the complication rate post-PRB in this group of patients. Corapi et al. [20], in a meta-analysis of >9000 PRBs of NKS performed with automated biopsy needles under real-time ultrasound guidance, found that studies in which >10% of patients were biopsied for AKI had an increased requirement for transfusions compared with those studies with <10% of biopsies for AKI (1.1% versus 0.04%, P < 0.001). A study by Tondel et al. [24], in >9000 biopsies, found that patients biopsied for evaluation of AKI were 2.3 times (1.7% versus 0.8%, P < 0.001) as likely to have a major complication (transfusion, surgery or interventional radiology procedure) compared with patients undergoing biopsy for other reasons. These observations are similar to ours, which demonstrate that patients undergoing biopsy for AKI are at twice the risk of a complication and need for a blood transfusion.

AKI is frequently observed in patients admitted to the intensive care unit (ICU), the majority of whom are elderly and critically ill with multiorgan failure. The use of PRB performed for the evaluation of AKI in the ICU setting has been reported in two retrospective studies. In a retrospective study conducted in 10 French ICUs for >10 years, Augusto et al. [25] reported 77 patients with AKI undergoing a renal biopsy during their ICU admission. The patients had significant comorbidity, with 68% of patients on renal replacement therapy, 57% on a ventilator and 13% on pressors at the time of the biopsy. The postbiopsy complication rate was high with 22% of the patients requiring 2–3 units of packed red cells and 2.5% requiring angiographic embolization by interventional radiology, but there were no deaths. In the second retrospective study involving five French ICUs, Philipponet et al. [26] report 56 adult patients with AKI undergoing PRBs over a 12-year period. The patients had increased comorbidity at the time of biopsy, with 44% of patients on ventilators, 30% in shock and 80% receiving renal replacement therapy. The biopsies were performed with ultrasound by nephrologists in 84% of cases. Postbiopsy complications occurred with 13% of patients requiring 2–3 units of PRBCs and 3.6% of patient’s requiring angiographic embolization by interventional radiology. The embolization was unsuccessful in one patient leading to multiorgan failure and death. Thus critically ill patients, those most at risk for AKI, have increased comorbidity and risk factors that results in an increased risk for a post-PRB complication.

Our study has a number of limitations. First, while information on baseline data and postbiopsy complications is obtained prospectively in all patients biopsied, this study was based on a retrospective evaluation of the data. Second, categorization of patients undergoing biopsy for AKI was based on the ‘reason for biopsy’ as defined at the time of biopsy by the nephrologist and was not based on a quantitative change in SCR level. Finally, patients undergoing biopsy for AKI were considered ‘stable’ for PRB. These limitations may have resulted in a misclassification of some patients in our study and may actually underrepresent the risk of post-PRB complication in patients with AKI. Despite these limitations, the fact that we observed an increased risk of post-PRB complications in patients biopsied for evaluation of AKI is clinically important given the paucity of existing data. Given the NIDDK Precision Medicine Project for obtaining PRB in AKI patients [17], we believe this information will be extremely beneficial in providing informed consent to participating patients.

In conclusion, patients undergoing PRB of NKS for evaluation of AKI have a greater rate of complication post-PRB compared with patients biopsied for other reasons. The increased complication rate in this patient population is likely a result of having a greater number of risk factors.

AUTHORS’ CONTRIBUTIONS
S.M.K. and W.L.W. designed the study. S.M.K. and J.K.E. performed the statistical analysis. S.M.K. drafted the manuscript. S.M.K., C.N.G., J.K.E. and W.L.W reviewed and revised the manuscript. All authors approved the final version of the manuscript.

CONFLICT OF INTEREST STATEMENT
The results presented in this paper have not been published previously in whole or part, except in abstract format.

REFERENCES
1. Iversen P, Brun C. Aspiration biopsy of the kidney. Am J Med 1951; 11: 324–330
2. Iversen P, Brun C. Aspiration biopsy of the kidney. 1951. J Am Soc Nephrol 1997; 8: 1778–1787
3. Kark RM, Muehrcke RC. Biopsy of the kidney in the prone position. Lancet 1954; 263: 1047–1049
4. Kark RM, Muehrcke RG, Pollak VE et al. An analysis of five hundred percutaneous renal biopsies. AMA Arch Intern Med 1958; 101: 439–451
5. Kark RM. Renal biopsy. JAMA 1968; 205: 220–226
6. Liano F, Pascual J. Epidemiology of acute renal failure: a prospective, multicenter, community-based study. Madrid Acute Renal Failure Study Group. Kidney Int 1996; 50: 811–818
7. Mehta RL, Pascual MT, Soroko S et al. Spectrum of acute renal failure in the intensive care unit: the PICARD experience. Kidney Int 2004; 66: 1613–1621
8. Nash K, Hafeez A, Hou S. Hospital-acquired renal insufficiency. Am J Kidney Dis 2002; 39: 930–936
9. Chertow GM, Burdick E, Honour M et al. Acute kidney injury, mortality, length of stay, and costs in hospitalized patients. J Am Soc Nephrol 2005; 16: 3365–3370
10. Hsu RK, McCulloch CE, Heung M et al. Exploring potential reasons for the temporal trend in dialysis-requiring AKI in the United States. Clin J Am Soc Nephrol 2016; 11: 14–20
11. Clinical competence in percutaneous renal biopsy. Health and Public Policy Committee, American College of Physicians. Ann Intern Med 1988; 108: 301–303
12. Hoste EAJ, Bagshaw SM, Bellomo R et al. Epidemiology of acute kidney injury in critically ill patients: the multinational AKI-EPI study. Intensive Care Med 2015; 41: 1411–1423
13. Collister D, Pannu N, Ye F et al. Health care costs associated with AKI. Clin J Am Soc Nephrol 2017; 12: 1733–1743
14. Bonventre JV, Basile D, Liu KD et al. AKI: a path forward. Clin J Am Soc Nephrol 2013; 8: 1606–1608
15. Bonventre JV, Boulware LE, Dember LM et al. The kidney research national dialogue: gearing up to move forward. Clin J Am Soc Nephrol 2014; 9: 1806–1811
16. Soley K, Racusen LC. Role of the renal biopsy in acute renal failure. Contrib Nephrol 2001; 132: 68–75
17. Norton JM, Ketchum CJ, Narva AS et al. Complementary initiatives from the NIDDK to advance kidney health. *Clin J Am Soc Nephrol* 2017; 12: 1544–1547
18. Malhotra R, Siew ED. Biomarkers for the early detection and prognosis of acute kidney injury. *Clin J Am Soc Nephrol* 2017; 12: 149–173
19. Dhaun N, Bellamy CO, Cattran DC et al. Utility of renal biopsy in the clinical management of renal disease. *Kidney Int* 2014; 85: 1039–1048
20. Corapi KM, Chen JL, Balk EM et al. Bleeding complications of native kidney biopsy: a systematic review and meta-analysis. *Am J Kidney Dis* 2012; 60: 62–73
21. Hogan JJ, Mocanu M, Berms JS. The native kidney biopsy: update and evidence for best practice. *Clin J Am Soc Nephrol* 2016; 11: 354–362
22. Korbet SM. Percutaneous renal biopsy. *Semin Nephrol* 2002; 22: 254–267
23. Korbet SM, Volpini KC, Whittier WL. Percutaneous renal biopsy of native kidneys: a single-center experience of 1,055 biopsies. *Am J Nephrol* 2014; 39: 153–162
24. Tondel C, Vikse BE, Bostad L et al. Safety and complications of percutaneous kidney biopsies in 715 children and 8573 adults in Norway 1988-2010. *Clin J Am Soc Nephrol* 2012; 7: 1591–1597
25. Augusto J-F, Lassalle V, Fillatre P et al. Safety and diagnostic yield of renal biopsy in the intensive care unit. *Intensive Care Med* 2012; 38: 1826–1833
26. Philipponnet C, Guerin C, Canet E et al. Kidney biopsy in the critically ill patient, results of a multicentre retrospective case series. *Minerva Anestesiologia* 2013; 79: 53–61
27. Birnholz JC, Kasinath BS, Corwin HL. An improved technique for ultrasound guided percutaneous renal biopsy. *Kidney Int* 1985; 27: 80–82
28. Beaufils M. Glomerular disease complicating abdominal sepsis. *Kidney Int* 1981; 19: 609–618
29. Madaio MP. Renal biopsy [clinical conference]. *Kidney Int* 1990; 38: 529–543
30. Haas M, Spargo BH, Wit BJ et al. Etiologies and outcome of acute renal insufficiency in older adults: a renal biopsy study of 259 cases. *Am J Kidney Dis* 2000; 35: 433–447
31. Stratta P, Canavese C, Marengo M et al. Risk management of renal biopsy: 1387 cases over 30 years in a single centre. *Eur J Clin Investig* 2007; 37: 954–963
32. Uezono S, Hara S, Sato Y et al. Renal biopsy in elderly patients: a clinicopathological analysis. *Ren Fail* 2006; 28: 549–555
33. Lopez-Gomez JM, Rivera F. Renal biopsy findings in acute renal failure in the cohort of patients in the Spanish Registry of Glomerulonephritis. *Clin J Am Soc Nephrol* 2008; 3: 674–681
34. Schena FP. Survey of the Italian Registry of Renal Biopsies. Frequency of the renal diseases for 7 consecutive years. The Italian Group of Renal Immunopathology. *Nephrol Dial Transplant* 1997; 12: 418–426
35. Richet G, Srar JD, Kourilsky O et al. [Renal puncture biopsy in acute renal insufficiency]. *Ann Med Interne (Paris)* 1978; 129: 445–447
36. Richet G, Srar JD, Kourilsky O et al. [Kidney puncture biopsy in acute renal failure]. *Rev Prat* 1978; 28: 3769–3774
37. Kazi JI, Mubarak M, Akhter F et al. Spectrum of pathological lesions in acute renal failure. *J Coll Physicians Surg Pak* 2003; 13: 22–24
38. Cohen AH, Nast CC, Adler SG et al. Clinical utility of kidney biopsies in the diagnosis and management of renal disease. *Am J Nephrol* 1989; 9: 309–315
39. Richards NT, Darby S, Howie AJ et al. Knowledge of renal histology alters patient management in over 40% of cases. *Nephrol Dial Transplant* 1994; 9: 1255–1259
40. Shidham GB, Siddiqi N, Beres JA et al. Clinical risk factors associated with bleeding after native kidney biopsy. *Nephrology (Carlton)* 2005; 10: 305–310
41. Simard-Meilleur MC, Troyanov S, Roy L et al. Risk factors and timing of native kidney biopsy complications. *Nephron Extra* 2014; 4: 42–49