Doppler ultrasonographic evaluation of renal arterial resistive and pulsatility indices in overhydrated Beagles

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Objective—To determine renal arterial resistive index (RI) and pulsatility index (PI) and clinical signs of overhydration induced by IV administration of saline (0.9% NaCl) solution and to assess RI and PI as variables for monitoring of dogs to detect overhydration.

Animals—10 clinically normal Beagles.

Procedures—Each dog received saline solution at a maintenance rate (2.5 mL/kg/h) and a rate 3 times that of the maintenance rate (overhydration rate; 7.5 mL/kg/h). Values of RI and PI were determined with pulsed-wave Doppler ultrasonographic examination of renal interlobar or arcuate arteries before saline solution administration, every hour during 5 hours of administration, and 1 hour after administration was stopped.

Results—No significant changes in RI or PI were detected during administration of saline solution at the maintenance rate. However, RI (starting 1 hour after the beginning of fluid administration [mean ± SD value, 0.589 ± 0.012]) and PI (starting 2 hours after the beginning of fluid administration [value, 0.867 ± 0.052]) were significantly lower during administration at the overhydration rate than they were during administration at the maintenance rate. Clinical signs of overhydration were observed in all dogs starting 4 hours after the beginning of fluid administration at the overhydration rate.

Conclusions and Clinical Relevance—Results indicated overhydration of dogs caused significant decreases in RI and PI prior to detection of clinical signs of overhydration. Ultrasonographic determination of renal arterial RI and PI seemed to be a noninvasive and sensitive method for evaluation of overhydration in dogs. (Am J Vet Res 2014;75:344–348)

Renal arterial RI and PI values calculated by means of blood flow velocity waveform analysis have been determined in other studies for clinically normal dogs; such values change with variations in renal peripheral vascular resistance. The RI and PI increase during various conditions, such as urinary tract obstruction, acute and chronic renal failure, sedation, and anesthesia. Such values can also be high in puppies < 4 months old and in dogs with hepatic disease. The diuretic effects of IV administration of saline (0.9% NaCl) solution and furosemide or mannitol result in a decrease in renal arterial RI and PI. In addition, IV administration of saline solution significantly decreases the RI of kidneys in humans without obstructed upper urinary tracts.

Determination of the optimal rate of IV fluid administration is important for the hydration status of a patient. Overhydration can be caused by administration of an overdose of fluid. Clinical signs of overhydration include wet mucus membranes, increased skin elasticity, shivering, restlessness, serous nasal discharge, chemosis, tachypnea, cough, nausea, vomiting, dyspnea, pulmonary adventitious sounds (crackles) and edema, pleural effusion, and ascites. Veterinarians should observe patients to identify such signs and determine whether animals have been overhydrated. However, clinical signs of early stages of overhydration (eg, shivering and cough) may be similar to signs of other diseases. Therefore, CVP measurements have been commonly used to assess the fluid volume and cardiac preload in patients. Unfortunately, technical errors and complications such as infection may develop as a result of CVP measurement. For this reason, practical and noninvasive alternative approaches are needed for evaluation of the hydration status of patients.

The objective of the study reported here was to evaluate alterations in renal arterial RI and PI in Beagles that received saline solution, determine clinical signs of experimentally induced overhydration, and assess the feasibility of RI and PI measurement for detection of overhydration in clinically normal dogs. We hypothesized that IV administration of saline solution at a rate

### Abbreviations

<table>
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<th>CVP</th>
<th>Central venous pressure</th>
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<tr>
<td>PI</td>
<td>Pulsatility index</td>
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<td>RI</td>
<td>Resistive index</td>
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greater than the maintenance rate would have a diuretic effect similar to that of mannitol or the combination of furosemide and saline solution and cause decreases in renal arterial RI and PI and development of clinical signs of overhydration.

Materials and Methods

Animals—Ten healthy Beagles (4 males and 6 females) with a mean age of 22.8 months (range, 15 to 25 months) and a mean body weight of 6.9 kg (range, 5.2 to 9.3 kg) were used in this study. The animals were determined to be clinically normal on the basis of results of physical examination, CBC, serum biochemical analyses, urinalysis, radiography, and abdominal ultrasonography. The study was approved by the Institutional Animal Care and Use Committee of Konkuk University.

Renal Doppler ultrasonography—Triplex Doppler ultrasonographic images were acquired by use of an ultrasound machine with a 10-MHz linear transducer. Hair was clipped, and acoustic gel was applied to the skin over the area of interest for each dog. Dogs were placed in right lateral recumbency and the nondependent left kidney was examined. Color flow Doppler ultrasonography was performed with a frequency of 6.15 MHz to evaluate intrarenal vasculature (eg, interlobar arteries along the borders of medullary pyramids and arcuate arteries at corticomedullary junctions). Subsequently, pulsed-wave Doppler ultrasonography was performed for one of the intrarenal arteries (sample width, 1 mm; frequency, 5.71 MHz; Figure 1). Dogs were not sedated and were manually restrained for Doppler ultrasonography.

The RI and PI were calculated automatically by the ultrasound machine software after manual delimitation of peak systolic blood velocity, end diastolic blood velocity, and time-averaged maximum blood velocity. Values were calculated as follows:

\[
\text{RI} = \frac{\text{peak systolic velocity} - \text{end diastolic velocity}}{\text{peak systolic velocity}}
\]

\[
\text{PI} = \frac{\text{peak systolic velocity} - \text{end diastolic velocity}}{\text{time average maximum velocity}}
\]

Administration of saline solution—Food was withheld, and dogs were confined to cages to reduce stress and limit exercise during IV administration of saline solution. Hair was clipped, skin was aseptically prepared, and a 22-gauge catheter was inserted into a cephalic vein and connected to an infusion pump with an extension tube. Saline solution was administered IV at a maintenance rate (2.5 mL/kg/h) for 5 hours; water intake was restricted for dogs during this time. Catheters were removed while pressing cotton soaked in alcohol around the insertion site after IV administration of saline solution was stopped. The RI and PI were measured at the start of IV saline solution administration (0 hours), every hour during administration (1, 2, 3, 4, and 5 hours), and 1 hour after administration was stopped (6 hours). Two weeks later, saline solution was administered IV to dogs at a rate 3 times that of the maintenance rate (7.5 mL/kg/h; overhydration fluid administration rate) for 3 hours. The RI and PI were measured by use of the same method and at the same times that were used during administration of saline solution at the maintenance rate. The overhydration saline solution administration rate was determined during a preliminary experiment; results of that experiment indicated fluid administration at a rate 3 times that of the maintenance rate resulted in significantly lower RI and PI than administration at a rate 2 times that of the maintenance rate. Observers were unaware of the fluid administration rate to minimize potential bias, because such bias could cause observers to predict results and select inappropriate renal vascular waveforms.

Clinical signs of overhydration—All dogs were monitored every 15 minutes during IV administration of saline solution. One veterinarian (SJL) determined whether dogs were overhydrated by measurement of heart and respiratory rates, auscultation of lungs, and observation of each animal to detect clinical signs such as shivering, serous nasal discharge, coughing, chemo- sis, restlessness, and nausea. The clinical sign considered to indicate nausea was retching. Administration of saline solution was to be immediately stopped if severe signs of overhydration were detected (eg, severe respiratory distress, pulmonary adventitious sounds [crackles] detected by means of auscultation, or vomiting). Furosemide (1 mg/kg, IV) was to be administered if signs of overhydration did not improve after discontinuation of saline solution administration.

Statistical analysis—The renal arterial RI and PI values were analyzed with statistical software. All values for each time were determined to have a normal distribution by use of the Kolmogorov-Smirnov test (P > 0.05); mean ± SD values were reported. Repeated-measures ANOVA and Greenhouse-Geisser correction were used to compare values between the maintenance fluid administration rate and the overhydration rate for each time; post hoc analy-
sis was performed to determine significant differences between the 2 groups by means of the independent t test with Bonferroni correction. For all comparisons, values of \( P < 0.05 \) were considered significant.

**Results**

Before IV administration of saline solution, mean ± SD RI and PI were 0.63 ± 0.014 and 1.075 ± 0.06, respectively. No significant changes in RI or PI values were detected during 5 hours of IV administration of saline solution at a maintenance rate; however, the pulsed-wave Doppler waveform signal seemed to have increased amplitude during that time, compared with the signal before fluid administration (Figure 2).

The RI and PI values decreased during IV administration of saline solution at the overhydration rate. The pulsed-wave Doppler waveform signal amplitude was higher during administration at the maintenance rate than it was before fluid administration (Figure 2). The RI (between 1 and 5 hours after start of IV administration of saline solution) and PI (between 2 and 5 hours after start of IV administration of saline solution) were significantly lower during IV administration of saline solution at the overhydration rate than they were during administration at the maintenance rate (Figure 3). After 1 hour of fluid administration at the overhydration rate, mean ± SD RI was 0.389 ± 0.012. After 2 hours of fluid administration at the overhydration rate, mean ± SD PI was 0.867 ± 0.052. After 5 hours of saline solution administration at the overhydration rate, the mean ± SD RI and PI were 0.512 ± 0.011 and 0.782 ± 0.042, respectively. One hour after administration of saline solution at the overhydration rate was stopped, the mean ± SD RI and PI were 0.624 ± 0.014 and 1.05 ± 0.053, respectively.

![Figure 2](image2.png)

**Figure 2**—Representative pulsed-wave Doppler ultrasonographic waveforms for a healthy Beagle before administration of saline (0.9% NaCl) solution (A) and after 5 hours of administration at a maintenance rate (2.5 mL/kg/h; B) and an overhydration rate (75 mL/kg/h; C).

![Figure 3](image3.png)

**Figure 3**—Mean renal arterial RI (A) and PI (B) in 10 clinically normal Beagles at various times before (0 hours), during (hours 1 through 5), and 1 hour after (6 hours) IV administration of saline solution at a maintenance rate (2.5 mL/kg/h; black solid line) and an overhydration rate (75 mL/kg/h; gray dashed line). *Value is significantly (\( P < 0.05 \)) different from the value for the maintenance rate of saline solution administration.

Clinical signs of overhydration were observed for dogs between 4 and 5 hours after the start of IV administration of saline solution at the overhydration rate. Serous nasal discharge (\( n = 8 \) dogs) was the most commonly detected clinical sign of overhydration. Cough and chemosis were observed in 5 dogs, and tachypnea, restlessness, shivering, and nausea were observed in 3 dogs. No clinical signs of overhydration were detected in dogs 1 hour after IV administration of fluids at the overhydration rate was stopped.

**Discussion**

Results of this study indicated ultrasonographic determination of renal arterial RI and PI was easily performed and values of those variables were significantly lower beginning 1 and 2 hours, respectively, after the start of IV administration of saline solution at the overhydration rate, compared with values determined during administration at a maintenance rate. Clinical signs of overhydration were not observed until 4 hours after the start of fluid administration at the overhydration rate. Therefore, RI and PI seemed to be more sensitive measures of overhydration than clinical signs, and determination of such values may be useful for monitoring of hydration status in dogs and early detection of overhydration during fluid administration.

When fluid volume in the body of an animal is high, various physiologic mechanisms are activated to induce fluid loss, such as urination via kidneys, breathing and sweating via the respiratory system, and vomiting and defecation via the gastrointestinal tract. Additionally, various other clinical signs may be observed, but such signs may not be attributable to overhydration.

Physiologic mechanisms increase renal blood flow when the volume of fluid in the body of an animal increases. In our experience, a renal vascular response may be detected by use of color Doppler ultrasonography for patients receiving fluids or blood transfusions. Such responses may be the result of an increase in renal blood flow attributable to an increase in circulating volume of fluid. Consequently, renal peripheral resistance decreases, which results in a decrease in RI and PI.

Determination of RI and PI provides information about vascular resistance in renal interlobar or arcuate arteries. Results of a study\(^ {13} \) of children indicate RI and PI are not significantly different between interlobar and arcuated arteries.\(^ \) Results of another study\(^ {7} \) indicate such values are not significantly different among intrarenal arteries at 3 locations (cranial pole, middle, and caudal pole of kidneys).\(^ \) The angle between blood flow and a Doppler ultrasonographic wave must be < 30° to reliably determine blood velocity by means of pulsed-wave Doppler ultrasonography.\(^ {2,16} \)

The mean RI and PI prior to administration of fluids were similar to values...
determined during administration at the maintenance rate for dogs in the present study and values for clinically normal dogs in another study. Those findings suggested that IV administration of fluids at a maintenance rate had no effect on renal peripheral vascular resistance. However, the pulsed-wave Doppler ultrasonographic waveform signals were stronger for dogs during administration of fluids at a maintenance rate than they were when dogs did not receive fluids, suggesting that body fluid volume might have increased enough to increase the strength of the Doppler wave signal for the dogs. The finding that administration of saline solution at the overhydration rate significantly decreased RI and PI suggested that administration at that rate caused renal venous congestion and renal peripheral blood vessel dilation as peak systolic blood velocity decreased and peak diastolic blood velocity increased. The finding that the RI significantly decreased starting 1 hour after the beginning of fluid administration and the PI decreased starting 2 hours after the beginning of fluid administration may have indicated RI was more sensitive to changes in renal peripheral vascular resistance than was PI to diuretic effects.

In clinical practice, CVP is the most frequently used and most reliable method for assessment of a patient’s hydration status. The CVP is the hydrostatic pressure in the intrathoracic cranial and caudal vena cava and is identical to the right atrial pressure if there is no vascular obstruction. Central venous catheterization is required for measurement of CVP; this procedure is expensive, invasive, and has possible complications such as mechanical problems associated with catheterization, infection, and thromboembolism. For these reasons, noninvasive methods for estimation of CVP (such as measurement of internal jugular vein and abdominal vein diameters and determination of hepatic venous blood flow by means of ultrasonography) have been evaluated.

In clinical practice, hydration status is typically evaluated with laboratory tests, objective noninvasive measurements of physiologic variables, and subjective observations. Such laboratory tests include determination of serum osmolality and sodium concentration, BUN concentration, Hct, and urine osmolality. Such objective noninvasive measurements include fluid intake and output values, body weight, temperature, heart rate, respiratory rate, and presence or absence of serous nasal discharge. An acute increase in body weight during a short period is frequently assumed to be attributable to an increase in total fluid volume in an animal. Therefore, patient weight is commonly used for monitoring of animals to detect overhydration. In the present study, subjective evaluation of clinical signs rather than determination of body weight were used for detection of overhydration. Starting 4 hours after the start of IV administration of saline solution at the overhydration rate, dogs had clinical signs of overhydration such as tachypnea, chemosis, shivering, serous nasal discharge, coughing, nausea, and restlessness. Nausea (ie, retching), which was considered the most severe sign of overhydration detected for dogs in this study, was observed for 3 dogs. More severe clinical signs, such as pulmonary edema and adventitious sounds (crackles), severe respiratory distress, ascites, vomiting, and pleural effusion were not observed; such signs would have indicated that fluid administration should be immediately discontinued. Clinical signs such as chemosis, shivering, and restlessness were considered subjective rather than objective signs of overhydration.

A limitation of the present study was that the RI and PI were determined for healthy dogs. The RI and PI are increased in animals with liver disease or renal disease because high renal vascular resistance and low renal blood flow result in marked reduction in diastolic blood flow as determined with pulsed-wave Doppler ultrasonographic analysis. In patients without upper urinary tract obstruction, IV fluid administration could increase renal blood flow and result in decreases in RI and PI. Another limitation of this study was that only 1 type of fluid was administered IV. Intravenous administration of saline solution at the overhydration rate resulted in a decrease in RI and PI. Because this decrease in renal vascular resistance was related to the volume of fluid administered, we presume that the administration of other types of fluids commonly used for treatment of animals would have similar effects on RI and PI when administered at a rate higher than a maintenance rate. Further studies would be required to evaluate the effects of other types of fluids or renal or hepatic disease on RI and PI in dogs. Although data in this study were determined for healthy dogs, results suggested that ultrasonographic determination of renal arterial RI and PI was a noninvasive and sensitive method for identification of animals with overhydration.

References

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