

Long-Term Evaluation of Kidney Biopsy Outcomes to Guide Continuous Quality Improvement

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Abstract

Background

Kidney biopsy is essential for diagnosis and management but carries bleeding risks. Efforts to reduce bleeding may compromise tissue adequacy, highlighting the need to systematically evaluate biopsy performance. Understanding factors that influence both safety and adequacy can guide targeted quality improvement (QI) efforts.

Methods

We conducted a retrospective single-center study of native kidney biopsies (2014–2023) as part of a QI initiative to improve biopsy safety and adequacy. Multivariable logistic regression identified factors associated with major complications (need for angiography, embolization, or transfusion within seven days of biopsy) and biopsy adequacy (≥ 10 glomeruli for light microscopy and ≥ 1 glomerulus for indirect immunofluorescence and electron microscopy).

Results

A total of 796 biopsies were analyzed (56.2% female; median age 54.9 years; median BMI 28.9 kg/m²). An 18-gauge needle was used in 98% of biopsies. Major complications occurred in 10.3%, improving from 14.5% in 2014 to 2.8% in 2023 following prior QI interventions. Biopsy adequacy was achieved in 58.4%. Higher hemoglobin (adjusted odds ratio (aOR) 0.73, 95% CI 0.60–0.90) and platelet count (aOR 0.88, 95% CI 0.79–1.00) were associated with lower complications, whereas acute kidney injury (aOR 4.44 (95% CI 1.49–13.24), elevated INR (aOR 2.72 (95% CI 1.03–7.19) increased risk. Biopsy adequacy was higher with Radiologist #6 (aOR 2.59, 95% CI 1.47–4.55) and #4 (aOR 2.24, 95% CI 1.07–4.66), longer biopsy core length (aOR 2.13, 95% CI 1.53–2.98), and lower BMI (aOR 0.97, 95% CI 0.94–0.99).

Conclusion

This study will inform the design of multidisciplinary QI interventions to improve kidney biopsy adequacy and further reduce the complication rate. Planned interventions include peer discussions led by proceduralists with the best adequacy outcomes and a high-risk biopsy protocol. Though center-specific, these results emphasize the value of local data in improving biopsy safety and establishing benchmarks for future guidelines.

Introduction

Kidney biopsies are essential in diagnosing, classifying, and managing renal diseases.¹ Additionally, with advances in molecular pathology and genomics, kidney biopsy is increasingly used in research to

identify biomarkers and advance personalized medicine in nephrology.²

Despite its diagnostic utility, kidney biopsies are invasive with inherent risks, including major bleeding that may require transfusion, diagnostic angiogram, or coil embolization, formation of arteriovenous fistula, and, in rare cases, nephrectomy or death.³ Major complications are rare and have declined over time.^{3,4} In addition to careful consideration of procedural risk, a kidney biopsy sample must be “adequate” for accurate diagnosis. Inadequate kidney biopsy risks misclassifying disease, delaying appropriate treatment, and increasing the need for repeat biopsy, thereby increasing healthcare costs and patient burden. In contrast to the declining trend in complications, a recent review of 123,372 native kidney biopsies from years 2005 to 2020 reported rising rates in biopsy inadequacy, attributed to smaller specimen sizes, insufficient cortical tissue, and fewer glomeruli per specimen.⁵

At our institution, we observed fluctuating inadequacy and occasional preventable complications suggesting that both local procedural practices and patient-specific factors may influence outcomes. This highlighted the need to closely examine our biopsy workflow to identify modifiable contributors to performance. Accordingly, this study evaluates clinical, laboratory, radiologic, and procedural factors associated with biopsy outcomes to identify actionable targets for an institution-level quality improvement (QI) initiative to simultaneously enhance overall biopsy adequacy rates and improve patient safety by minimizing complications.

Methods

Study design and patient selection

This was a retrospective cohort study that included adults older than 18 years of age who underwent a clinically indicated native kidney biopsy from January 2014 to December 2023 at the University of Kansas Medical Center (KUMC), a tertiary referral center in Kansas. We excluded allograft and renal mass biopsies.

Biopsy technique

Interventional radiologists (IR) performed biopsies by real-time ultrasound (USG) or computed tomography (CT) guidance, using a spring-loaded biopsy gun. Complete blood count (CBC), international normalized ratio (INR), and basic metabolic panel (BMP) were required within the last 30 days before the biopsy. The acceptable pre-biopsy levels of hemoglobin, platelet count, and INR were ≥ 8.5 g/dL, $\geq 100 \times 10^9/L$ and ≤ 1.5 , respectively. For elective biopsies, the hospitalist service admitted patients overnight for observation. Patients maintained 6 hours of bed rest and avoided strenuous activity for 24 hours. Hemoglobin was measured 5 hours post-biopsy, CBC and BMP the next morning. Hospitalists or nephrologists ordered post-procedure imaging if bleeding was clinically suspected.

Data extraction and Definitions

We reviewed electronic medical records to obtain demographic, radiologic, laboratory, histopathological, procedure-related, and clinical data. We defined pre-biopsy serum creatinine, INR, and platelet count as the most recent values obtained within 30 days, pre-biopsy hemoglobin within 7 days, and post-biopsy hemoglobin obtained 4–6 hours afterwards. We recorded estimated glomerular filtration rate (eGFR) only in patients with stable creatinine and Chronic Kidney Disease (CKD) stages 3–5. The laboratory used the Modification of Diet in Renal Disease (MDRD) equation to calculate eGFR before 2021, and the Chronic Kidney Disease Epidemiology Collaboration (2021) equation afterwards. We recorded systolic (SBP) and diastolic blood pressures (DBP) immediately pre-biopsy, and the maximum SBP and DBP within 24 hours after biopsy based on review of all vital signs. We defined post-biopsy hypotension as SBP < 100 mm Hg within 24 hours. Kidney length was based on radiology reports within one year of biopsy, and if radiologic reported size was unavailable, we manually measured length from available images. We manually measured cortical thickness from USG images within one year before or after the biopsy, with no data if images were of poor quality. The investigators obtained procedure details from IR reports and specimen details from histopathology reports. We defined “active anticoagulation” as the use of therapeutic heparin, intravenous heparin bridging (held 4–6 hours pre-biopsy) and subcutaneous low-molecular-weight- heparin (LMWH) bridging (held 24 hours pre-biopsy) for patients on warfarin (held 5 days, INR $\leq$ 1.5), or direct oral anticoagulants (held for 4–6 doses). We did not consider aspirin, clopidogrel, or prophylactic dosing of pharmacological anticoagulation as part of this definition. We classified biopsies as “elective” if they were preplanned.

Outcomes

We defined a major complication as the need for angiography, embolization, or transfusion within 7 days of biopsy. Hematoma detected on imaging within 7 days post-biopsy was a minor complication. For adequacy, we utilized 2 different definitions. We defined adequacy as a composite of $\geq$ 10 glomeruli in light microscopy (LM), *and* $\geq$ 1 glomerulus for indirect immunofluorescence (IF), *and* $\geq$ 1 glomerulus for electron microscopy (EM). We defined “minimal adequacy” as $\geq$ 10 total glomeruli (including LM and IF and EM).^{6,7} (Table 1)

Table 1
Definitions of Outcomes

Major Complication	Need for angiography, embolization, or transfusion within 7 days of biopsy
Minor Complication	Hematoma detected on imaging within 7 days post-biopsy
Biopsy Adequacy	≥ 10 glomeruli in light microscopy (LM), <i>and</i> ≥ 1 glomerulus for indirect immunofluorescence (IF), <i>and</i> ≥ 1 glomerulus for electron microscopy (EM)
Minimal Adequacy	≥ 10 total glomeruli (including LM and IF and EM)

Statistical Analysis

We summarized categorical variables using absolute and relative frequencies and continuous variables using the median and interquartile range. We used generalized estimating equations (GEE) with a logistic link function and an independent working correlation structure to account for potential nonindependence of observations from individuals contributing to repeat biopsies. This allowed us to estimate odds ratios of major complication, hematoma, biopsy adequacy, and minimal adequacy (each using a separate model) for covariates selected a priori based on clinical knowledge. To address missing data across all regression models, we used multiple imputation by chained equations with $M = 20$ imputed datasets, as implemented in the “mice” package, and pooled estimates using Rubin’s rules. We set statistical significance at $\alpha = 0.05$ and conducted all analyses in R (v4.4.1). We also analyzed trends in complication and adequacy outcomes over time.

Ethics and Funding

This study was approved by the Institutional Review Board of University of Kansas Medical Center (IRB#STUDY00161445) and conducted in accordance with the Declaration of Helsinki; informed consent was waived due to the retrospective design. The clinical and research activities being reported are consistent with the Principles of the Declaration of Istanbul as outlined in the “Declaration of Istanbul on Organ Trafficking and Transplant Tourism”. All authors declare no conflict of interest.

Results

Baseline characteristics

We included 796 kidney biopsies performed in 763 adult patients. Eleven biopsies in children were excluded. The median age was 54.9 (IQR 37.9–66.0) years, 447 (56.2%) were females, and the median BMI was 28.9 (IQR 24.6–34.3) kg/m². Median pre-biopsy hemoglobin was 10.5 (IQR 9.1–12.6) g/dL, platelet count 231 (IQR 176.0–299.8) $\times 10^9$ /L, and INR 1.0 (IQR 1.0–1.1). Median pre-biopsy serum creatinine was 2.0 (IQR 1.2–3.5) mg/dL. Of 796 biopsies, 95.4% were US-guided, 4.6% were CT-guided, and 432 (54.3%) were elective biopsies. Median length of the kidney was 11.0 (IQR 10.0–12) cm and

median cortical thickness was 9.6 (IQR 8.1–10.8) mm. 18-gauge biopsy needles were used in 780 (97.99%) biopsies; 16-gauge biopsy needles were used in 16 (2.01%) biopsies. The median number of passes and cores was 3 each. Patients with acute kidney injury (AKI) or AKI on CKD comprised 18.9% of biopsies. In patients with CKD, eGFR (mL/min/1.73 m²) ranged from ≥ 60 in 24%, 45–59 in 8.2%, 30–44 in 8.2%, 15–29 in 19.2%, and < 15 in 14.5%. The median eGFR (mL/min/1.73 m²) in CKD stage ≥3 was 31.0 (IQR 19.5–43.0). Median pre-biopsy SBP was 132.0 (IQR 119.0–144.0) mm Hg and DBP was 77.0 (IQR 69.0–87.0) mm Hg. Median peak post-biopsy SBP was 146.0 (133.0–159.0) mm Hg and DBP was 85.0 (75.0–95.0) mm Hg. Fifty-two (6.4%) biopsies received active anticoagulation. Seventeen biopsies (2.1%) were repeats for inadequacy and 16 (2.01%) for other clinical indications.

Baseline characteristics are described in Table 2.

Table 2. Baseline demographic and clinical data.

Demographics	
Age at biopsy (years)—median (IQR)	54.9 (37.9–66.0)
Sex— <i>n</i> (%)	
Female	447 (56.2)
Male	349 (43.8)
Body mass index (kgm ⁻²)—median (IQR)	28.9 (24.6–34.3)
Laboratory measures	
Preprocedural hemoglobin (g/dL)—median (IQR)	10.5 (9.1–12.6)
Preprocedural platelet count (×10 ⁹ /L)—median (IQR)	231.0 (176.0–299.8)
Preprocedural INR—median (IQR)	1.0 (1.0–1.1)
Preprocedural creatinine (mg/dL)—median (IQR)	2.0 (1.2–3.5)
Preprocedural estimated glomerular filtration rate (mL/min/1.73 m ²)— <i>n</i> (%)	
≥60	191/795 (24.0)
<60	604/795 (75.1)
45–59	65/795 (8.2)
30–44	121/795 (15.2)
15–29	153/795 (19.2)
<15	115/795 (14.5)
Preprocedural estimated glomerular filtration rate (mL/min/1.73 m ²) in CKD stage ≥3—median (IQR)	31.0 (19.5–43.0)
Clinical measures	
Preprocedural systolic blood pressure (mm Hg)—median (IQR)	132.0 (119.0–144.0)
Preprocedural diastolic blood pressure (mm Hg)—median (IQR)	77.0 (69.0–87.0)
Peak postprocedural systolic blood pressure (mm Hg)—median (IQR)	146.0 (133.0–159.0)
Peak postprocedural diastolic blood pressure (mm Hg)—median (IQR)	85.0 (75.0–95.0)
Active Anticoagulation*— <i>n</i> (%)	52 (6.5)
Elective biopsy— <i>n</i> (%)	432 (54.3)

Acute kidney injury — <i>n</i> (%)	150/795 (18.9)
Radiologic measures	
Length of kidney biopsied (cm)—median (IQR)	11.0 (10.0–12.0)
Cortical thickness of kidney (mm)—median (IQR)	9.6 (8.1–10.8)
Guidance type— <i>n</i> (%)	
Ultrasound	759 (95.4)
Computed tomography	37 (4.6)
Number of passes —median (IQR)	3
Needle Gauge — <i>n</i> (%)	
18-gauge	780(97.99%)
16-gauge	16(2.01%)

INR, International Normalized Ratio, *active anticoagulation: use of therapeutic heparin drip, intravenous heparin bridge and subcutaneous low molecular weight heparin (LMWH) bridge for patients previously on warfarin, or direct oral anticoagulants.

Outcomes

Complications: Major complications occurred in 82 biopsies (10.3%). Twenty-three (2.9%) biopsies required angiography alone, and 21 (2.6%) required embolization. Blood transfusion was required in 9.8% of biopsies: 32 (4.0%) within 24 hours and 46 (5.8%) after 24 hours. Hypotension developed in 109 (13.7%) biopsies after procedure. Median change in hemoglobin after biopsy was -0.3 (IQR -0.8–0.2) g/dL. A hemoglobin drop of >1 g/dL was observed in 109 (13.7%) biopsies and hematoma within 7 days post-biopsy was observed in 93 (11.7%) biopsies. (Table 3)

Table 3: Outcomes: Complications and Adequacy

Complications	
At least one major complication— <i>n</i> (%)	82/795 (10.3)
Embolization— <i>n</i> (%)	23 (2.9)
Angiography— <i>n</i> (%)	21 (2.6)
Blood transfusion (within 24 hours)— <i>n</i> (%)	32/795 (4.0)
Blood transfusion (within 1–7 days)— <i>n</i> (%)	46/795 (5.8)
Clinical concern for hypotension (within 24 hours)— <i>n</i> (%)	109/793 (13.7)
Hematoma— <i>n</i> (%)	93 (11.7)
≥1 g/dL drop in hemoglobin— <i>n</i> (%)	142/724 (19.6)
Specimen adequacy	
Biopsy adequacy— <i>n</i> (%) *	441/755 (58.4)
Minimal adequacy— <i>n</i> (%) #	669 (84.0)
Number of cores —median	3
Total glomeruli count—median (IQR)	21.5 (14.0–33.0)
Re-biopsy for inadequacy— <i>n</i> (%)	17 (2.1)
<i>Light microscopy</i>	
Glomeruli count—median (IQR)	14.0 (8.0–20.0)
Specimen adequacy— <i>n</i> (%) ¹	529/786 (67.3)
<i>Immunofluorescence</i>	
Glomeruli count—median (IQR)	6.0 (3.0–10.0)
Specimen adequacy— <i>n</i> (%) ²	677/775 (87.4)
<i>Electron microscopy</i>	
Glomeruli count—median (IQR)	2.0 (1.0–3.5)
Specimen adequacy— <i>n</i> (%) ³	660/742 (88.9)

*Biopsy adequacy defined as ≥ 10 glomeruli in light microscopy (LM), and ≥ 1 glomerulus for indirect immunofluorescence (IF), and ≥ 1 glomerulus for electron microscopy (EM), #Minimal adequacy defined as ≥ 10 total glomeruli (including LM and IF and EM), ¹Specimen adequacy for LM defined as ≥ 10 glomeruli, ²Specimen adequacy for IF defined as ≥ 1 glomerulus, ³Specimen adequacy for EM defined as ≥ 1 glomerulus

Adequacy: Samples were “adequate” in 441 (58.4%) biopsies, and “minimally adequate” in 669 (84.0%) cases. Adequacy rates for LM, EM, and IF were 67.3%, 87.4%, and 88.9%, respectively. The median number of total glomeruli was 21.5 (IQR 14.0–33.0). The median number of glomeruli in LM, IF, and EM were 14.0 (IQR 8.0–20.0), 6.0 (IQR 3.0–10.0) and 2.0 (IQR 1.0–3.5), respectively. (Table 3)

Figure 1 illustrates the trends in complication and adequacy rates over time.

Figure 1. Trends in major complication and biopsy adequacy rates over time

Figure Legend: Panel a: Major complications over time: horizontal axis describes the year of biopsy; vertical axis describes the biopsy counts; the bar graphs represent the rate and percentage of major complications, Panel b: Biopsy adequacy over time: horizontal axis describes the year of biopsy; vertical axis describes the biopsy counts; the bar graphs represent the rate and percentage of biopsy adequacy

Multivariable GEE analysis of factors associated with major complications and hematoma

Higher hemoglobin was associated with lower odds of major complication (adjusted OR (aOR) 0.73, 95% CI 0.60–0.90, $p=0.003$). Higher platelet count was associated with lower odds of both major complications (aOR 0.88, 95% CI 0.79–1.00, $p=0.045$) and hematoma (aOR 0.86, 95% CI 0.76–0.99, $p=0.031$). AKI (aOR 4.44 (95% CI 1.49–13.24), $p=0.007$) and higher INR (aOR 2.72, 95% CI 1.03–7.19, $p=0.043$) had higher odds of major complications. CKD stage 5 had an aOR of 3.09, 95% CI 0.98–9.69, $p=0.053$). Higher cortical thickness had higher odds of major complications (aOR 1.22, 95% CI 1.03–1.44, $p=0.019$). Biopsies by Radiologist #2 were associated with higher odds of hematoma (aOR 3.12, 95% CI 1.06–9.16, $p=0.038$). Age, sex, BMI, USG versus CT guidance, 16g versus 18g, number of passes, preprocedural SBP and DBP, length of the kidney, elective versus emergency biopsy, and active anticoagulation were not associated with major complications or hematoma. (Table 4, Figure 2)

Table 4. Multivariable GEE analysis of factors associated with major complications and hematoma

	Major complication		Hematoma	
	aOR (95% CI)	p-value	aOR (95% CI)	p-value
Age at biopsy (years)	1.01 (0.99–1.03)	0.47	1.00 (0.99–1.02)	0.93
Male vs Female	1.39 (0.78–2.47)	0.26	0.87 (0.52–1.43)	0.57
Body mass index (kg/m ²)	0.99 (0.95–1.03)	0.50	0.99 (0.95–1.02)	0.38
Preprocedural hemoglobin (g/dL)	0.73 (0.60–0.90)	0.003	0.98 (0.85–1.13)	0.75
Preprocedural platelet count (×10 ⁹ /L) ¹	0.88 (0.79–1.00)	0.045	0.86 (0.76–0.99)	0.031
Preprocedural INR	2.72 (1.03–7.19)	0.043	1.37 (0.43–4.31)	0.59
Radiologist ²				
#2 vs #1	1.80 (0.54–5.99)	0.34	3.12 (1.06–9.16)	0.038
Guidance type				
Computed tomography vs Ultrasound	1.76 (0.64–4.87)	0.28	1.38 (0.51–3.74)	0.53
Number of passes	0.99 (0.75–1.31)	0.95	1.05 (0.80–1.38)	0.72
Maximum core length (cm)	1.24 (0.86–1.81)	0.25	1.14 (0.80–1.62)	0.46
Needle gauge				
18 vs 16	0.50 (0.10–2.50)	0.40	0.29 (0.07–1.14)	0.077
Length of kidney biopsied (cm)	0.90 (0.74–1.08)	0.24	1.02 (0.87–1.20)	0.80
Cortical thickness of kidney (mm)	1.22 (1.03–1.44)	0.019	1.05 (0.92–1.19)	0.47
Estimated glomerular filtration rate (mL/min/1.73 m ²)				
45–59 vs ≥60	1.61 (0.33–7.95)	0.56	1.11 (0.39–3.15)	0.85

30–44 vs ≥60	1.43 (0.37–5.50)	0.60	1.59 (0.65–3.88)	0.31
15–29 vs ≥60	1.86 (0.60–5.77)	0.28	1.43 (0.65–3.17)	0.37
<15 vs ≥60	3.09 (0.98–9.69)	0.053	1.67 (0.67–4.18)	0.27
Acute kidney injury	4.44 (1.49–13.24)	0.007	1.51 (0.65–3.53)	0.34
Elective biopsy	0.65 (0.34–1.25)	0.19	0.82 (0.45–1.49)	0.51
Preprocedural systolic blood pressure (mm Hg)	1.00 (0.98–1.02)	0.89	1.00 (0.99–1.02)	0.90
Preprocedural diastolic blood pressure (mm Hg)	1.02 (1.00–1.04)	0.11	1.02 (1.00–1.04)	0.10
Active anticoagulation ³	1.15 (0.43–3.08)	0.78	1.60 (0.71–3.59)	0.26

GEE, generalized estimating equations; Major complications, need for angiography, embolization, or transfusion within seven days of biopsy; aOR, adjusted Odds Ratio; INR, International Normalized Ratio; ¹Platelet count was rescaled so that each unit represents a change of $50 \times 10^9/L$ for interpretation of odds ratio, ²Radiologist #1 used as reference, For major complications: radiologists #3–#9 had aORs 0.91–3.95 (all $p > 0.05$)., For hematoma: only Radiologist #2 showed a significant association; others not significant., Radiologist #8 was excluded due to insufficient sample size ($n=1$), ³active anticoagulation: use of therapeutic heparin drip, intravenous heparin bridge and subcutaneous low molecular weight heparin (LMWH) bridge for patients previously on warfarin, or direct oral anticoagulants.

Figure 2: Forest plot of factors associated with major complications

Figure Legend: Forest plot displays the adjusted odds ratios (aORs) and 95% confidence intervals for variables included in the multivariable generalized estimating equations (GEE) analysis evaluating major biopsy complications. The vertical dashed line represents the null value (aOR = 1). Point estimates are shown with black circles and horizontal 95% confidence-interval bars; variables with statistically significant associations ($p < 0.05$) have blue labels. CT, Computed Tomography; USG, Ultrasound; eGFR, estimated glomerular filtration rate; SBP, systolic blood pressure; DBP, diastolic blood pressure; *Radiologist #1 used as reference, radiologists #2, #3, #4, #5, #6, #7, and #9 had aORs 0.98–1.75 (all $p > 0.05$), Radiologist 8 was excluded due to insufficient sample size ($n=1$); #active anticoagulation: use of therapeutic heparin drip, intravenous heparin bridge and subcutaneous low molecular weight heparin (LMWH) bridge for patients previously on warfarin, or direct oral anticoagulants.

Sensitivity analysis for major complications using dichotomous pre-biopsy hemoglobin, excluding biopsies with INR>1.5 and/or platelet count <100×10⁹/L

Hemoglobin <10 g/dL (aOR 2.4, 95% CI 1.17-5.06, p=0.017) and AKI (aOR 3.73, 95% CI 1.20-11.56, p=0.023) was associated with major complications. Cortical thickness, platelet count, and INR showed no association to major complications. (Table S1)

Multivariable GEE analysis of factors associated with biopsy adequacy

Biopsies performed by Radiologist #6 (aOR 2.13, 95% CI 1.53–2.98, p<0.001) and longer maximum core length (aOR 2.59, 95% CI 1.47–4.55, p<0.001) were associated with greater biopsy adequacy. Higher BMI was associated with lower biopsy adequacy (aOR 0.97, 95% CI 0.94–0.99, p=0.003). Biopsies performed by Radiologist #4 (aOR 2.24, 95% CI 1.07–4.66, p=0.031) and #6 (aOR 6.09, 95% CI 2.74–13.53, p=<0.001) were associated with greater “minimal adequacy”. Age, sex, USG versus CT guidance, 16g versus 18g, number of passes, cortical thickness, kidney length, elective versus emergency biopsy, AKI, and CKD stages were not associated with biopsy adequacy or minimal adequacy. (Table 5, Figure 3)

Table 5. Multivariable GEE analysis of factors associated with biopsy adequacy

	Biopsy adequacy		Minimal adequacy	
	aOR (95% CI)	p-value	aOR (95% CI)	p-value
Age at biopsy (years)	0.99 (0.98–1.00)	0.10	0.99 (0.98–1.00)	0.21
Male	0.79 (0.57–1.09)	0.15	0.79 (0.53–1.19)	0.26
Body mass index (kg/m ²)	0.97 (0.94–0.99)	0.003	0.98 (0.95–1.01)	0.22
Radiologist ¹				
#4 vs #1	1.15 (0.63–2.08)	0.65	2.24 (1.07–4.66)	0.031
#6 vs #1	2.59 (1.47–4.55)	<0.001	6.09 (2.74–13.53)	<0.001
Guidance type				
Computed tomography vs Ultrasound	0.83 (0.41–1.68)	0.60	0.44 (0.19–1.02)	0.056
Number of passes	1.21 (0.95–1.55)	0.12	0.94 (0.72–1.21)	0.61
Maximum core length (cm)	2.13 (1.53–2.98)	<0.001	1.84 (1.16–2.91)	0.009
Needle gauge				
18 vs 16	1.72 (0.44–6.66)	0.43	2.53 (0.77–8.26)	0.12
Length of kidney biopsied (cm)	1.08 (0.96–1.21)	0.22	0.94 (0.81–1.10)	0.45
Cortical thickness of kidney (mm)	0.96 (0.87–1.07)	0.47	0.93 (0.81–1.08)	0.35
Estimated glomerular filtration rate (mL/min/1.73 m ²)				
45–59 vs ≥60	0.78 (0.41–1.48)	0.44	1.26 (0.51–3.10)	0.62
30–44 vs ≥60	0.86 (0.50–1.47)	0.57	0.87 (0.44–1.71)	0.69
15–29 vs ≥60	0.90 (0.55–1.47)	0.67	0.96 (0.49–1.86)	0.90

<15 vs ≥60	0.84 (0.48–1.47)	0.53	0.69 (0.34–1.39)	0.30
Acute kidney injury	1.12 (0.66–1.89)	0.68	1.13 (0.56–2.29)	0.74
Elective biopsy	1.35 (0.95–1.93)	0.10	0.92 (0.58–1.45)	0.71

GEE, generalized estimating equations; INR, International Normalized Ratio; ¹Radiologist #1 used as reference, For biopsy adequacy: radiologists #2, #3, #5, #7, and #9 had aORs 0.98–1.75 (all $p > 0.05$), For minimal adequacy: radiologists #2, #3, #5, #7, and #9 had aORs 1.02–1.61 (all $p > 0.05$), Only radiologists #4 and #6 were significantly associated with biopsy adequacy outcomes, Radiologist #8 was excluded due to insufficient sample size ($n=1$)

Figure 3: Forest plot of factors associated with biopsy adequacy

Figure Legend: Forest plot displays the adjusted odds ratios (aORs) and 95% confidence intervals for variables included in the multivariable generalized estimating equations (GEE) analysis evaluating biopsy adequacy. The vertical dashed line represents the null value (aOR = 1). Point estimates are shown with black circles and horizontal 95% confidence-interval bars; variables with statistically significant associations ($p < 0.05$) have blue labels. CT, Computed Tomography; USG, Ultrasound; eGFR, estimated glomerular filtration rate; SBP, systolic blood pressure; DBP, diastolic blood pressure; *Radiologist #1 used as reference, radiologists #2, #3, #4, #5, #7, and #9 had aORs 0.98–1.75 (all $p > 0.05$), Radiologist 8 was excluded due to insufficient sample size ($n=1$) [#] active anticoagulation: use of therapeutic heparin drip, intravenous heparin bridge and subcutaneous low molecular weight heparin (LMWH) bridge for patients previously on warfarin, or direct oral anticoagulants.

Discussion

In this large single-center retrospective study of nearly 800 native kidney biopsies for over a decade, we observed an overall major complication rate of 10.3%, primarily associated with lower pre-biopsy hemoglobin and platelet count, elevated INR, and presence of AKI and CKD 5. Only 58.4% of biopsies were adequate, with a striking association between proceduralist identity and adequacy, in addition to longer biopsy cores, and lower BMI. Major complication rates declined over time, likely reflecting the impact of prior QI efforts, whereas biopsy adequacy remained largely unchanged.

The major complication and the individual angiography and embolization rates in this cohort were higher than those reported in previous studies^{3,4}. Two meta-analyses of native kidney biopsies studies conducted worldwide report blood transfusion rates of 0.9%-1.6%, embolization of 0.3%, and angiography of 0.62%.^{3,4} Major complication rate in our study however, declined over the years from 14.5% in 2014 to 2.8% in 2023, approaching the complication rate described in literature. The hematoma rate in biopsies that had post-biopsy imaging was 11.9%, similar to the rate reported in a meta-analysis.³

This likely reflects our selective imaging approach, in contrast to studies using routine ultrasound—which detect substantially more, often clinically insignificant, hematomas.^{9,10}

This study found that hemoglobin >10 g/dL was associated with lower odds of major complications. Anemia worsens bleeding due to functional platelet dysfunction and decreased margination with increased laminar platelet flow when hematocrit is low.^{11,12} Additionally, anemia may reflect an inflammatory systemic disease or advanced kidney disease, potentially serving as a proxy for other risk factors for bleeding, including uremic platelet dysfunction. Higher hemoglobin also decreases the clinical trigger to transfuse in response to post-biopsy hemoglobin drop. A meta-analysis found that pre-biopsy hemoglobin of ≥ 12 g/dL was associated with a lower blood transfusion rate (0.5% vs 2.6%, $p=0.001$).⁴ Higher platelet count was protective against complications in our study, consistent with previous studies.^{8,13,14} Elevated INR was also associated with 2.84-fold higher odds of major complications. Complications were especially higher among biopsies with a platelet count $<100 \times 10^9/L$ (19.35%) and INR of >1.5 (23.8%). In the sensitivity analysis that excluded biopsies with platelet count of $<100 \times 10^9/L$ and INR >1.5 , INR and platelet count were not associated with complications, reiterating the safety of these cut-offs.

AKI was associated with major biopsy complications in our cohort, and this association is well known.^{3,4,8,14–16} In a study of hospitalized acute kidney disease patients undergoing kidney biopsy, 8% required blood transfusion, and 2% required intervention, which is higher than general complication rate.¹⁷ AKI patients are more likely to be critically ill with other systemic illnesses, which may explain the higher risk of bleeding complications. CKD stage 5 had increased odds of major complication in our cohort, although not reaching significance. In a study of kidney biopsy in patients with an eGFR <15 ml/min/m², 28% had complications, including blood transfusion and intervention.¹⁸ This higher bleeding complication can be explained by the acquired platelet dysfunction seen in advanced uremia.¹⁹

Higher blood pressure was not associated with complications in our study. Hypertension, when defined as SBP higher than 160 mm Hg, has been associated with complications, although a meta-analysis failed to show an increased risk with SBP >130 mm Hg.^{4,15,20,21} Median blood pressure in our study was well controlled and within protocol threshold ($<150/90$ mm Hg), reflecting real-world practice. Notably, inpatient blood pressure does not consistently represent true blood pressure and is subject to several confounding physiological and hospital environmental factors.²² Hematoma was significantly more with biopsies by Radiologist #2, although not associated with major complications. Age, sex, and BMI were not associated with complications unlike some other studies that have shown an association of female sex and advanced age with complications.^{8,16,23,14} Higher cortical thickness was associated with major complications, which was unexpected; however, the clinical significance of this finding is limited due to measurement error from manually assessing limited or poor-quality USG images. This is also demonstrated by the fact that cortical thickness was not associated with major complications in sensitivity analysis. Biopsy needle gauge (16-gauge vs 18-gauge) was not associated with complications; however, this comparison is not reliable due to the small number of biopsies performed

with 16-gauge (2%). Prior studies demonstrate comparable complication risks between the two needle sizes.^{24–26}

KDIGO and Banff recommend 8–10 glomeruli ≥ 10 glomeruli with 2 arteries for native and transplant biopsies, respectively.^{6,7} However, these guidelines do not specify whether the thresholds apply only to LM or also to IF/EM. We defined adequacy by requiring sufficient glomeruli on LM, along with minimum glomerular counts on IF and EM to ensure each modality could be meaningfully interpreted and contribute to diagnostically adequate tissue across the spectrum of kidney diseases. Only 58.4% of biopsies in this cohort were “adequate,” and 84% were “minimally adequate,” per our defined methods. A retrospective study of 123,372 native kidney biopsies analyzed at Arkana Laboratories from 2005 to 2020 reported an increasing rate of inadequate biopsy samples, rising from 2% in 2005 to 14% in 2020.⁵ The adequacy rates in our study remained predominantly similar from 2016 to 2023, with a maximum adequacy of 65.5% achieved in 2020. Longer biopsy core, reflecting greater biopsy depth, was associated with higher adequacy suggesting shallower biopsies contributed to inadequate samples. Higher total core length has been shown to result in a higher glomerular yield.²⁷ Very deep biopsies, however, predominantly sample the medulla, missing the cortex, whereas superficial biopsies sample the cortex incompletely. The optimal biopsy starts at the outer cortex and has adequate depth in order to obtain sufficient glomeruli, while avoiding complications. Deep medullary biopsies cause more bleeding due to the presence of larger vessels.^{27,28} The relationship of biopsy depth and adequacy also depends on biopsy angle, as tangential approach has better adequacy and lower complications compared to perpendicular approach.²⁹ Calculating optimal depth of biopsy using patient body weight and height improved outcomes in one study.³⁰

Proceduralist identity significantly influenced adequacy. Radiologist #6 had the highest odds of adequate biopsy, and #4 and #6 had higher odds of obtaining a minimally adequate biopsy. This finding is novel, and it underscores the critical role of the individual proceduralist, as several factors are operator-dependent and unique to individual techniques and experience. While biopsies were traditionally performed by nephrologists and in recent years are more often performed by radiologists, this appears less important than individual proceduralist experience. Some studies have shown nephrologists to have fewer miss rates compared to radiologists, while others have shown similar adequacy rates.^{5,31–33} Higher BMI was associated with lower adequacy, consistent with a study that showed lower glomeruli count in obese compared to non-obese patient biopsies.³⁴

We could not assess the association of needle gauge with adequacy, as very few biopsies were performed with 16-gauge. 16-gauge needles provide higher glomeruli count than 18-gauge with greater percentage of adequate biopsy samples.²⁵ 18-gauge needle has a diameter of 350 μm , only slightly larger than the average glomerular diameter (250 μm), whereas the 16-gauge needle measures 700 μm , supporting its use for improved glomerular yield.³⁵ As the gauge size increased from 14 G to 20 G, Nissen et al. observed a decline in glomerular count from $25 \pm 0.9/\text{cm}$ to $2 \pm 1.0/\text{cm}$ (mean $\pm$ SEM).⁵

The overarching aim of this study is to implement QI initiatives. Although complication rates improved, this was not paralleled by gains in adequacy rates, possibly due to proceduralists performing shallower biopsies with an 18-gauge needle to minimize complications. Our goal, as part of ongoing QI, will be to optimize adequacy rates to 90% while continuing to minimize complications: we feel the most impactful intervention is targeted training by radiologists with highest adequacy rates that involves learning from their procedural nuances including angle and depth of biopsy. Utilizing real-time bedside scanning microscope to confirm adequate glomerular sampling can be useful.^{31,36} Similarly, assessment of biopsies using web-based tools to analyze photographs taken with smartphones and utilizing machine learning algorithms to analyze the cortical percentage can improve adequacy.^{37–39} Switching to 16-gauge will best balance complications and adequacy. Complications can be further minimized by implementing a specific protocol for patients at higher risk (AKI, CKD 5), including a stricter pre-biopsy hemoglobin of ≥ 10 g/dL, avoiding biopsies in patients with INR >1.5 and platelet count $<100 \times 10^9/L$, and performing eligible tests closer to elective biopsy. Pre-biopsy use of desmopressin 0.3–0.4 mcg/kg in the minutes just prior to biopsy was used in selected patients, based on theoretical and limited clinical evidence of reduced bleeding in advanced CKD.^{40,41} The next phase in our QI project will analyze the benefits of desmopressin in a larger patient cohort.

The strength of this study is the large sample size and extensive analysis of variables that can affect both biopsy complications and adequacy. Importantly, our findings provide real, center-specific data to guide future QI efforts. The limitations are the inherent flaws of a retrospective study and limited applicability due to single-center design. Kidney length and cortical thickness were manually measured, and subject to interobserver variability and possible inaccuracies due to poor imaging quality. We did not measure the angle of biopsy, and assessing the angle based on available images is challenging, if not impossible. Lastly, although there was missing data, we managed this by multiple imputation methods.

In conclusion, in this study of native kidney biopsies over a decade, the overall major complication rate declined with earlier QI initiatives. Biopsy adequacy, however, remained suboptimal, with an inadequacy rate of 40% and no significant improvement over time — emphasizing the need for continued, targeted efforts to optimize adequacy. Based on our finding of higher risk of complications in patients with AKI, CKD stage 5 and low hemoglobin, we plan to implement measures to further improve safety in this high-risk group. Peer-training by specific proceduralists—a key determinant of adequacy—will guide future QI efforts for adequacy.

Declarations

Ethics approval and consent to participate

1. Study approval statement: This study was approved by the Institutional Review Board of University of Kansas Medical Center (IRB#STUDY00161445) and conducted in accordance with the Declaration of Helsinki

2. Consent to participate statement: Informed consent was waived by the IRB of University of Kansas Medical Center (IRB#STUDY00161445) due to the retrospective design

Consent for publication: Not applicable

Availability of data and materials: The data that support the findings of this study are openly available in “figshare” at <https://doi.org/10.6084/m9.figshare.31222999>

Competing interests: The authors declare that they have no competing interests

Conflict of Interest Statement: The authors have no conflicts of interest to declare

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Authors' contributions

NG: Led data extraction, supervised the project, managed project administration, and wrote the original draft of the manuscript.

MA: Performed statistical analyses, provided methodological support, prepared figures, and critically reviewed the manuscript.

MC: Contributed to data extraction and reviewed the manuscript.

PP: Contributed to data extraction and reviewed the manuscript.

CS: Contributed to data extraction and reviewed the manuscript.

MZ: Contributed to data extraction and reviewed the manuscript.

GG: Contributed to data extraction and reviewed the manuscript.

JA: Provided statistical expertise and analysis, prepared figures, and reviewed the manuscript.

DJ: Conceived and conceptualized the project, provided oversight and methodological support, and critically revised the manuscript.

RM: Conceived and oversaw the project, designed the study, managed project administration, provided methodological support, and critically revised the manuscript.

Acknowledgements: The authors declare that they have no competing interests

References

1. Dhaun N, Bellamy CO, Cattran DC, Kluth DC. Utility of renal biopsy in the clinical management of renal disease. *Kidney Int.* 2014;85(5):1039–48. 10.1038/ki.2013.512.

2. de Boer IH, Alpers CE, Azeloglu EU, et al. Rationale and design of the Kidney Precision Medicine Project. *Kidney Int.* 2021;99(3):498–510. 10.1016/j.kint.2020.08.039.
3. Poggio ED, McClelland RL, Blank KN, et al. Systematic Review and Meta-Analysis of Native Kidney Biopsy Complications. *Clin J Am Soc Nephrol.* 2020;15(11):1595. 10.2215/CJN.04710420.
4. Corapi KM, Chen JLT, Balk EM, Gordon CE. Bleeding complications of native kidney biopsy: a systematic review and meta-analysis. *Am J Kidney Dis.* 2012;60(1):62–73. 10.1053/j.ajkd.2012.02.330.
5. Nissen CJ, Moreno V, Davis VG, Walker PD. Increasing Incidence of Inadequate Kidney Biopsy Samples Over Time: A 16-Year Retrospective Analysis From a Large National Renal Biopsy Laboratory. *Kidney Int Rep.* 2022;7(2):251–8. 10.1016/j.ekir.2021.11.026.
6. Kidney Disease: Improving Global Outcomes (KDIGO) Glomerular Diseases Work Group. KDIGO 2021 Clinical Practice Guideline for the Management of Glomerular Diseases. *Kidney Int.* 2021;100(4S):S1–276. 10.1016/j.kint.2021.05.021.
7. Roufosse C, Naesens M, Haas M, et al. The Banff 2022 Kidney Meeting Work Plan: Data-driven refinement of the Banff Classification for renal allografts. *Am J Transpl.* 2024;24(3):350–61. 10.1016/j.ajt.2023.10.031.
8. Monahan H, Gunderson T, Greene E, Schmit G, Atwell T, Schmitz J. Risk factors associated with significant bleeding events after ultrasound-guided percutaneous native renal biopsies: a review of 2204 cases. *Abdom Radiol.* 2019;44(6):2316–22. 10.1007/s00261-019-01962-z.
9. Palsson R, Short SAP, Kibbelaar ZA, et al. Bleeding Complications After Percutaneous Native Kidney Biopsy: Results From the Boston Kidney Biopsy Cohort. *Kidney Int Rep.* 2020;5(4):511–8. 10.1016/j.ekir.2020.01.012.
10. Xu S, Xiong B, Lin S, Li Q, Wang L, Zhao W. Predictors of perirenal haematoma post-percutaneous ultrasound-guided renal biopsy. *J Int Med Res.* 2021;49(11):03000605211058377. 10.1177/03000605211058377.
11. Valles J, Santos MT, Aznar J, et al. Erythrocytes metabolically enhance collagen-induced platelet responsiveness via increased thromboxane production, adenosine diphosphate release, and recruitment. *Blood.* 1991;78(1):154–62.
12. Turitto VT, Weiss HJ. Red blood cells: their dual role in thrombus formation. *Science.* 1980;207(4430):541–3. 10.1126/science.7352265.
13. Kajawo S, Ekrikpo U, Moloi MW, et al. A Systematic Review of Complications Associated With Percutaneous Native Kidney Biopsies in Adults in Low- and Middle-Income Countries. *Kidney Int Rep.* 2021;6(1):78–90. 10.1016/j.ekir.2020.10.019.
14. Xu Dmin, Chen M, de Zhou F, Zhao Mhui. Risk Factors for Severe Bleeding Complications in Percutaneous Renal Biopsy. *Am J Med Sci.* 2017;353(3):230–5. 10.1016/j.amjms.2016.12.019.
15. 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(2):153–62. 10.1159/000358334.

16. Palsson R, Short SAP, Kibbelaar ZA, et al. Bleeding Complications After Percutaneous Native Kidney Biopsy: Results From the Boston Kidney Biopsy Cohort. *Kidney Int Rep.* 2020;5(4):511–8. 10.1016/j.ekir.2020.01.012.
17. Moledina DG, Luciano RL, Kukova L, et al. Kidney Biopsy–Related Complications in Hospitalized Patients with Acute Kidney Disease. *Clin J Am Soc Nephrol.* 2018;13(11):1633–40. 10.2215/CJN.04910418.
18. Alkadi MM, Abuhelaiqa EA, Thappy SB, et al. Kidney Biopsy in Patients With Markedly Reduced Kidney Function. *Kidney Int Rep.* 2022;7(11):2505–8. 10.1016/j.ekir.2022.08.004.
19. Sohal AS, Gangji AS, Crowther MA, Treleaven D. Uremic bleeding: Pathophysiology and clinical risk factors. *Thromb Res.* 2006;118(3):417–22. 10.1016/j.thromres.2005.03.032.
20. Shidham GB, Siddiqi N, Beres JA, et al. Clinical risk factors associated with bleeding after native kidney biopsy. *Nephrology.* 2005;10(3):305–10. 10.1111/j.1440-1797.2005.00394.x.
21. Kriegshauser JS, Patel MD, Young SW, Chen F, Eversman WG, Chang YHH. Risk of Bleeding after Native Renal Biopsy as a Function of Preprocedural Systolic and Diastolic Blood Pressure. *J Vasc Interv Radiol.* 2015;26(2):206–12. 10.1016/j.jvir.2014.10.020.
22. Bress AP, Anderson TS, Flack JM, et al. The Management of Elevated Blood Pressure in the Acute Care Setting: A Scientific Statement From the American Heart Association. *Hypertension.* 2024;81(8):e94–106. 10.1161/HYP.0000000000000238.
23. Anpalahan A, Malacova E, Hegerty K et al. Bleeding Complications of Percutaneous Kidney Biopsy: Does Gender Matter? *Kidney360.* 2021;2(8):1308–1312. 10.34067/KID.0002432021
24. Mai J, Yong J, Dixon H, et al. Is bigger better? A retrospective analysis of native renal biopsies with 16 Gauge versus 18 Gauge automatic needles. *Nephrology.* 2013;18(7):525–30. 10.1111/nep.12093.
25. Xie W, Xu J, Xie Y, et al. Adequacy and complication rates of percutaneous renal biopsy with 18- vs. 16-gauge needles in native kidneys in Chinese individuals. *BMC Nephrol.* 2020;21(1):337. 10.1186/s12882-020-01987-3.
26. Roth R, Parikh S, Makey D, et al. When Size Matters: Diagnostic Value of Kidney Biopsy according to the Gauge of the Biopsy Needle. *Am J Nephrol.* 2013;37(3):249–54. 10.1159/000347219.
27. Torigoe K, Sakamoto R, Abe S, Muta K, Mukae H, Nishino T. Factors Associated with Glomerular Yield in Percutaneous Kidney Biopsy. *J Clin Med.* 2023;12(12):3877. 10.3390/jcm12123877.
28. Beckingham IJ, Nicholson ML, Bell PR. Analysis of factors associated with complications following renal transplant needle core biopsy. *Br J Urol.* 1994;73(1):13–5. 10.1111/j.1464-410x.1994.tb07449.x.
29. Sawicka K, Hassan N, Dumaine C, et al. Direction of the Biopsy Needle in Ultrasound-Guided Renal Biopsy Impacts Specimen Adequacy and Risk of Bleeding. *Can Assoc Radiol J.* 2019;70(4):361–6. 10.1016/j.carj.2018.11.006.
30. Pasquariello A, Innocenti M, Batini V, et al. Theoretical calculation of optimal depth in the percutaneous native kidney biopsy to drastically reduce bleeding complications and sample

- inadequacy for histopathological diagnosis. *Nephrol Dial Transpl.* 2007;22(12):3516–20. 10.1093/ndt/gfm272.
31. Ferrer G, Andeen NK, Lockridge J, et al. Kidney biopsy adequacy: A metric-based study. *Am J Surg Pathol.* 2019;43(1):84–92. 10.1097/PAS.0000000000001102.
32. Emelianova D, Prikis M, Morris CS, et al. The evolution of performing a kidney biopsy: a single center experience comparing native and transplant kidney biopsies performed by interventional radiologists and nephrologists. *BMC Nephrol.* 2022;23(1):226. 10.1186/s12882-022-02860-1.
33. Pettit C, Kanagaratnam R, Coughlan F, Graf N, Hahn D, Durkan A. Kidney biopsy adequacy and complications in children — does technique matter? *Eur J Pediatr.* 2022;181(7):2677–84. 10.1007/s00431-022-04464-1.
34. Qian L, Menez S, Hu D, et al. Safety and Adequacy of Kidney Biopsy Procedure in Patients with Obesity. *Kidney360.* 2023;4(1):98. 10.34067/KID.0006602022.
35. Luciano RL, Moeckel GW. Update on the Native Kidney Biopsy: Core Curriculum 2019. *Am J Kidney Dis.* 2019;73(3):404–15. 10.1053/j.ajkd.2018.10.011.
36. Wooldridge JT, Davis A, Fischer WG, Khalil MF, Zhang M, Afrouzian M. The Impact of Renal Tissue Procurement at Bedside on Specimen Adequacy and Best Practices. *Am J Clin Pathol.* 2019;151(2):205–8. 10.1093/ajcp/aqy120.
37. Ahangaran M, Sun E, Le K, et al. Pilot Study of a Web-Based Tool for Real-Time Adequacy Assessment of Kidney Biopsies. *Kidney Int Rep.* 2024;9(9):2809–13. 10.1016/j.ekir.2024.06.019.
38. Eigbire-Molen OJ, Cassol CA, Kenan DJ, et al. Smartphone-based machine learning model for real-time assessment of medical kidney biopsy. *J Pathol Inf.* 2024;15:100385. 10.1016/j.jpi.2024.100385.
39. Singh G, Massak M, Czaplicki M, et al. Use of a Smartphone Camera at the Bedside to Assess Adequacy of Kidney Biopsies. *J Am Soc Nephrol.* 2021;32(12):3024–6. 10.1681/ASN.2021070898.
40. Leclerc S, Nadeau-Fredette AC, Elftouh N, Lafrance JP, Pichette V, Laurin LP. Use of Desmopressin Prior to Kidney Biopsy in Patients With High Bleeding Risk. *Kidney Int Rep.* 2020;5(8):1180–7. 10.1016/j.ekir.2020.05.006.
41. Athavale A, Kulkarni H, Arslan CD, Hart P. Desmopressin and bleeding risk after percutaneous kidney biopsy. *BMC Nephrol.* 2019;20:413. 10.1186/s12882-019-1595-4.

Figures

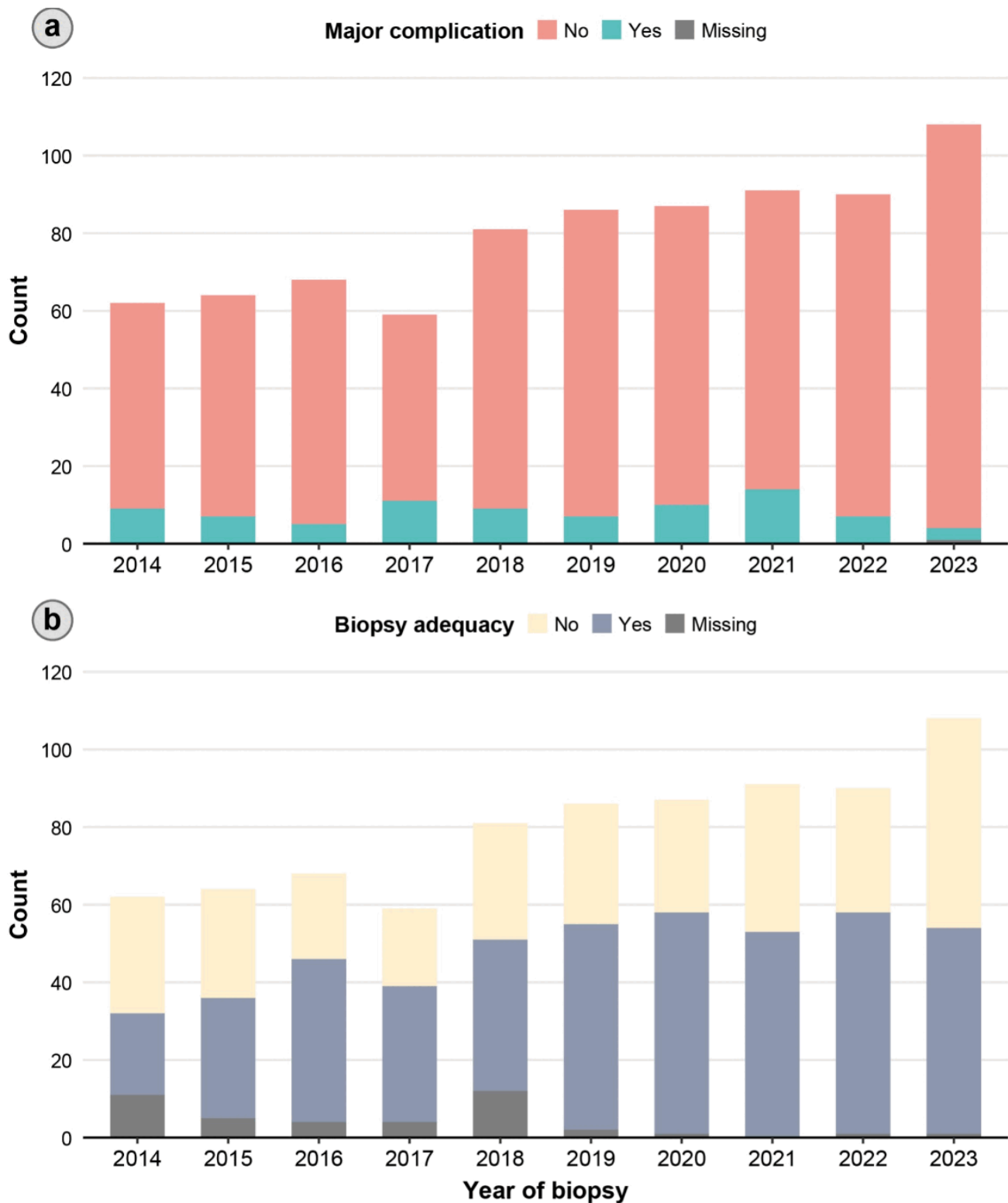


Figure 1

Trends in major complication and biopsy adequacy rates over time

Figure Legend: Panel a: Major complications over time: horizontal axis describes the year of biopsy; vertical axis describes the biopsy counts; the bar graphs represent the rate and percentage of major

complications, Panel b: Biopsy adequacy over time: horizontal axis describes the year of biopsy; vertical axis describes the biopsy counts; the bar graphs represent the rate and percentage of biopsy adequacy

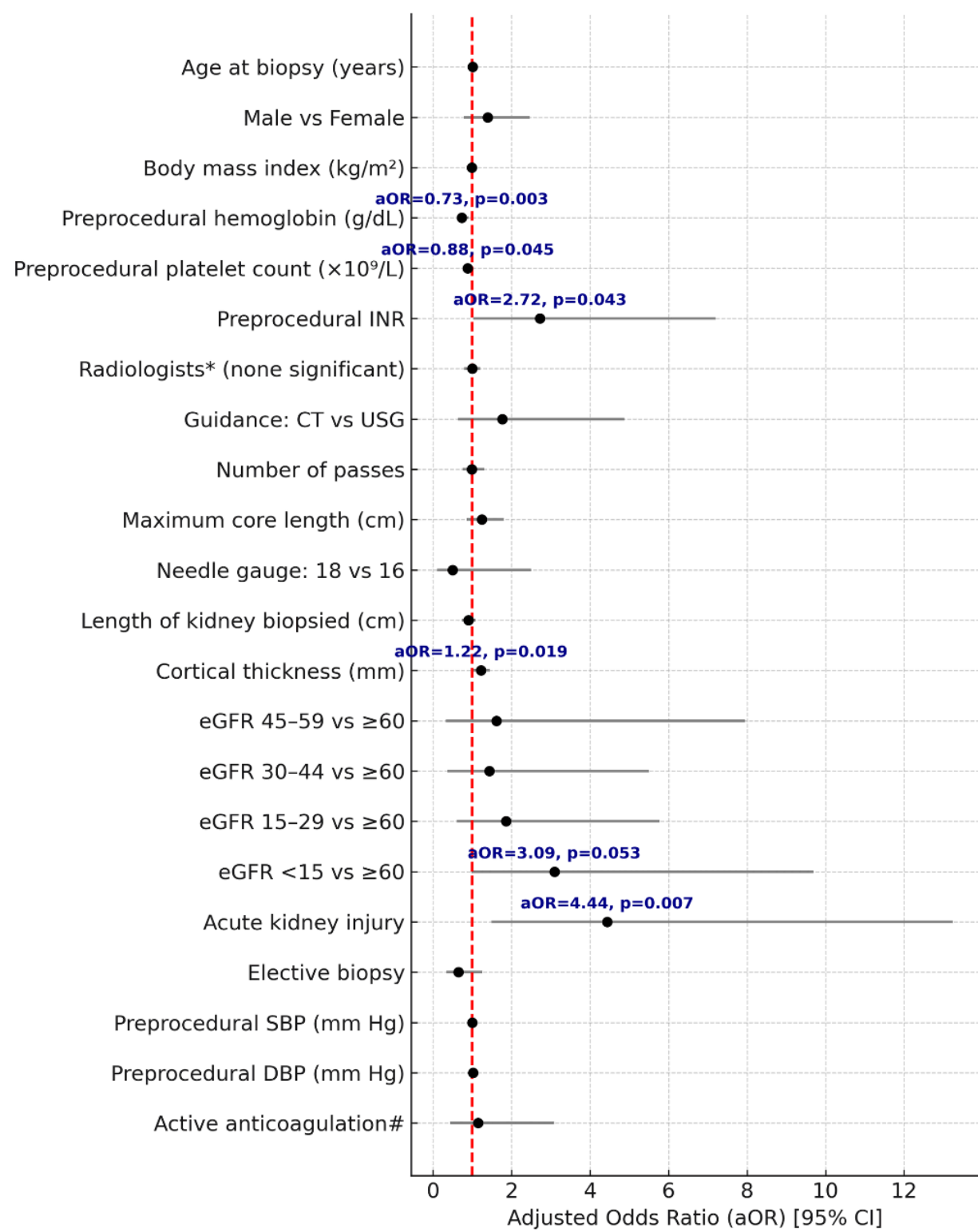


Figure 2
Forest plot of factors associated with major complications

Figure Legend: Forest plot displays the adjusted odds ratios (aORs) and 95% confidence intervals for variables included in the multivariable generalized estimating equations (GEE) analysis evaluating major biopsy complications. The vertical dashed line represents the null value (aOR = 1). Point estimates are shown with black circles and horizontal 95% confidence-interval bars; variables with statistically significant associations ($p < 0.05$) have blue labels. CT, Computed Tomography; USG, Ultrasound; eGFR, estimated glomerular filtration rate; SBP, systolic blood pressure; DBP, diastolic blood pressure; *Radiologist #1 used as reference, radiologists #2, #3, #4, #5, #6, #7, and #9 had aORs 0.98–1.75 (all $p > 0.05$), Radiologist 8 was excluded due to insufficient sample size ($n=1$); #active anticoagulation: use of therapeutic heparin drip, intravenous heparin bridge and subcutaneous low molecular weight heparin (LMWH) bridge for patients previously on warfarin, or direct oral anticoagulants.

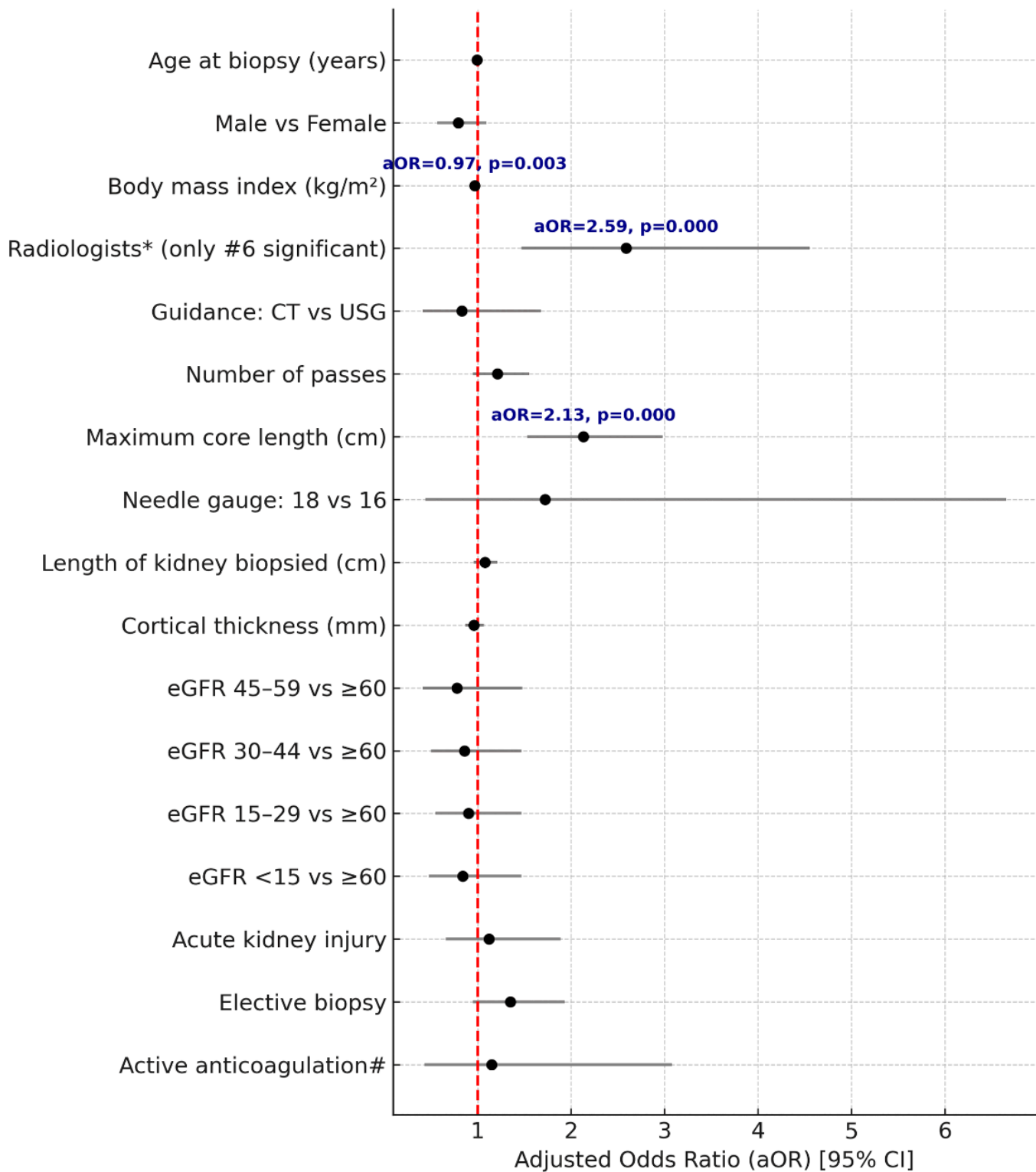


Figure 3

Forest plot of factors associated with biopsy adequacy

Figure Legend: Forest plot displays the adjusted odds ratios (aORs) and 95% confidence intervals for variables included in the multivariable generalized estimating equations (GEE) analysis evaluating biopsy adequacy. The vertical dashed line represents the null value (aOR = 1). Point estimates are shown with

black circles and horizontal 95% confidence-interval bars; variables with statistically significant associations ($p < 0.05$) have blue labels. CT, Computed Tomography; USG, Ultrasound; eGFR, estimated glomerular filtration rate; SBP, systolic blood pressure; DBP, diastolic blood pressure; *Radiologist #1 used as reference, radiologists #2, #3, #4, #5, #7, and #9 had aORs 0.98–1.75 (all $p > 0.05$), Radiologist 8 was excluded due to insufficient sample size ($n=1$) # active anticoagulation: use of therapeutic heparin drip, intravenous heparin bridge and subcutaneous low molecular weight heparin (LMWH) bridge for patients previously on warfarin, or direct oral anticoagulants.

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