Urine Transit Time Distribution in Cardiac Surgery Patients as a Window to Assess Acute Kidney Injury

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Introduction:

Up to 40% of patients undergoing cardiac surgery experience Acute Kidney Injury (AKI), which notably raises morbidity and mortality rates as well as healthcare expenses. A major factor in the development of AKI is low kidney tissue oxygen concentration, particularly in the medullary region. Studies have demonstrated a strong relationship between urine oxygen levels and medullary oxygenation [1-5]. Transit times of urine through the urinary catheter delay and can distort real-time urine oxygen measurements, reducing their reliability as indicators of kidney tissue oxygenation. Knowing transit time facilitates compensating for these distortions, flagging unreliable data, and future analysis of other real-time urinary biomarkers [6,7]. This study applies a urine transit time calculation algorithm to highly variable urinary flow data collected from 86 cardiac surgery patients, analyzing the distribution of transit times across perioperative phases to enhance understanding of renal function during surgery.

Methods:

The algorithm models urine flow as discrete particles based on urinary flow rate, tracking each particle from entry to exit using a double-ended queue (deque) data structure. This approach efficiently manages particle timestamps and calculates transit times by maintaining the sequence and timing of urine particles as they pass through the urinary catheter. The data was divided into four phases: pre-cardiopulmonary bypass (PreCPB), during cardiopulmonary bypass (CPB), post-CPB, and post-surgery. For each phase, we calculated transit times and analyzed their distributions using statistical measures, including mean, median, quartiles, and interquartile range (IQR). This distribution was determined from data with non-negative and non-stagnant urinary flows. Additionally, we separately determined the distribution based on the validity of each data point according to a flow-based model, which uses the KDIGO urine output criteria. Specifically, this model discards any data where urine flow is less than 0.5 ml/kg/h [8].

Results:

In the PreCPB phase, the transit time distribution was right-skewed, with a higher density of shorter transit times (1–10 minutes). The mean transit time was 5.88 minutes, with a median (IQR) of 3.17 (5.26) minutes, indicating moderate spread. During CPB, the distribution remained right-skewed but was more concentrated between 0.5 and 10 minutes, with a mean of 3.59 minutes and a median of 1.13 (2.10) minutes, reflecting a sharper peak and less variability. In the PostCPB phase, the distribution continued to be right-skewed, with most transit times between 1 and 10 minutes, a mean of 3.56 minutes, and a median of 1.53 (1.92) minutes. The Post-Surgery phase exhibited the widest distribution, indicating more significant variability. The mean transit time was 25.06 minutes and the median 4.25 (4.66) minutes (Figure).

Discussion:

All phases exhibited right-skewed distributions, indicating that most transit times were short. The PreCPB phase displayed moderate variability, while the CPB and PostCPB phases showed narrower distributions and lower mean transit times, suggesting more consistent and efficient urine flow during these periods. In contrast, the post-surgery phase had the highest variability and mean transit time, likely reflecting the complexities and heterogeneity of post-operative recovery and patient movement, resulting in higher fluctuations.

The algorithm's ability to reveal transit time distributions enhances understanding of renal function dynamics during cardiac surgery and post-surgery. By identifying patterns and outliers, clinicians can better assess renal stress and potentially intervene earlier to prevent AKI. The discrete particle model ensures more precise tracking of urine packets, maintaining accuracy even under variable flow conditions, which is critical for early detection of renal stress and timely intervention.

Conclusion:

Applying the urine transit time algorithm provides valuable insights into renal function during different surgical phases. The analysis of transit time distributions highlights periods of increased variability and potential AKI risk, supporting early detection and timely intervention.

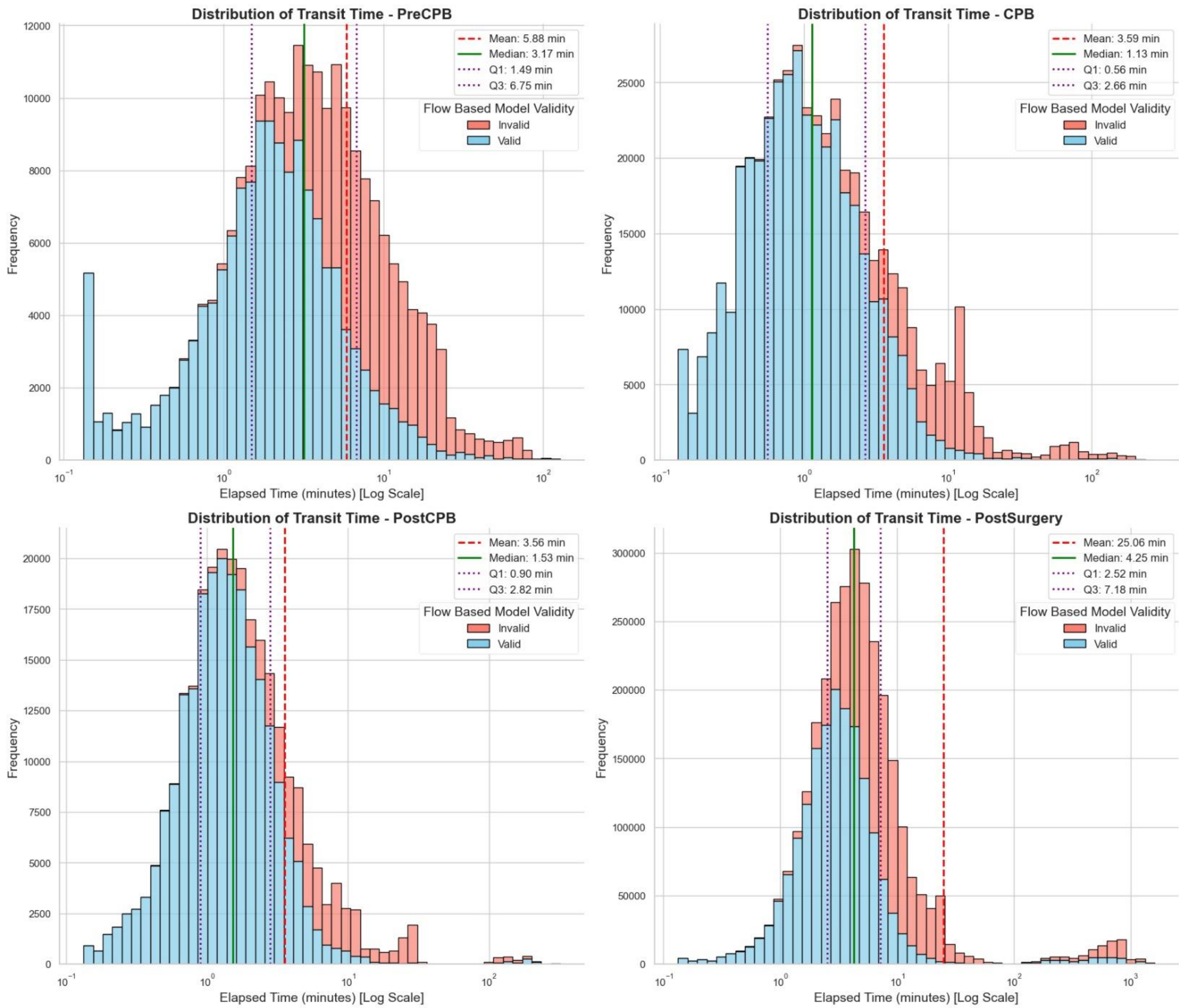

Figure: Distribution of urine transit times across different surgical phases (Pre-CPB, CPB, PostCPB, PostSurgery).

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