Influence of anesthetic variables on short-term and overall survival rates in cats undergoing renal transplantation surgery

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Objective—To identify factors associated with short-term (30-day) and overall survival rates in cats that underwent renal transplantation surgery (RTS).

Design—Retrospective cohort study.

Animals—94 cats that underwent RTS from 1998 through 2010.

Procedures—Data obtained from the medical records pertinent to RTS included cat signalment; anesthetic agents, techniques, and timings; supportive treatment; perioperative physiologic findings; and surgery and warm ischemia times. Associations with short-term and overall survival rates were investigated.

Results—Median survival time was 653 days (range, 2 to 4,580 days). Prolonged anesthesia (median, 300 minutes; range, 225 to 445 minutes) reduced overall survival rate but did not influence short-term survival rate. No associations were identified between survival rates and anesthetic agent used, amount and type of fluid administered IV, physiologic abnormalities, and blood product administration. All cats that received µ-opioid receptor antagonists at anesthetic recovery to reverse the effects of µ-opioid receptor agonists survived for at least 30 days. High Hct at the end of anesthesia was also associated with an increase in short-term survival rate. Two cats had an intraoperative hemoglobin oxygen saturation <90%, and both died within 7 days after surgery. Cats > 12 years old had a lower overall survival rate than did younger cats.


Since 1987, RTS has become a recognized treatment option for cats with end-stage renal disease.1,2 Although a considerable amount of data exists on surgical techniques, postoperative medical treatments, and RTS complications,3–9 information is limited on the impact of anesthetic-related variables on overall survival rate in cats undergoing RTS.3,4,7,10

Patients undergoing RTS pose major challenges for surgeons and anesthesiologists. Both human and feline RTS patients may be anemic, and many have hypertension, serious electrolyte abnormalities, acid-base imbalances, and other systemic effects of uremia.4,11,12 Because of these changes, homeostasis may be difficult to maintain when patients are additionally challenged by anesthesia. Optimal allograft function and survival time in cats undergoing RTS are reportedly impacted by the degree of preoperative azotemia and postoperative serum or plasma creatinine concentrations and whether normothermia, normovolemia, normotension, healthy acid-base balance, and appropriate electrolyte balance are maintained.1,11 Although some anesthetic techniques and perianesthetic complications have been described for RTS in cats,7,11 no information has been reported regarding the relationship between anesthetic agents or techniques used and patient outcome.

The objectives of the study reported here were to retrospectively evaluate whether anesthetic agent or technique or physiologic variables related to anesthesia would affect short-term (1-month) and overall survival rates in cats that underwent RTS. We hypothesized that prolonged surgical or anesthesia time, in addition to abnormal intra-anesthetic physiologic values, would be associated with a decrease in short-term and overall survival rates. In addition, we hypothesized that amounts and types of fluids administered and types of drugs used for anesthesia would not affect survival rates.

ABBREVIATIONS

| CI | Confidence interval |
| MAP | Mean arterial blood pressure |
| P_{\text{ETCO}} | End-tidal partial pressure of carbon dioxide |
| RTS | Renal transplantation surgery |
| \text{SpO}_2 | Oxygen saturation as measured by pulse oximetry |

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Cats—Medical records of cats that underwent RTS at the Mathew J. Ryan Veterinary Hospital of the University of Pennsylvania from 1998 through 2010 were reviewed, and all available anesthesia records were included in the analysis. All cats were evaluated for candidacy for transplantation in accordance with published guidelines. Information was reviewed regarding age at the time of surgery, sex and neuter status, breed, and body weight. An anesthesiologist evaluated all cats prior to RTS. Heart rate and MAP as estimated with a Doppler ultrasonographic flow detector were recorded. Blood pressure was measured with cats positioned in lateral recumbency, with the ultrasonographic probe placed on the palmar aspect of a metacarpus and a sphygmomanometer attached to an appropriately sized cuff placed around the ipsilateral antebrachium.

Anesthetic variables—Information obtained from each anesthetic record included whether a specific drug or general pharmacological category of drug (eg, benzodiazepine or anticholinergic) was administered for anesthetic premedication, induction, maintenance, and recovery. For statistical analysis, opioid agents were grouped as μ-opioid receptor agonists (buprenorphine, hydromorphone, methadone, morphine, and oxymorphone) or μ-opioid receptor antagonists (butorphanol and naloxone [ie, used to reverse the effects of μ-opioid receptor agonists]). The rate and total volume of crystalloid fluid administered IV were also recorded. In addition, the dose of mannitol, volume of synthetic colloid solution, and type and amount of blood products administered were also recorded.

Anesthetic and physiologic data were recorded at 5-minute intervals and evaluated. Variables recorded during the maintenance phase of anesthesia included heart rate (obtained from continuous lead II ECG), respiratory rate and PETCO₂ (evaluated by use of capnography), MAP (estimated by use of the Doppler technique), and SpO₂. Duration of hypotension (MAP < 60 mm Hg), severe hypertension (MAP > 160 mm Hg), tachycardia (heart rate, > 220 beats/min), bradycardia (heart rate, < 80 beats/min), hyperventilation (PETCO₂ > 55 mm Hg) were calculated. Duration of intraoperative hypothermia, defined as body temperature < 35°C (95°F) as measured with rectal, esophageal, or oral probes, was recorded. In addition, change in body temperature from initial values measured immediately after anesthetic induction to final values measured at the end of anesthesia was recorded. Immediately before or after anesthetic induction and at the end of the surgical procedure, venous blood samples were assessed for pH, Pco₂, HCO₃⁻ and K⁺ concentrations, base excess, and Hct. Vascular clamp time (period from placement of occluding clamps on the aorta and vena cava until removal of the clamps) and warm ischemia time (period from clamping of the donor renal artery and vein to release of the aortic and caval clamps in the recipient) were calculated. Surgery time was recorded for each recipient study and defined as the period from celiotomy incision until completion of the last closing suture. Total anesthesia time was defined as the period from anesthetic induction until endotracheal extubation.

Statistical analysis—Data were assessed for normal distribution by means of the Shapiro-Wilk test. Parametric data are reported as mean ± SD and nonparametric data as median and range. Frequencies and proportions are reported as counts and percentages. For cats that underwent RTS more than once, only the anesthetic record of the final anesthetic episode was considered for analysis.

For short-term survival rate, cats were noted to have survived or not survived during the 30-day period after RTS, and proportions of cats that survived in each group were compared. For overall survival analysis, the status of cats (survivor or nonsurvivor) at the time of data analysis was used and the hazard of nonsurvival in one group versus nonsurvival in another was assessed. Overall survival time was calculated in days from the date of RTS until the date each cat died or was euthanized or the date of data analysis if the cat remained alive. Information on cat survival and death date, when applicable, was obtained from the medical records and confirmed by direct communication with the cats’ owners. A Kaplan-Meier survival curve was plotted to estimate overall survival rate.

Relationships between variables (eg, cat characteristics, anesthesia and surgery times, frequency and type of drug and fluid administration, occurrence and duration of complications, peri- and intra-anesthetic physiologic variables, and blood test results) and short-term and overall survival rates were analyzed by means of logistic regression and Cox proportional hazards regression, respectively. Variables with < 6 data points were excluded from these analyses. For short-term survival rate, odds of survival and 95% CI were calculated. When all cats survived within the follow-up period, the OR was estimated by means of the null hypothesis approach. For Cox proportional hazards analysis, cats were censored if they were alive at the time of data analysis. The HR and 95% CI of the HR were calculated by use of the exact method for ties. For categorical variables with 2 values, such as whether complications developed or a particular drug was administered (yes or no), sex (spayed female or castrated male), breed (domestic shorthair or other breeds), and type of blood product administered (packed RBCs or whole blood), the HR and 95% CI of the HR were calculated. For the continuous variables anesthesia time and age, values were converted into categories (anesthesia time: 3 to 4 hours, > 4 to 5 hours, > 5 to 6 hours, > 6 to 7 hours, and > 7 hours; age: < 5 years, 5 to 8 years, > 8 to 12 years, and > 12 years) and evaluated by means of Kaplan-Meier survival analysis and Cox proportional hazards regression analysis (overall survival rate). Results of blood tests performed at anesthetic induction or immediately after surgery were compared by means of the paired t test (parametric data) or Wilcoxon signed rank test for difference in medians (nonparametric data). Standard analytic software was used for all analyses. Values of P ≤ 0.05 were considered significant.

Results

Cats—Anesthesia record information for 94 cats that underwent RTS was available for retrospective analysis. Data regarding their age, body weight, breed,
sex, and treatments were summarized (Tables 1 and 2). Seventy-eight (83%) cats were domestic shorthairs; other breeds included domestic longhair (n = 5 [5%]), Siamese (5 [5%]), and Persian (2 [2%]) as well as Abyssinian, Himalayan, Maine Coon, and Ragdoll (1 [1%] each) At the time of analysis, 16 of 94 (17%) cats were still alive and 78 (83%) were dead.

Anesthetic and surgical variables—Five (5%) cats received preanesthetic medication (ie, ketamine hydrochloride, methadone, hydromorphone, and midazolam) IM prior to RTS, and the remainder received no preanesthetic medication. Eighty-eight (94%) cats underwent RTS once, and the remaining 6 (6%; 2 spayed females and 4 castrated males) underwent RTS twice. Median

<table>
<thead>
<tr>
<th>Variable</th>
<th>Did not survive for 30 days</th>
<th>Survived ≥ 30 days</th>
<th>OR</th>
<th>95% CI</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>7 (2–15)</td>
<td>7 (2–18)</td>
<td>0.95</td>
<td>0.81–1.12</td>
<td>0.58</td>
</tr>
<tr>
<td>Body weight (kg)</td>
<td>3.5 (2.2–5.1)</td>
<td>3.8 (2.3–6.4)</td>
<td>1.41</td>
<td>0.86–2.21</td>
<td>0.36</td>
</tr>
<tr>
<td>Castrated males</td>
<td>10 (87%)</td>
<td>53 (84)</td>
<td>0.78</td>
<td>0.22–2.73</td>
<td>0.70</td>
</tr>
<tr>
<td>Domestic shorthair (vs spayed females)</td>
<td>13 (93)</td>
<td>64 (80)</td>
<td>0.30</td>
<td>0.03–2.59</td>
<td>0.27</td>
</tr>
<tr>
<td>Anesthesia time (min)</td>
<td>308 ± 48</td>
<td>312 ± 48</td>
<td>1.00</td>
<td>0.98–1.01</td>
<td>0.74</td>
</tr>
<tr>
<td>Surgery time (min)</td>
<td>216 ± 33</td>
<td>220 ± 36</td>
<td>1.00</td>
<td>0.94–1.06</td>
<td>0.90</td>
</tr>
<tr>
<td>Vascular clamp time (min; n = 78)</td>
<td>60 ± 9</td>
<td>68 ± 13</td>
<td>1.05</td>
<td>0.99–1.11</td>
<td>0.10</td>
</tr>
<tr>
<td>Warm ischemia time (min; n = 65)</td>
<td>43 ± 5</td>
<td>47 ± 14</td>
<td>1.03</td>
<td>0.96–1.11</td>
<td>0.30</td>
</tr>
</tbody>
</table>

Values are median (range) for age and body weight, mean ± SD for all times, and No. (%) of all cats with the given characteristic or treatment for all other variables. Values of \( P \leq 0.05 \) were considered significant.

Odds ratios were interpreted as an estimate of the odds of one group of cats versus odds of another group developing an outcome (in this situation, survival for at least 30 days), with an OR of 1 indicating no difference in odds, an OR > 1 indicating an increased odds of survival and an OR < 1 indicating a reduced odds of survival.
interval between first and second surgeries in cats that underwent RTS twice was 40 days (range, 7 to 197 days). All cats underwent RTS by end-to-side anastomosis of the renal artery to the aorta and the renal vein to the caudal vena cava as described elsewhere. Vascular clamp time was recorded for 78 cats, with a median duration of 65 minutes (range, 23 to 125 minutes). Warm ischemia time was recorded for 65 cats, with a median duration of 45 minutes (range, 25 to 70 minutes).

Anesthetic induction was achieved in cats through IV administration of etomidate (n = 71 [76%]), etomidate and propofol (13 [14%]), or propofol (10 [11%]). Median doses were 2 mg/kg (0.9 mg/lb; range, 1 to 3 mg/kg [0.45 to 1.4 mg/lb]) and 1.5 mg/kg (0.7 mg/lb; range, 0.5 to 2 mg/kg [0.23 to 0.9 mg/lb]) for propofol and etomidate, respectively. Isoflurane was additionally administered via face mask to 1 cat that received etomidate. All cats were administered 1 or more µ-opioid receptor agonists IV as coinduction agents as follows: oxymorphone, n = 38 (40%); hydromorphone, 32 (34%); methadone, 8 (9%); fentanyl, 7 (7%); oxymorphone, fentanyl, and hydromorphone, 6 (6%); and fentanyl and oxymorphone, 3 (3%). Benzodiazepines and lidocaine were also administered IV as coinduction agents to 88 (94%) cats (midazolam, n = 83 [88% of all cats]; diazepam, 5 [5%]). Anesthesia was maintained with a balanced technique for all cats with isoflurane (n = 93 [99%]). Comaintenance was achieved for 88 (94%) cats by IV administration of µ-opioid receptor agonists as follows: fentanyl, 61 (65% of all cats); fentanyl and hydromorphone, 6 (6%); remifentanil, 5 (5%); fentanyl and oxymorphone, 2 (2%); and fentanyl and morphine, fentanyl and remifentanil, remifentanil and methadone, morphine, oxymorphone, and hydromorphone, 1 [1%] each. Morphine was administered neuraxially to 15 cats (epidural space, n = 11 [12% of all cats]; subarachnoid space, 4 [4%]). In addition,
cats received IV boluses of etomidate (n = 70 [74%]), corticosteroid drugs (dexamethasone, 11 [12%]; methylprednisolone, 2 [2%]), and benzodiazepines (midazolam, n = 10 [11%]; diazepam, 1 [1%]).

After surgery, the following drugs were administered IV or IM to cats: µ-opioid receptor antagonists (oxy-morphine, n = 30 [32%]; hydromorphone, 21 [22%]; buprenorphine, 13 [14%]; methadone, 8 [9%]; fentanyl, 2 [2%]), µ-opioid receptor antagonists (butorphanol, n = 11 [12%]; naloxone, 2 [2%]; acepromazine (12 [13%]), and flumazenil (5 [5%]). Miscellaneous drugs administered during anesthetic maintenance or recovery that were not included in survival analyses included propofol boluses (n = 6 [6%]), hydralazine (3 [3%]), diphenhydramine (3 [3%]), and furosemide (2 [2%]) and insulin, cis-atracurium, neostigmine, and heparin (1 [1%] each).

Antimuscarinic agents were administered IV to 63 (67%) cats (glycopyrrolate, n = 56 [60% of all cats]; atropine, 7 [7%]). Adrenergic agents were administered IV to 39 (41%) cats (phenylephrine, 20 [21% of all cats]; dopamine, 18 [19%]; dobutamine, 1 [1%]). One (1%) cat that received dopamine also received vasopressin for additional blood pressure support.

All cats received a balanced crystalloid solution during anesthesia at a median total volume of 39.5 mL/kg (19.0 mL/lb; 6.25 to 150 mL/kg [2.8 to 68.2 mL/lb]) and a median rate of 11 mL/kg/h (5 mL/lb/h; 1.3 to 36 mL/kg/h [0.6 to 16.4 mL/lb/h]). Five cats received synthetic colloid (hydroxethyl starch) solution at a median dose of 9 mL/kg (4.1 mL/lb; 1.5 to 15 mL/kg [0.7 to 6.8 mL/lb]). Blood products were administered to 90 (96%) cats in the form of whole blood (n = 71 [76%]) or packed RBCs (19 [20%]). Median values for total volumes of whole blood and packed RBCs administered were 1 U/cat (range, 1 to 3 U/cat) and 2 U/cat (range, 1 to 3 U/cat), respectively. Fifty-two (55%) cats received mannitol solution at the time of allograft transplantation following vascular clamp release at a standardized dose of 0.5 g/kg (0.23 g/lb), IV, for a 20-minute period.

**Physiologic and hematologic variables**—Median body temperature at anesthetic induction was 36.9°C (98.4°F; range, 33.9° to 38.9°C [93.0° to 102.2°F]). Median heart rate and MAP were 188 beats/min (range, 120 to 240 beats/min) and 154 mm Hg (range, 100 to 220 mm Hg), respectively.

During anesthesia, hypotension was detected in 39 (41%) cats, with a median duration of 5 minutes (range, 5 to 25 minutes). None of the cats became hypertensive. Tachycardia was detected in 8 (9%) cats, with a median duration of 12.5 minutes (range, 5 to 170 minutes). Other complications included bradycardia (n = 4 [4%]; median duration, 10 minutes [range, 5 to 60 minutes]), SpO2 < 90% (2 [2%]; median duration, 25 minutes [range, 15 to 35 minutes]), and hypercapnia (2 [2%]; median duration, 10 minutes [range, 5 to 15 minutes]). Median hypothermia time in the 55 (59%) cats that became hypothermic was 30 minutes (range, 5 to 45 minutes).

Median change in body temperature between anesthetic induction and end of surgery was 0.2°C (0.34°F; range, –4.6° to 2.8°C [–7.8° to 4.8°F]). Hematologic test results for venous blood obtained at anesthetic induction and end of surgery were summarized (Table 3). Blood pH, base excess, and Hct increased significantly whereas blood PCO2 and K+ concentration decreased significantly toward the end of anesthesia. Mean ± SD Hct after RTS for cats that did not or did survive for at least 30 days was 17.7 ± 2.3% and 20.8 ± 4.9%, respectively.

**Survival rates**—Median overall survival time (for all cats) was 653 days (range, 2 to 4,580 days; Figure 1). For cats that underwent RTS once, median survival time was 666 days (range, 2 to 4,580 days), and for cats that underwent RTS twice, median survival time was 90% (2 [2%]; median duration, 10 minutes [range, 5 to 60 minutes]). SpO2 < 90% (2 [2%]; median duration, 25 minutes [range, 15 to 35 minutes]), and hypercapnia (2 [2%]; median duration, 10 minutes [range, 5 to 15 minutes]). Median hypothermia time in the 55 (59%) cats that became hypothermic was 30 minutes (range, 5 to 45 minutes).

**Table 3**—Results of hematologic tests performed at anesthetic induction and end of surgery and their association with survival rates for 94 cats that underwent RTS at a teaching veterinary hospital.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Reference limits</th>
<th>No. of cats</th>
<th>Value</th>
<th>OR</th>
<th>95% CI</th>
<th>P value</th>
<th>HR</th>
<th>95% CI</th>
<th>P value</th>
<th>No. of cats</th>
<th>Value</th>
<th>OR</th>
<th>95% CI</th>
<th>P value</th>
<th>HR</th>
<th>95% CI</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>7.31 to 7.41</td>
<td>78</td>
<td>7.21</td>
<td>57.5</td>
<td>0.02 to 1.05 (7.03 to 7.46)</td>
<td>0.29</td>
<td>0.25</td>
<td>0.01 to 4.26</td>
<td>0.29</td>
<td>88</td>
<td>7.28</td>
<td>0.04 to 1.03 (6.89 to 7.43)*</td>
<td>0.54</td>
<td>0.01 to 1.34 (6.99 to 7.43)*</td>
<td>0.83</td>
<td>0.37</td>
<td>0.04 to 3.5</td>
</tr>
<tr>
<td>Pco2 (mm Hg)</td>
<td>41 to 51</td>
<td>77</td>
<td>49.6</td>
<td>0.96</td>
<td>0.90 to 1.03 (24.6 to 87.8)</td>
<td>0.15</td>
<td>1.01</td>
<td>0.01 to 1.04</td>
<td>0.15</td>
<td>88</td>
<td>42.7</td>
<td>0.01 to 1.09 (24.5 to 96.4)*</td>
<td>1.01</td>
<td>0.09 to 1.09</td>
<td>0.69</td>
<td>1.00</td>
<td>0.98 to 1.03</td>
</tr>
<tr>
<td>HCO3 (mmol/L)</td>
<td>22 to 28</td>
<td>76</td>
<td>40</td>
<td>0.97</td>
<td>0.91 to 1.15 (12.3 to 30.0)</td>
<td>0.74</td>
<td>1.023</td>
<td>0.05 to 1.09</td>
<td>0.73</td>
<td>87</td>
<td>21.0</td>
<td>0.01 to 1.09 (11.0 to 40.0)</td>
<td>1.01</td>
<td>0.09 to 1.19</td>
<td>0.78</td>
<td>1.00</td>
<td>0.94 to 1.06</td>
</tr>
<tr>
<td>Base excess (mmol/L)</td>
<td>0 to 3</td>
<td>77</td>
<td>0.50</td>
<td>0.60</td>
<td>0.41 to 1.14 (&lt;1.0 to 3.0)</td>
<td>0.86</td>
<td>1.01</td>
<td>0.05 to 1.09</td>
<td>0.86</td>
<td>87</td>
<td>0.97</td>
<td>0.05 to 1.19 (&lt;1.0 to 3.0)</td>
<td>0.96</td>
<td>0.04 to 1.03</td>
<td>0.63</td>
<td>0.98</td>
<td>0.04 to 1.03</td>
</tr>
<tr>
<td>K+ (mEq/dl)</td>
<td>3.5 to 4.8</td>
<td>80</td>
<td>4.1</td>
<td>0.62</td>
<td>0.25 to 1.10 (2.5 to 7.2)</td>
<td>0.11</td>
<td>1.00</td>
<td>0.07 to 1.36</td>
<td>0.11</td>
<td>91</td>
<td>3.7</td>
<td>0.02 to 1.03 (2.5 to 7.2)</td>
<td>0.52</td>
<td>0.26 to 1.03</td>
<td>0.06</td>
<td>1.23</td>
<td>0.91 to 1.86</td>
</tr>
<tr>
<td>Hct(%)</td>
<td>31.7 to 46.0</td>
<td>75</td>
<td>18.2</td>
<td>0.52</td>
<td>0.98 to 1.33 (5.2 to 7.2)</td>
<td>0.14</td>
<td>0.98</td>
<td>0.03 to 1.03</td>
<td>0.01</td>
<td>87</td>
<td>20.4</td>
<td>0.04 to 1.03 (11.0 to 40.0)</td>
<td>1.16</td>
<td>1.00 to 1.04 (1.1 to 4.0)</td>
<td>0.03</td>
<td>0.95</td>
<td>0.91 to 1.01 (1.0 to 4.0)</td>
</tr>
</tbody>
</table>

Values are reported as median (range) for all variables, except for Hct, which is reported as mean ± SD. The P values represent results of logistic regression analysis (short-term survival rate) or Cox proportional hazards analysis (overall survival rate).

Values differ significantly (P < 0.05) between the 2 measurement points, with comparisons performed by use of a t test (normally distributed data) or Wilcoxon signed rank test (nonnormally distributed data).

See Tables 1 and 2 for remainder of key.
was 546 days (range, 9 to 2,389 days); these values did not differ significantly ($P = 0.87$). Fourteen of 94 (15%) cats did not survive for 30 days after RTS (median, 9 days [range, 2 to 26 days]). Proportions of all cats that survived were 85% (80/94) at 30 days, 78% (74/94) at 6 months, and 41% (39/94) at 3 years.

A significant correlation was identified between age and overall survival rate. When comparisons were made between survival curves at the age categories $< 5$ years ($n = 24$ [26%]), 5 to 8 years (41 [44%]), $> 8$ to 12 years (20 [21%]), and $> 12$ years (9 [10%]), a significant ($P < 0.001$) difference in overall survival rate was only identified for the age category $> 12$ years, which had a lower rate than did the other categories (Figure 2).

Anesthesia time as a continuous variable negatively influenced overall but not short-term survival rate (Tables 1 and 2). This relationship was significant ($P = 0.04$) and also apparent in survival curves created for the time categories 3 to 4 hours ($n = 4$), > 4 to 5 hours (34), > 5 to 6 hours (40), > 6 to 7 hours (12), and > 7 hours (7; Figure 3). Surgery time had no influence on short-term or overall survival rate.

All 5 cats that received preanesthetic medication survived > 30 days after RTS. None of the drugs administered during anesthetic induction or maintenance influenced the 2 survival variables (Tables 1 and 2). Administration of µ-opioid receptor antagonists during anesthetic recovery increased the odds of short-term survival. No other associations were identified for drugs used in anesthetic recovery. Type of blood product or drugs administered to support cardiovascular function and renal perfusion had no influence on short-term or overall survival rate.

Heart rate as measured prior to anesthetic induction was not associated with short-term (OR, 0.96; 95% CI, 0.92 to 1.01; $P = 0.09$) or overall (HR, 1.00; 95% CI, 0.99 to 1.01; $P = 0.12$) survival rate, nor was MAP (short-term OR, 0.99; 95% CI, 0.96 to 1.02; $P = 0.74$; overall, HR, 0.99; 95% CI, 0.99 to 1.00; $P = 0.91$). Median body temperature at anesthetic induction had no effect on short-term (OR, 0.91; 95% CI, 0.53 to 1.56; $P = 0.73$) or overall (HR, 1.11; 95% CI, 0.99 to 1.37; $P = 0.16$) survival rate. Similarly, body temperature change between anesthetic induction and end of surgery had no effect on short-term (OR, 0.75; 95% CI, 0.50 to 1.13; $P = 0.16$) or overall (HR, 1.12; 95% CI, 0.95 to 1.32; $P = 0.13$) survival rate. Duration of hypothermia had no influence on short-term (OR, 0.99; 95% CI, 0.98 to 1.06; $P = 0.56$) or overall (HR, 1.12; 95% CI, 0.95 to 1.32; $P = 0.87$) survival rate, nor did duration of hypotension (short-term OR, 0.99; 95% CI, 0.97 to 1.03; $P = 0.16$;...
overall HR, 0.99; 95% CI, 0.98 to 1.00; P = 0.52). Duration of tachycardia had no association with short-term (OR, 22.60; 95% CI, 0.01 to 225.90; P = 0.09) or overall (HR, 1.01; 95% CI, 0.99 to 1.02; P = 0.19) survival rate. Neither vascular clamp time nor warm ischemia time was associated with short-term or overall survival rate (Tables 1 and 2). High Hct at the end of anesthesia was indicative of increased odds of survival (Table 3). None of the other hematologic variables measured before and after anesthesia appeared to influence short-term or overall survival rate.

Discussion

Median survival time in the present study was 653 days for cats with end-stage renal disease that underwent RTS, which is greater than previously reported survival times (360 to 613 days).2,6,13 Proportions of cats that survived for 30 days (84%), 6 months (76%), and 3 years (40%) were comparable with those reported by Schmiedt et al13 (78%, 65%, and 40% survived to and 3 years (40%) were comparable with those reported for cats that survived for 30 days (84%), 6 months (76%), and 3 years (40%) after RTS, respectively). Although the anesthetic techniques used in other studies2,6,7,10 have been described and variables investigated for an influence on survival time, to the authors’ knowledge, the present study was the first in which prolonged anesthesia time was associated with a decreased overall survival rate in cats that underwent RTS. This is in contrast to the findings of Schmiedt et al,13 who reported that anesthesia time had no significant influence on survival rate.

Several factors may prolong anesthesia time. For example, prolonged surgical time typically requires prolonged exposure to anesthetic agents and affects the overall health of humans undergoing RTS.41 In the present study, surgical time was not associated with short-term and overall survival rates. Factors other than surgical time that may affect anesthesia time include application of monitoring equipment, establishment of sufficient vascular access, provision of neuraxial anesthesia or local anesthesia after anesthetic induction, clipping of hair, transportation to the operating room, surgical preparation of the skin, draping of the patient, synchronicity with another surgical team to remove the donor kidney, and emergence from anesthesia. The latter is considered in humans to be influenced by several variables, such as function of the cardiovascular system, perfusion of organs of elimination, metabolic capacity of the patient, effects of concurrent medical conditions (eg, acidosis) and drug interactions of specific anesthetic agents, and body temperature and age of the patient.29 Because of the retrospective nature of the present study, the reason that prolonged anesthesia was associated with a decrease in overall survival rate could not be identified. Additional prospective, controlled studies are necessary to corroborate and explain this finding.

Some anesthetic agents have been associated with a decrease in long-term survival rate or disease recurrence in various surgical conditions in human patients and research settings.21–26 To the authors’ knowledge, no studies have shown that the choice of a particular anesthetic drug or technique influences the probability of survival in human and veterinary patients undergoing RTS. Drug choice is considered an important factor in management of anesthesia in humans or cats undergoing RTS.7,12,27–35 Plasma concentrations and pharmacokinetics of most clinically available anesthetic and analgesic drugs are altered in such patients as a result of impaired renal and hepatic elimination and hypalbuminemia.30,36 In the present study, anesthesia was induced in all cats with injectable anesthetic agents following IV coadministration of an opioid and, in most situations, a benzodiazepine. However, only 5 cats received preanesthetic medications IM prior to anesthetic induction. This situation differs from that in another study7 in which cats undergoing RTS received a combination of glycopyrrolate and oxymorphone administered SC 30 minutes before anesthetic induction with isoflurane in oxygen. Given that most cats in the present study underwent anesthesia with patent IV access and cats with end-stage renal disease may have unreliable drug absorption from the tissues, IV administration of drugs may have been preferable to SC or IM administration.12,35 Anesthetic induction via inhalation of a volatile anesthetic agent may avoid altered drug elimination resulting from renal disease and was used in 1 cat as a coinduction technique. However, isoflurane was not chosen for anesthetic induction in most of the cats of the study reported here because we believed the inhalation anesthetic may have caused a physiologic stress response and release of catecholamines that may have impaired renal perfusion and may have polluted the operating room environment.5,37,38

Lidocaine was administered IV to approximately two-thirds of the cats during induction of anesthesia. Lidocaine has been administered IV to cats to allow a reduction in the dose of volatile anesthetics required to achieve anesthesia.39 However, lidocaine infusions can reduce the cardiac index in cats, and a recommendation has been made to avoid administering this drug IV in that species.60 Intravenous administration of lidocaine was performed in most of the study cats before the recommendation was made. In support of the recommendation, lidocaine administration during anesthesia induction appeared to be associated with approximately a 3.4-fold decrease (OR, 0.29) in the odds of survival within 30 days after RTS. However, this association was not significant (P = 0.08), and a larger number of cats would be necessary to reduce the potential for type II error associated with a small sample size.

As was performed in another study,7 a balanced anesthetic protocol was used for anesthetic maintenance in all cats in the present study, mainly by combining isoflurane (inhalation anesthetic) with a µ-opioid receptor agonist administered IV. Additionally, opioid-based analgesia was provided to most cats during the anesthetic recovery period. The attending anesthesiologist’s drug choice for each cat undergoing RTS may have been influenced by many variables, such as personal experience and the cat’s clinical signs, temperament, and age. Nonetheless, the anesthetic protocols used did not differ to any important degree from those previously recommended for cats with renal disease.41
approximately half of the cats received mannitol solution IV prior to clamp removal. Mannitol is used to expand intravascular volume, thereby increasing renal tubular flow rate and decreasing the risk of renal tubular obstruction. Administration of mannitol solution immediately after kidney transplantation did not affect short-term or overall survival rate in the present study. These results are comparable with those of a previous study in humans, which revealed no significant differences in renal function 3 months after RTS between patients who received mannitol and those who did not.

In the present study, preoperative MAP as measured with a Doppler ultrasonographic device was not associated with short-term or overall survival rate. These results conflict with those reported by Schmiedt et al., who detected a negative relationship between preoperative MAP and survival rate in 50 cats that underwent RTS. Perioperative administration of hydralazine has been advocated to minimize the incidence of postsurgical neurologic complications associated with hypertensive events. Also in contrast to the findings of Schmiedt et al., an increase in duration of intra-anesthetic hypotension did not predict a decrease in survival rate, although in the present study, hypotension was detected in 39 of 94 (41%) cats. In that previous study, longer duration of intraoperative hypotension (MAP < 60 mm Hg) was a risk factor for perioperative death. Cats that died before hospital discharge had a mean duration of hypotension of 70 minutes, and cats that survived to discharge had a mean duration of 33 minutes. Interestingly, cats in the present study had a median duration of hypotension of only 5 minutes, which may explain the discrepancy between study findings. Similar to methods used in other studies, MAP < 60 mm Hg was used to define hypotension in the present study. This definition has been supported by findings from a systematic review of reports regarding anesthesia and kidney transplantation in humans that suggested an MAP of 60 to 70 mm Hg was ideal.

Accurate but practical methods of blood pressure measurement in cats are difficult to identify. Ideally, arterial blood pressure should be monitored invasively. However, arterial catheterization of cats may be challenging. In anesthetized cats, the Doppler ultrasonographic technique is reportedly an accurate predictor of MAP with a bias close to 0 mm Hg, compared with a bias of –25 mm Hg for systolic arterial blood pressure. Despite the use of vasoactive drugs in humans during RTS are am

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with an increase in mortality rate after RTS. In the present study, use of adrenergic drugs appeared to have decreased the overall hazard of nonsurvival (HR, 0.64). Nevertheless, the lack of a significant (P = 0.08) difference may have reflected a type II statistical error and additional studies with a larger sample size may be warranted.

Warm ischemia time should be as short as possible to prevent renal allograft injury. A previous study revealed that graft function can be delayed in cats with autologous kidney transplantation as a result of ischemic episodes lasting 32 ± 3.7 minutes. However, in the present study, clamp placement and warm ischemia times of 65 and 45 minutes were not associated with survival rates.

Two study cats in the present study had an SpO₂ < 90% during anesthesia, which may be interpreted as intra-anesthetic hypoxemia. The reason these 2 cats had this low value despite the use of a volatile anesthetic agent vaporized in oxygen was unclear. Post hoc evaluation of the medical records revealed that both cats required mechanical ventilation and died 2 and 7 days after surgery of complications related to renal insufficiency and pleural and abdominal effusion, respectively. Pulse oximeter accuracy may decrease in patients with severe anemia, hypotension, or vasoconstriction, also leading to an SpO₂ < 90%. Monitoring techniques such as serial arterial blood gas evaluations or near-infrared spectroscopy may be more precise for assessment of hypoxemia.

Hematologic tests results in the study reported here also indicated an increase in blood Pco₂ and decrease in blood pH and base excess at anesthetic induction that were compatible with metabolic and respiratory acidosis, probably as a result of a decrease in tissue perfusion, uremia, and anesthetic-induced respiratory depression. These values significantly improved toward the end of anesthesia, suggesting better respiratory, organ, and tissue perfusion in affected cats. A significant decrease in blood K⁺ concentration was detected toward the end of anesthesia and, similar to previous findings, was not associated with survival rate. The Hct increased significantly toward the end of anesthesia, suggesting better oxygen delivery to the tissues. Similarly, perioperative anemia was associated with increased risk of morbidity and death 3 days after major surgery in people.

However, the beneficial effects of high Hct may not be constant. For instance, the risk of death was increased with both low (< 30%) and high (> 50%) Hct in people that underwent successful RTS.

Schmiedt et al reported that increasing preoperative body weight and older age were associated with a lower survival rate after RTS. We found that age but not body weight was associated with a lower overall survival rate, whereas neither variable was associated with short-term survival. Specifically, cats > 12 years old had a lower overall survival rate than did younger cats. Older cats could be anticipated to have a shorter survival time than younger cats as a consequence of aging. In support of our findings, 10- to 14-year-old cats had an increased risk of nonsurvival relative to that for younger cats within the first 6 months following RTS in another study. Survival plots in the present study revealed that 50% of cats > 12 years old lived ≥ 501 days after RTS. Interestingly, no differences in overall survival rate were identified among the younger subgroups in the present study.

Results of the present study highlighted the importance of developing a plan to efficiently manage the anesthetic process to reduce the negative impact on overall survival rate. Cats > 12 years old that underwent RTS had a decreased overall survival rate, compared with that of younger cats. Administration of μ-opioid receptor antagonists after surgery to reverse the effects of μ-opioid receptor agonists on cats undergoing RTS and maintaining adequate Hct may improve the odds of cats surviving for at least 30 days. The impact of intraoperative SpO₂ and oxygenation on survival rates requires further investigation.

References


b. MedCalc statistical software, version 11.6.1.0. MedCalc Software bvba, Ostend, Belgium.


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**From this month’s AJVR**

**Discrimination of healthy versus sick steers by means of continuous remote monitoring of animal activity**

Jacqueline L. Smith et al

**Objective**—To test a unique electronic ear tag designed to collect movement data to determine whether physical activity of sick steers differed from that of healthy steers.

**Sample**—206 steers.

**Procedures**—Physical activity in 2 groups of steers during November and December of 2010 (101 steers; the tag of 1 steer failed, and thus that steer was removed from the study, which resulted in data for 100 steers) and 2011 (105 steers) was monitored with an electronic ear tag device with an on-board triple-axis accelerometer. The accelerometer recorded motion in all 3 axes in the form of counts per minute. A radio-frequency transmitter on the ear tag delivered serial packets of motion data to a local server. An algorithm was developed to analyze the activity data to determine whether this technique could be used to assess health status with high accuracy.

**Results**—Steers that became sick had significantly fewer activity counts (approx 25% fewer), compared with the activity counts of steers that remained healthy the entire time.

**Conclusions and Clinical Relevance**—In this study, automated detection of health status in growing cattle was feasible through remote monitoring of animal activity. Early identification of sick animals should lead to improved health outcomes, increased marketability, and improved animal well-being and help to minimize the use of antimicrobials that could contribute to resistant bacteria. (Am J Vet Res 2015;76:739–744)