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Study of renal resistive index and renal pulsatility index in non-azotaemic healthy dogs segmented by age group.

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ABSTRACT

Renal resistive index (RRI) and pulsatility index (RPI) are valuable tools for the early diagnosis and monitoring of acute and chronic kidney injury, yet age-specific reference values in non-azotemic healthy dogs have not been clearly defined. This study aimed to establish these reference values by evaluating 85 healthy, client-owned dogs, which were divided into five age groups (juvenile, young adult, adult, senior, and geriatric), with 17 dogs per group. Each dog underwent blood tests and physical examinations without abnormalities. Using a standardized protocol, a single operator measured RRI and RPI, revealing a moderate significant correlation between age and both indices (RRI $\rho = .41$, $p < .001$; RPI $\rho = .40$, $p < .001$). In the total sample, the mean RRI and RPI values were 0.613 ± 0.062 (95% confidence interval (95% CI): 0.600 – 0.627) and 1.144 ± 0.236 (95% CI: 1.093 – 1.195), respectively. In geriatric dogs, these values increased to 0.663 ± 0.064 (95% CI: 0.630 – 0.695) for RRI and 1.305 ± 0.263 (95% CI: 1.170 – 1.440) for RPI. Notably, significant differences in RRI and RPI were found between all groups of dogs younger than 11 years and the geriatric dog group ($p = .0004$ and $p = .0007$, respectively). The proposed reference values were 0.71 for RRI and 1.51 for RPI in dogs younger than 11 years old, compared to 0.79 and 1.83, respectively, in geriatric dogs. These findings demonstrate that RRI and RPI vary with age, with younger dogs showing lower values than older dogs, emphasizing the importance of age-specific thresholds to improve the accuracy of renal assessment in dogs.

1. Introduction

Renal diseases, are characterized by a decline in kidney function and are associated with high morbidity and mortality due to the challenges involved in managing disease progression (Geetika et al., 2024; Rimer et al., 2022). Early diagnosis and appropriate follow-up are therefore essential for preventing renal failure and improving quality of life (Bartges, 2012).

Ultrasound imaging is a key step in kidney evaluation, as it provides information on their location, size, shape, and architecture. It is also a non-invasive, rapid, inexpensive and repeatable diagnostic tool (Novellas et al., 2010). Doppler ultrasound complements this by assessing renal perfusion (Novellas et al., 2010) and detecting changes in tissue perfusion in critically ill patients (Deruddre et al., 2007). The Doppler assessment is based on calculating of the renal resistance index (RRI) and the renal pulsatility index (RPI), both of which reflect the resistance in the renal microvascular bed to the arterial flow (Boddi et al., 2015).

Abbreviations: RPI, renal pulsatility index; RRI, renal resistive index.

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This method detects reductions in renal arterial flow, which are strongly associated with pathophysiological changes in the kidney (Baltazar et al., 2016; Novellas et al., 2008; Platt, 1989). RRI and RPI have been used in human medicine to diagnose acute kidney injury at an early stage (Bellos et al., 2019; Le Dorze et al., 2012; Marty et al., 2015; Song et al., 2018; Wybraniec et al., 2017) as well as to diagnose and monitor chronic kidney disease (Di Nicolò & Granata, 2019; Radermacher et al., 2002). In humans, both RRI and RPI vary with age (Boddi et al., 2015; Kawai et al., 2011; Lin & Cher, 1997; Mostbeck et al., 1991; Pontremoli, 1999; Siğirci et al., 2006), with higher values observed in children under one year of age and in geriatric patients. Thus, these levels vary throughout the lifespan (Terry et al., 1992). These indices are also influenced by extrarenal factors, including heart rate and blood pressure (Boddi et al., 2016).

Although normal RRI and RPI values in healthy dogs have been described, their clinical utility remains unclear because of the small sample sizes of previous studies, which failed to consider variables such as age, weight, arterial blood pressure, or heart rate (Ostrowska et al., 2016). To the authors' knowledge, no study has evaluated in depth whether these indices vary with the age of dogs. Only puppies in the first 12 weeks of life have been found to have a higher RRI (Agut et al., 2020; Chang et al., 2010). For this reason, it is essential to determine normal values in dogs using larger and more representative samples of animals (Evangelista et al., 2022).

The main objective of this research was therefore to establish age-specific reference values for RRI and RPI. The secondary objectives were to evaluate whether there is a relationship between these indices and heart rate, arterial blood pressure, body weight, body temperature, sex, reproductive status, hematocrit, serum urea, and serum creatinine. Finally, the third objective was to establish whether there are significant differences in RRI and RPI between the left and right kidney, and to assess the repeatability and success rate of these ultrasound techniques.

2. Material And Methods

2.1. Animals

The dogs included in the study were healthy animals who attended a Veterinary Clinical Teaching Hospital for elective surgeries or geriatric health controls. These dogs underwent renal Doppler ultrasound examinations on a voluntary basis. To include the dogs in the study, their caregivers signed an informed consent form agreeing to the ultrasound examination and the use of the data. All procedures were approved by the Animal Experimentation Ethics Committee of the Veterinary Clinical Teaching Hospital (09/2024).

To be considered healthy, the dogs must have a normal physical examination (including normal blood pressure), a normal blood test performed within one month prior to the ultrasound examination (including complete blood count, total solids, glucose, urea, creatinine, and alanine aminotransferase), and show no evidence of systemic disease. Complete blood counts were processed using an ADVIA 120® hematology analyzer (Siemens Healthineers, Munich, Germany), and biochemical analyses were performed with a Catalyst One® dry chemistry analyzer (IDEXX Laboratories Inc., Westbrook, Maine, USA).

The dogs were divided into groups according to a life stage classification system established by Harvey (2021): Juvenile (6–12 months), young adult (1–2 years), adult (3–6 years), senior (7–10 years), and geriatric (11 years and over).

2.2. Blood pressure monitoring

Arterial blood pressure (systolic, diastolic and mean) was measured before the start of the ultrasound examination according to the ACVIM guidelines (Acierno et al., 2018), using the Braun SunTech® Vet20TM oscillometric device (B. Braun Vetcare S.A.). Patients with a systolic blood pressure greater than 140 mmHg were excluded.

2.3. Ultrasonography. RRI and RPI measurements

Ultrasound measurements were performed using a Toshiba Xario 200 ultrasound machine, using triplex Doppler with a Toshiba Aplio 300 PVU−712BT 11mc4 microconvex probe. All measurements were performed by the same operator in awake dogs. The principal investigator (JOG) received 90 h of specific training in ultrasound image acquisition from the diagnostic imaging team of the institution.

Examinations were performed in a quiet room in the hospitalization area after a 5-minute acclimatization period. After this period, the animal was placed in the right lateral decubitus position, the projection area of the left kidney was shaved, and ultrasound gel was applied.

First, the left kidney was localized using two-dimensional ultrasound at a frequency of 6–10 MHz, with the settings (gain, depth and focus) adjusted to obtain the best possible image quality of the kidney. Next, the renal arterial tree was visualized using Doppler power ultrasound (with the lowest speed scale that allows correct visualization without motion artifacts) and the interlobar and arcuate arteries were localized (Fig. 1). A pulsed Doppler measurement was then completed on one of these arteries (Fig. 2). The gate size used ranged from 1 mm to 2.5 mm and a 4.2–5 MHz. frequency was used.

The RRI measures the arterial resistance in the peripheral renal vessels by calculating the ratio of the difference between peak systolic velocity (PSV) and end diastolic velocity (EDV) to the PSV (RRI = (PSV – EDV) / PSV). Similarly, the RPI uses the ratio of the difference between PSV and EDV to time-average velocity (TAV) (RPI = (PSV – EDV) / TAV).

Sampling for the RRI and RPI was taken at the level of the arcuate or interlobar arteries, as resistance to blood flow increases progressively from the hilar arteries towards the peripheral parenchymal vessels (Andrikou et al., 2018).

Adjustment of the insonation angle was not required for the calculation of these indices. Doppler-derived velocities are proportional to the cosine of the insonation angle (Anjou & Pennick, 2025); therefore, peak systolic velocity and end-diastolic velocity are affected by the same multiplicative factor. When these parameters are used to calculate RRI and RPI, this factor cancels out between the numerator and denominator, making the indices independent of the Doppler angle. This is justified because both indices reflect the relative relationship between systolic and diastolic flow rather than absolute velocity measurements, meaning exact velocity quantification is not required (Di Nicolò & Granata, 2019).

For a pulsed Doppler curve to be considered valid, it must contain three waves of comparable speed and shape. Using the aforementioned

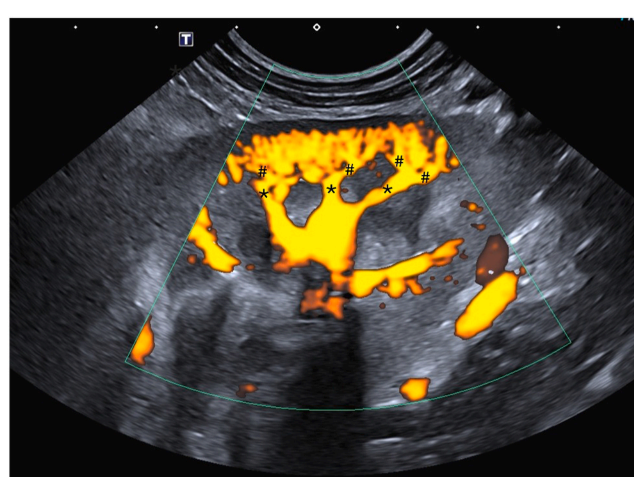

Fig. 1. Power Doppler visualization of the renal vasculature. * *Indicates interlobar arteries; # indicates arcuate arteries.*

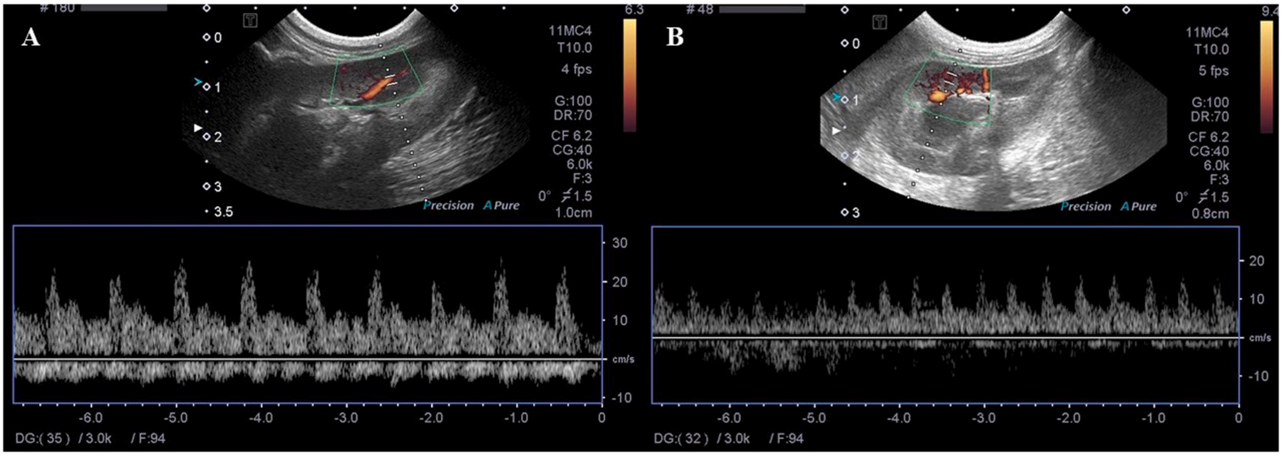

Fig. 2. Renal power Doppler visualization and the corresponding pulsed Doppler graph obtained from an interlobar artery (A) and an arcuate artery (B).

calculations, the ultrasound machine automatically determined the RRI and RPI in these graphs.

All dogs underwent measurements following the same standardized protocol. Whenever possible (depending on behavior and the acoustic window), indices were obtained from three different arteries, all of them interlobar or arcuate, to compare the results between measurements from a single artery with the average of three different ones. Finally, the dog was placed in the left lateral decubitus position, and the right kidney underwent the same procedure.

The repeatability of the RRI and RPI was evaluated by performing two measurements 15 min apart on the same dog in a total of 15 dogs.

2.4. Statistical methods

A power analysis for comparison between age groups indicated that a minimum of 17 dogs per group was required to calculate the reference values for the indices, with a statistical power of 85% and a confidence level of 99% ($\alpha = 0.01$). This analysis was performed using previous data extracted from the first 30 animals measured, which had a mean RRI of 0.6 ± 0.068. Similarly, a power analysis revealed that a minimum of 15 dogs were needed to calculate repeatability using the Pearson's correlation coefficient, with 85% power and an α of 0.05.

The normality of the variables' distribution was evaluated using the Shapiro-Wilk test. All variables followed a normal distribution except for body weight. For normally distributed variables, Pearson's correlation coefficient was used, while Spearman's correlation was applied for non-normally distributed variables. Additionally, a multiple linear regression model was employed to assess the combined effect of age, sex, reproductive status, heart rate, systolic arterial pressure and diastolic arterial pressure on RRI and RPI. Model assumptions were assessed by examining residuals. Normality was evaluated using Q–Q plots and the Shapiro–Wilk test, homoscedasticity was assessed through residuals versus fitted values plots, and influential observations were identified using Cook's distance. No major deviations from these assumptions were observed.

Student's *t*-test was used to determine whether there were differences in the indices according to sex, reproductive status, age (dogs under 11 years and dogs over 11 years) and arteries (interlobar vs. arcuate arteries).

The reference values were determined by adding two standard deviations to the mean values, in accordance with the methodology reported in previous studies (Novellas et al., 2007).

Student's *t*-test, Pearson's correlation coefficient, and the intraclass correlation coefficient (ICC (1,1)) were used to assess the repeatability of the indices.

Statistical significance was set at $p < .05$, except for comparisons between age groups, where a more conservative threshold of $p < 0.01$ was applied. All statistical tests except for the ICC were performed using the SAS 9.4 package (SAS Institute). The ICC was performed using IBM SPSS Statistics 29. All statistical analyses were performed by a statistician from the university's research unit.

3. Result

3.1. Sample description

85 dogs were included in the study. The mean age was 5.55 years ($\pm$4.73), and the mean weight was 14.64 kg ($\pm$10.09). There were 47 females (55.30%) and 38 males (44.70%). 44 dogs (51.76%) were intact and 41 (48.24%) were neutered. The study group consisted of the following breeds: mixed breeds (n = 21), Labrador Retriever (n = 7), Jack Russell (n = 5), Golden Retriever, Maltese Bichon and Border Collie (n = 4 of each one), Poodle, German Shepherd, Schnauzer and Yorkshire Terrier (n = 3 of each one), Greyhound, Teckel, West Highland Terrier and Water Dog (n = 2 of each one), French Bichon, Boxer, Bull Terrier, Cairn Terrier, Cavalier King Charles Spaniel, Chihuahua, Cocker Spaniel, Fox Terrier, Mastiff, Pit Bull, Pomeranian, Andalusian Buzzard, Spanish Hound, Scottish Terrier, English Tetter, Belgian Shepherd Malinois, Shiba Inu, Breton Spaniel, Whippet, and Xoloitzcuintle (n = 1 of each one).

Junior dogs had a mean age of 0.7 years ($\pm$0.14) and weighed 12.05 kg on average ($\pm$8.75). Young adults averaged 1.47 years ($\pm$0.5) with a mean weight of 12.26 kg ($\pm$7.36). Adult dogs had an average age of 4.17 years ($\pm$1.15) and weighed 14.51 kg ($\pm$8.72). Seniors showed a mean age of 8.35 years ($\pm$1.03) and an average weight of 16.13 kg ($\pm$9.81). The geriatric group presented a mean age of 13.06 years ($\pm$1.30) and an average weight of 18.13 kg ($\pm$13.07).

The mean serum urea concentration was 36 mg/dL (6.8–58 mg/dL), and the mean serum creatinine concentration was 0.91 mg/dL (0.4–1.4 mg/dL). The mean hematocrit was 46% (35.3–54%). The mean heart rate was 98 bpm (72–180 bpm), and the mean temperature was 38.7 ºC (37.3–39.1 ºC). Blood pressure measurements showed a mean systolic pressure of 128 mmHg (118–140 mmHg), a mean diastolic pressure of 74 mmHg (55–98 mmHg), and a mean arterial pressure of 102 mmHg (77–123 mmHg).

3.2. Age effect, measurements results and reference values

The results of the RRI and RPI measurements for the entire sample, as well as by age groups, are shown in Table 1. The proposed upper reference values for this population are also shown in Table 1.

The RRI remains comparatively constant until approximately 11

Table 1
Results of the RRI and RPI measurements. Abbreviations: SD, standard deviation; 95% CI, 95% confidence intervals; URV, upper reference value (calculated with two SD added to the mean).

Age	RRI				RPI			
	Mean	SD	95% CI	URV	Mean	SD	95% CI	URV
Juniors	0.599	0.052	0.572–0.625	0.703	1.081	0.211	0.973–1.189	1.503
Young adults	0.583	0.066	0.549–0.617	0.715	1.023	0.255	0.892–1.154	1.533
Adults	0.606	0.053	0.579–0.634	0.712	1.109	0.188	1.012–1.206	1.485
Seniors	0.615	0.048	0.590–0.640	0.711	1.201	0.161	1.119–1.284	1.523
Geriatrics	0.663	0.064	0.630–0.695	0.791	1.305	0.263	1.170–1.440	1.831
Total sample	0.613	0.062	0.600–0.627	0.737	1.144	0.236	1.093–1.195	1.616

years of age, after which a marked and statistically significant increase is observed. In parallel, the RPI demonstrates a more progressive upward trend, with dogs aged 11 years or older exhibiting substantially higher values.

A moderate, significant positive correlation was observed between age and both RRI ($\rho = .41$, $p < .001$) and RPI ($\rho = .40$, $p < .001$), as can be seen in Fig. 3. Furthermore, significant differences were found between geriatric dogs (11 years or older) and younger dogs for both RRI ($p = .0004$) and RPI ($p = .0007$).

3.3. Effect of other factors on the indices

Significant differences were found between neutered and unneutered dogs for both RRI ($p = .0015$) and RPI ($p = .014$). Similarly, a significant difference was observed in RPI between males and females ($p = .045$), but not in the RRI ($p = .063$).

No correlation was found between the indices and body weight, hematocrit, serum urea, serum creatinine, body temperature, heart rate and systolic, diastolic, and mean arterial blood pressure.

When the combined effects of age, sex, body weight, reproductive status, heart rate, systolic blood pressure, and diastolic blood pressure on RRI and RPI were evaluated, significant differences in the indices were observed only for sex in addition to age. Females exhibited a mean RRI 0.03 units higher than that of males ($p = 0.028$) and a mean RPI 0.012 units higher ($p = 0.017$).

3.4. Repeatability and effect of the technique

The two subsequent assessments of RRI ($\rho = .88$, $p < .001$) and RPI ($\rho = .77$, $p = .001$) showed a strong positive association. These measures also had a good ICC for RRI (ICC $= .875$, $p < .001$) and RPI (ICC $= .77$, $p < .001$).

No significant differences were found between the left and right kidneys for RRI ($p = .252$) or RPI ($p = .753$). In addition, there was a strong positive correlation ($\rho = .77$, $p < .001$) between both kidneys for RRI. Similarly, there was a moderate positive correlation ($\rho = .49$, $p = .002$) between the two kidneys for RPI. No discernible difference was observed between the mean of the measurements from 3 different arteries in the same kidney and a single measurement ($p = .959$). Additionally, there was a strong positive correlation between the first measurement and the mean of the 3 measurements ($\rho = .91$, $p < .001$), with an excellent ICC (ICC $= .99$, $p < .001$). No difference was demonstrated between the indices measured in the arcuate and the interlobar arteries ($p = .82$). Finally, a strong positive correlation between RRI and RPI was found ($\rho = .85$, $p < .001$).

3.5. Success rate of the technique

The technique could not be performed successfully on all dogs in which it was attempted, with 105 ultrasound examinations conducted on different dogs to achieve a total amount of 85 dogs. The success rate of the technique was 80.95%.

The duration of the Doppler ultrasound examination ranged from 5 to 25 min, with a mean of 10.9 min.

4. Discussion

The main goal of our study was to determine upper reference values for RRI and RPI according to life stage. Based on our findings, the difference between age and both indices becomes more pronounced after the age of 11, with a significant difference between dogs aged 11 years or older and those younger than 11 years. This highlights the importance of using different reference values depending on age.

A similar pattern has been observed in human medicine, where values steady increase, with a significant difference between people under and over 50 years old (Boddi et al., 2016). This could be explained by the fact that the ageing effect on the kidneys is insufficient to cause a significant change in the indices until a certain age is reached.

To the authors' knowledge, this is the first study to provide data on RRI and RPI across all life stages of dogs. The fact that the variation of

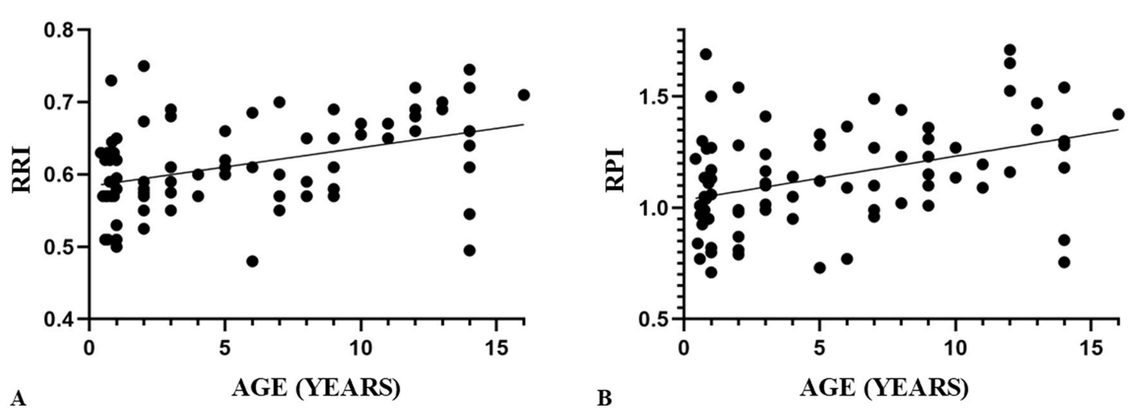

Fig. 3. Scatter plots showing the relationship between age and RRI (A) and RPI (B). Each point represents an individual dog. Solid lines indicate the fitted linear trend. The graphs were generated using GraphPad Prism version 10.5. Abbreviations: RRI, renal resistive index; RPI, renal pulsatility index.

these indices with age has not been studied is relevant because, in human medicine, the RRI has been shown to positively correlate with age. In humans, RRI is increased in individuals younger than one year old and in geriatric patients, with levels varying throughout life (Boddi et al., 2016; Kawai et al., 2011; Mostbeck et al., 1991; Pontremoli, 1999). The lower indices in younger animals may be due to their smaller renal volume, reduced vessel diameters, and the low diastolic flow. This reduced flow is associated with a lower glomerular filtration rate, which is caused by the large number of immature glomeruli present in neonates (Siğirci et al., 2006).

Most of the studies performed in veterinary medicine have not found a correlation between the indices and age (Matos et al., 2018; Morrow et al., 1996; Novellas et al., 2007; Pollard et al., 1999; Rivers et al., 1997). This is probably attributed to the small population sizes in these studies and the fact that in many of these studies, the ages of the individuals were very similar. In contrast, the study with the largest population size of dogs (n = 44) found a correlation between the indices and age (Ostrowska et al., 2016). However, this study did not examine how these indices fluctuate throughout the life stages of dogs and did not establish references values by age.

In human medicine, an increase in these indices in geriatric patients has been shown to reduce the test`s specificity, complicating its use in these patients (Kelahan et al., 2019). Therefore, a specific upper reference value should be established for this group of patients, as healthy geriatric patients may present values above the general threshold (Doi et al., 2012; Tublin et al., 2003).

The mean RRI in our study was 0.613. This result is consistent with previous reports on dogs, which documented mean values of 0.64 (Dodd et al., 1991; Ostrowska et al., 2016) and 0.62 (Novellas et al., 2007). The mean RPI in our study was 1.144, which closely aligns with the only previously reported mean of 1.15 (Novellas et al., 2007). This consistency suggests that RRI and RPI measurements are relatively stable across different populations and methodologies, thereby reinforcing their potential clinical utility.

The fact that hemodynamic values change with age highlights the need for age-specific reference values. However, it would only be necessary to establish specific reference values for dogs older than 11 years, as values do not change sufficiently until the age of 11. Therefore, all dogs between 4 months and 10 years of age would have the same reference value. Additionally, only the upper limit is used in clinical practice.

The upper reference values suggested in this study for dogs between 4 months and 10 years of age are 0.71 for RRI and 1.51 for RPI. The previously described reference values in dogs are 1.52 for RPI (Novellas et al., 2007) and range from 0.7 to 0.73 for RRI (Novellas et al., 2007; Platt, 1989; Rivers et al., 1997), which are highly consistent with our proposed values. Moreover, these values closely resemble those established in humans, where the upper reference values are 0.7 for RRI and 1.5 for RPI (Gottlieb et al., 1989; Kim et al., 1992; Platt, 1989).

In contrast, the proposed upper reference values for dogs aged 11 years and older are 0.79 and 1.83 for RRI and RPI respectively. The difference in these indices between dogs younger and older than 11 years is significant. This increase may be attributable to physiological changes secondary to reduced vascular compliance and age-related alterations in renal architecture (Boddi et al., 2016), as well as a greater prevalence of atherosclerosis in older individuals (Mostbeck et al., 1991). Therefore, applying the standard reference values to geriatric patients could lead to an overdiagnosis of renal disease in this age group.

The second objective of our study was to assess the potential relationship between these indices and heart rate, arterial blood pressure, body weight, body temperature, sex, reproductive status, hematocrit, serum urea, and serum creatinine.

Although arterial pressure and heart rate have been documented to influence RRI and RPI in humans (Boddi et al., 2016; Cauwenberghs & Kuznetsova, 2015), no correlation was found between these variables and the indices in this study. This finding is consistent with previous studies in veterinary medicine (Novellas et al., 2007, 2008). The primary reason for not detecting an association may be the study's inclusion criteria, which required a normal physical examination (including normal blood pressure) and an absence of systemic diseases such as arterial hypertension or hypotension. As a result, the dogs included in the study may not have exhibited blood pressure or heart rate values extreme enough to influence the indices. Similarly, body temperature did not affect the indices, and no significant correlation was found between either index, or body weight.

Neither the correlation analysis between the indices and body weight, nor the multiple regression model, demonstrated any influence of body weight on RRI or RPI. These findings indicate that the values of these indices are not affected by dog size, with comparable levels observed across dogs of different body weights. This result is relevant for interpreting Doppler measurements, as it supports using RRI and RPI without the need for weight-based adjustment. Moreover, this observation is consistent with previously published data on the canine species (Ostrowska et al., 2016). A significant difference was observed between neutered and unneutered dogs. However, when evaluated alongside the other variables, no significant effect was identified, which may be attributable to an interaction with age. The average age of the neutered dogs (7.34 years) was higher than the average age of the unneutered dogs (3.88 years), and as previously noted, RRI and RPI values show an age-related increase.

In contrast, a significant difference was found between males and females. Previous studies conducted in human, canine, feline, and equine medicine have generally not reported significant sex-related differences in RRI values. The only exception is a human study by Ponte et al. (2014), which found that women had an RRI value 0.20 units higher than men, a difference similar to that observed in the present study. It is noteworthy that this study had the largest sample size among those investigating this variable, which may have enabled the detection of a difference that remained unnoticed in studies with lower statistical power. It has been reported that women have smaller kidneys and a finer vascular network, which is more susceptible to variations in vascular tone. Such anatomical and physiological characteristics could increase renal blood flow resistance, thereby explaining the higher values observed for these indices (Harvey & Alvarez de la Rosa, 2025). The observed difference is minor and, although it should be considered when interpreting the results, further studies are warranted to investigate this finding.

No correlation was found between the indices and hematocrit, serum urea or serum creatinine. These were analyzed as indicators of renal function and systemic status; notably, hematocrit is related to blood viscosity and may influence renal hemodynamics. This may be attributed to the fact that all dogs included in the study were healthy with normal blood test results.

The third objective of the study was to establish whether there are significant differences in RRI and RPI between the left and right kidney, as well as to assess repeatability and success rate of these ultrasound techniques.

As described in other veterinary studies (Agut et al., 2020; Chang et al., 2010; Novellas et al., 2007, 2010; Ostrowska et al., 2016), no statistically significant differences were found between the left and right kidneys. However, it is important to note that the strength of the correlation was moderate and that interclass correlation was sufficient. This underscores the need to examine both kidneys in all dogs.

In human medicine, it is recommended to take a measure of the cranial, middle and caudal thirds of the kidney (Andrikou et al., 2018; Di Nicolò & Granata, 2019), but in veterinary medicine it is more difficult to obtain a measurement of the 3 thirds of the kidney. This difficulty may be attributed to the fact that the technique is easier to perform in humans due to patient cooperation and their ability to control respiratory rate during ultrasound. The results of this study suggest that, in healthy dogs, there is no difference between a single measurement and the average of 3 different regions. This suggests that a single measurement may be sufficient. Nevertheless, this should be re-evaluated in dogs with renal pathology, as the kidneys may become damaged in a non-uniform manner.

RRI and RPI should be determined in the arcuate or interlobar arteries because the resistance to blood flow through the renal arterial tree increases as the arteries become more peripheral (Viazzi et al., 2014). The lack of a difference between the interlobar and arcuate arteries for RRI and RPI indicates that these indices can be measured indistinguishably in both arteries, which is consistent with what has been observed previously (Keogan et al., 1996).

The strong positive correlation between RRI and RPI suggests that individuals with higher levels of one index are also likely to have higher levels of the other. This is because both indices measure the same physiological phenomenon: the resistance of blood vessels to blood flow. While this relationship is also likely applicable to patients with kidney disease, further research is needed to confirm this hypothesis.

The Doppler estimation of RRI and RPI can be influenced by different technical and physiological factors, such as the depth of the kidneys and the quality of the sonographic window (Freccero et al., 2020).

The absence of differences between two Doppler measurements in the same dog, separated by 15 min, indicates good repeatability of the RRI and RPI. Therefore, the results are expected to be consistent each time an operator measures the indices in the same individual. This result has already been previously reported in humans (Le Dorze et al., 2012; Lerolle et al., 2006; Schnell et al., 2012, 2014), cats (Matos et al., 2018) and horses (Siwinska et al., 2021), but not in dogs. To the authors` knowledge, this is the first study to describe the repeatability of the RRI and RPI in dogs. However, it should be noted that low repeatability has also been reported in human medicine (Theertha et al., 2023; Wybraniec et al., 2017).

The test`s success rate was 80.95%, which can be attributed to the fact that this technique is highly patient-dependent. To the authors' knowledge, no study has previously reported the success rate of this test. The arteries in which the indices are measured are very small (usually less than 3 mm), so any movement of the kidney makes their measurement challenging. For this reason, this technique is particularly difficult to accomplish if the dog is moving, howling, panting or breathing rapidly.

The duration of the Doppler ultrasound (with an average duration of 10.9 min) is very similar to the duration of the measurement times reported for healthy humans (10 min) and healthy cats (12–15 min) (Cruz et al., 2022; Matos et al., 2018; Rivers et al., 1997). On the other hand, it has also been reported that Doppler measurements in healthy humans can last up to 30 min (Keogan et al., 1996), which was the maximum measurement duration in our study.

The primary limitation of this study is that it was conducted in a single facility by a single operator. A multicentre study would be necessary to determine whether our results can be generalized to other hospitals.

On the other hand, reference values for renal resistive and pulsatility indices were derived only from non-azotaemic healthy dogs and should not be interpreted as diagnostic cut-off points. Their clinical application requires careful consideration of the individual patient. In the absence of values from diseased populations, these upper reference limits may still provide useful guidance, particularly in geriatric dogs. Further studies including dogs with renal disease are needed to establish disease-specific thresholds and clarify the diagnostic and prognostic value of RRI and RPI.

Additionally, further studies involving animals of similar body size and body weight, but different ages may be warranted, as these variables could potentially influence the hemodynamic indices.

5. Conclusions

Renal resistive and pulsatility indices vary with age, emphasizing the importance of using age-specific upper reference values. For dogs under 11 years of age, reference values of 0.71 for RRI and 1.51 for RPI would be optimal. In contrast, for dogs aged 11 years and older, reference values of 0.79 for RRI and 1.83 for RPI would be more favorable.

Sex may represent a potentially relevant factor influencing RRI and RPI and should be considered when interpreting the results.

On the other hand, RRI and RPI are not significantly influenced by heart rate, blood pressure, body condition, body temperature, reproductive status, or hematocrit.

RRI and RPI measurement is a repeatable technique.

In dogs that are difficult to handle and where measurement of the indices is difficult, a single valid Doppler measurement of one vessel may be sufficient, as no differences were found between measuring one artery and measuring three different arteries.

Finally, it is essential to recognize that this technique is highly patient-dependent, with a success rate of 80.95% in this study.

Human Ethics Approval Declaration

Authors declared human ethics approval was not needed for this study.

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Jorge Ortiz-Gutiérrez: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **María Ángeles Daza:** Writing – review & editing, Validation, Supervision, Formal analysis, Data curation. **Hernán L. Fominaya:** Writing – review & editing, Supervision, Data curation. **Miriam Portero-Fuentes:** Writing – review & editing, Supervision, Formal analysis, Data curation.

Previous presentation or publication disclosure

This work has not been previously published in any other journal or congress.

Informed Consent

The author affirms that the owners of all dogs signed an informed consent form indicating their agreement to participate in the study.

Use Of Images

All images presented in this manuscript are owned by the corresponding author, and their use did not require additional permission.

Institutional Animal Care And Use Committee (Iacuc) Or Other Approval Declaration

Approved by the Animal Experimentation Ethics Committee of the Complutense Veterinary Clinical Teaching Hospital (09/2024).

Declaration of Generative AI and AI-assisted technologies in the writing process

The author affirms that no generative artificial intelligence (AI) tools were used in the writing or content generation of this work.

Declaration of Competing Interest

The authors have no relevant financial or non-financial interests to disclose.

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Data availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

References

Acierno, M.J., Brown, S., Coleman, A.E., Jepson, R.E., Papich, M., Stepien, R.L., Syme, H. M., 2018. ACVIM consensus statement: Guidelines for the identification, evaluation, and management of systemic hypertension in dogs and cats. Article 6. Journal of Veterinary Internal Medicine 32 (6). https://doi.org/10.1111/jvim.15331.

Agut, A., Soler, M., Fernández-del Palacio, M.J., 2020. Changes in Renal Resistive Index Values in Healthy Puppies during the First Months of Life. Article 8. Animals 10 (8). https://doi.org/10.3390/ani10081338.

Andrikou, I., Tsioufis, C., Konstantinidis, D., Kasiakogias, A., Dimitriadis, K., Leontsinis, I., Andrikou, E., Sanidas, E., Kallikazaros, I., Tousoulis, D., 2018. Renal resistive index in hypertensive patients. Article 12. The Journal of Clinical Hypertension 20 (12). https://doi.org/10.1111/jch.13410.

Anjou, M., Pennick, D., 2025. Practical physical concepts and artefacts. In: Pennick, En. D., Anjou, M. (Eds.), Atlas of small animal ultrasonography. Wiley, pp. 1–48.

Baltazar, P.I., Da Silva Moura, L., Pessoa, G.T., De Sá Rodrigues, R.P., Sanches, M.P., Das Neves Diniz, A., Das Chagas Araújo Sousa, F., Guerra, P.C., Neves, W.C., Giglio, R.F., De Jesus Rosa Pereira Alves, J., De Assis Leite Souza, F., Braga, J.F.V., Alves, F.R., 2016. Comparative B-mode and Doppler renal ultrasonography with histopathological findings in dogs positive for canine visceral leishmaniasis. Article 7. Microscopy Research and Technique 79 (7). https://doi.org/10.1002/jemt.22677.

Bartges, J.W., 2012. Chronic Kidney Disease in Dogs and Cats. Article 4. Veterinary Clinics of North America Small Animal Practice 42 (4). https://doi.org/10.1016/j.cvsm.2012.04.008.

Bellos, I., Pergialiotis, V., Kontzoglou, K., 2019. Renal resistive index as predictor of acute kidney injury after major surgery: A systematic review and meta-analysis. Journal of Critical Care 50, 36–43. https://doi.org/10.1016/j.jcrc.2018.11.001.

Boddi, M., Bonizzoli, M., Chiostri, M., Begliomini, D., Molinaro, A., Tadini Buoninsegni, L., Gensini, G.F., Peris, A., 2016. Renal Resistive Index and mortality in critical patients with acute kidney injury. Article 3. European Journal of Clinical Investigation 46 (3). https://doi.org/10.1111/eci.12590.

Boddi, M., Natucci, F., Ciani, E., 2015. The internist and the renal resistive index: Truths and doubts. Article 8. Internal and Emergency Medicine 10 (8). https://doi.org/10.1007/s11739-015-1289-2.

Cauwenberghs, N., Kuznetsova, T., 2015. Determinants and Prognostic Significance of the Renal Resistive Index. Article 3-4. Pulse 3 (3-4). https://doi.org/10.1159/000442445.

Chang, Y.J., Chan, I.P., Cheng, F.P., Wang, W.S., Liu, P.C., Lin, S.L., 2010. Relationship Between Age, Plasma Renin Activity, And Renal Resistive Index In Dogs: Age vs. Renal Resistive Index in Dogs. Article 3. Veterinary Radiology & Ultrasound 51 (3). https://doi.org/10.1111/j.1740-8261.2010.01669.x.

Cruz, E.G., Broca Garcia, B.E., Sandoval, D.M., Gopar-Nieto, R., Gonzalez Ruiz, F.J., Gallardo, L.D., Ronco, C., Madero, M., Vasquez Jimenez, E., 2022. Renal Resistive Index as a Predictor of Acute Kidney Injury and Mortality in COVID-19 Critically Ill Patients. Article 4. Blood Purification 51 (4). https://doi.org/10.1159/000517469.

Deruddre, S., Cheisson, G., Mazoit, J.-X., Vicaut, E., Benhamou, D., Duranteau, J., 2007. Renal arterial resistance in septic shock: Effects of increasing mean arterial pressure with norepinephrine on the renal resistive index assessed with Doppler ultrasonography. Article 9. Intensive Care Medicine 33 (9). https://doi.org/10.1007/s00134-007-0665-4.

Di Nicolò, P., Granata, A., 2019. Renal intraparenchymal resistive index: The ultrasonographic answer to many clinical questions. Article 4. Journal of Nephrology 32 (4). https://doi.org/10.1007/s40620-018-00567-x.

Dodd, G.D., Kaufman, P.N., Bracken, R.B., 1991. Renal Arterial Duplex Doppler Ultrasound in Dogs with Urinary Obstruction. Article 3. Journal of Urology 145 (3). https://doi.org/10.1016/s0022-5347(17)38412-4.

Doi, Y., Iwashima, Y., Yoshihara, F., Kamide, K., Takata, H., Fujii, T., Kubota, Y., Nakamura, S., Horio, T., Kawano, Y., 2012. Association of Renal Resistive Index With Target Organ Damage in Essential Hypertension. American Journal of Hypertension. https://doi.org/10.1038/ajh.2012.113.

Evangelista, G.C.L., Viana, A.G.D.A., Neves, M.M., Reis, E.C.C., 2022. Resistivity and pulsatility indexes in feline kidney disease: A systematic review. Article 3. Veterinary Radiology & Ultrasound 63 (3). https://doi.org/10.1111/vru.13102.

Freccero, F., Petrucelli, M., Cipone, M., Nocera, I., Sgorbini, M., 2020. Doppler evaluation of renal resistivity index in healthy conscious horses and donkeys. Article 2. PLOS ONE 15 (2). https://doi.org/10.1371/journal.pone.0228741.

Geetika, B., Saradhi, K.P., Prabavathy, A., Vijayalakshmi, P., 2024. Chronic kidney disease in dogs: a comprehensive review. International Journal of Advanced Biochemistry Research 8 (12S), 1099–1105. https://doi.org/10.33545/26174693.2024.v8.i12sn.3291.

Gottlieb, R.H., Luhmann, K., Oates, R.P., 1989. Duplex ultrasound evaluation of normal native kidneys and native kidneys with urinary tract obstruction. Article 11. Journal of Ultrasound in Medicine 8 (11). https://doi.org/10.7863/jum.1989.8.11.609.

Harvey, B.J., Alvarez de la Rosa, D., 2025. Sex Differences in Kidney Health and Disease. Nephron 149 (2), 77–103. https://doi.org/10.1159/000541352.

Harvey, N.D., 2021. How Old Is My Dog? Identification of Rational Age Groupings in Pet Dogs Based Upon Normative Age-Linked Processes. Frontiers in Veterinary Science 8. https://doi.org/10.3389/fvets.2021.643085.

Kawai, T., Kamide, K., Onishi, M., Yamamoto-Hanasaki, H., Baba, Y., Hongyo, K., Shimaoka, I., Tatara, Y., Takeya, Y., Ohishi, M., Rakugi, H., 2011. Usefulness of the resistive index in renal Doppler ultrasonography as an indicator of vascular damage in patients with risks of atherosclerosis. Article 10. Nephrology Dialysis Transplantation 26 (10). https://doi.org/10.1093/ndt/gfr054.

Kelahan, L.C., Desser, T.S., Troxell, M.L., Kamaya, A., 2019. Ultrasound Assessment of Acute Kidney Injury. Article 2. Ultrasound Quarterly 35 (2). https://doi.org/10.1097/ruq.0000000000000389.

Keogan, M.T., Kliewer, M.A., Hertzberg, B.S., DeLong, D.M., Tupler, R.H., Carroll, B.A., 1996. Renal resistive indexes: Variability in Doppler US measurement in a healthy population. Article 1. Radiology 199 (1). https://doi.org/10.1148/radiology.199.1.8633141.

Kim, S.H., Kim, W.H., Choi, B.I., Kim, C.W., 1992. Duplex Doppler US in patients with medical renal disease: Resistive index vs serum creatinine level. Article 2. Clinical Radiology 45 (2). https://doi.org/10.1016/s0009-9260(05)80060-1.

Le Dorze, M., Bouglé, A., Deruddre, S., Duranteau, J., 2012. Renal Doppler Ultrasound: A New Tool to Assess Renal Perfusion in Critical Illness. Article 4. Shock 37 (4). https://doi.org/10.1097/shk.0b013e3182467156.

Lerolle, N., Guérot, E., Faisy, C., Bornstain, C., Diehl, J.-L., Fagon, J.-Y., 2006. Renal failure in septic shock: Predictive value of Doppler-based renal arterial resistive index. Article 10. Intensive Care Medicine 32 (10). https://doi.org/10.1007/s00134-006-0360-x.

Lin, G.J., Cher, T.W., 1997. Renal vascular resistance in normal children—A color Doppler study. Pediatric Nephrology (Berlin Germany) 11 (2), 182–185. https://doi.org/10.1007/s004670050255.

Marty, P., Szatjnic, S., Ferre, F., Conil, J.-M., Mayeur, N., Fourcade, O., Silva, S., Minville, V., 2015. Doppler renal resistive index for early detection of acute kidney injury after major orthopaedic surgery: A prospective observational study. Article 1. European Journal of Anaesthesiology 32 (1). https://doi.org/10.1097/eja.0000000000000120.

Matos, I., Azevedo, P., Carreira, L.M., 2018. Pilot study to evaluate the potential use of the renal resistive index as a preliminary diagnostic tool for chronic kidney disease in cats. Article 10. Journal of Feline Medicine and Surgery 20 (10). https://doi.org/10.1177/1098612x17736656.

Morrow, K.L., Salman, M.D., Lappin, M.R., Wrigley, R., 1996. Comparison Of The Resistive Index To Clinical Parameters In Dogs With Renal Disease. Article 3. Veterinary Radiology & Ultrasound 37 (3). https://doi.org/10.1111/j.1740-8261.1996.tb01220.x.

Mostbeck, G.H., Kain, R., Mallek, R., Derfler, K., Walter, R., Havelec, L., Tscholakoff, D., 1991. Duplex Doppler sonography in renal parenchymal disease. Histopathologic correlation. Article 4. Journal of Ultrasound in Medicine 10 (4). https://doi.org/10.7863/jum.1991.10.4.189.

Novellas, R., Espada, Y., Ruiz de Gopegui, R., 2007. Doppler ultrasonographic estimation of renal and ocular resistive and pulsatility indices in normal dogs and cats. Veterinary Radiology & Ultrasound The Official Journal of the American College of Veterinary Radiology and the International Veterinary Radiology Association 48 (1), 69–73. https://doi.org/10.1111/j.1740-8261.2007.00206.x.

Novellas, R., Ruiz De Gopegui, R., Espada, Y., 2008. Determination of renal vascular resistance in dogs with diabetes mellitus and hyperadrenocorticism. Article 20. Veterinary Record 163 (20). https://doi.org/10.1136/vr.163.20.592.

Novellas, R., Ruiz De Gopegui, R., Espada, Y., 2010. Assessment of renal vascular resistance and blood pressure in dogs and cats with renal disease. Article 20. Veterinary Record 166 (20). https://doi.org/10.1136/vr.b4820.

Ostrowska, J., Kiełbowicz, Z., Zaleska-Dorobisz, U., Atamaniuk, W., Pietsch-Fulbiszewska, A., & Kinda, W. (2016). Resistive Index (RI) Obtained in Renal Interlobar Arteries of Normal Dogs and Cats by Means of Doppler Ultrasonography. *Pak Vet J*.

Platt, J.F., 1989. Duplex Doppler evaluation of native Kidney dysfunction Obstructive and nonobstructive Disease 171 (2), 515–517.

Pollard, R., Nyland, T.G., Bernsteen, L., Gregory, C.R., Hornof, W.J., 1999. Ultrasonographic evaluation of renal autografts in normal cats. Article 4. Veterinary Radiology & Ultrasound 40 (4). https://doi.org/10.1111/j.1740-8261.1999.tb02130.x.

Ponte, B., Pruijm, M., Ackermann, D., Vuistiner, P., Eisenberger, U., Guessous, I., Rousson, V., Mohaupt, M.G., Alwan, H., Ehret, G., Pechere-Bertschi, A., Paccaud, F., Staessen, J.A., Vogt, B., Burnier, M., Martin, P.-Y., Bochud, M., 2014. Reference values and factors associated with renal resistive index in a family-based population study. Hypertension (Dallas Tex 1979) 63 (1), 136–142. https://doi.org/10.1161/113.02321.

Pontremoli, R., 1999. Increased renal resistive index in patients with essential hypertension: A marker of target organ damage. Article 2. Nephrology Dialysis Transplantation 14 (2). https://doi.org/10.1093/ndt/14.2.360.

Radermacher, J., Ellis, S., Haller, H., 2002. Renal Resistance Index and Progression of Renal Disease. Article 2. Hypertension 39 (2). https://doi.org/10.1161/hy0202.103782.

Rimer, D., Chen, H., Bar-Nathan, M., Segev, G., 2022. Acute kidney injury in dogs: Etiology, clinical and clinicopathologic findings, prognostic markers, and outcome. Article 2. Journal of Veterinary Internal Medicine 36 (2). https://doi.org/10.1111/jvim.16375.

Rivers, B.J., Walter, P.A., Polzin, D.J., King, V.L., 1997. Duplex Doppler Estimation of Intrarenal Pourcelot Resistive Index in Dogs and Cats With Renal Disease. Article 4. Journal of Veterinary Internal Medicine 11 (4). https://doi.org/10.1111/j.1939-1676.1997.tb00099.x.

Schnell, D., Deruddre, S., Harrois, A., Pottecher, J., Cosson, C., Adoui, N., Benhamou, D., Vicaut, E., Azoulay, E., Duranteau, J., 2012. Renal Resistive Index Better Predicts the Occurrence of Acute Kidney Injury Than Cystatin C. Article 6. Shock 38 (6). https://doi.org/10.1097/shk.0b013e318271a39c.

Schnell, D., Reynaud, M., Venot, M., Baulieu, M., Ducos, G., Terreaux, J., Zeni, F., Azoulay, E., Meziani, F., Duranteau, J., & Darmon, M. (2014). *Resistive Index or color-Doppler semi-quantitative evaluation of renal perfusion by inexperienced physicians: Results of a pilot study*.

Siğirci, A., Hallaç, T., Akýncý, A., Temel, İ., Gülcan, H., Aslan, M., Koçer, M., Kahraman, B., Alkan, A., Kutlu, R., 2006. Renal Interlobar Artery Parameters with Duplex Doppler Sonography and Correlations with Age, Plasma Renin, and Aldosterone Levels in Healthy Children. American Journal of Roentgenology 186(3) Article 3. https://doi.org/10.2214/ajr.04.1445.

Siwinska, N., Zak, A., Slowikowska, M., Paslawska, U., 2021. Renal Resistive Index as A Potential Indicator of Acute Kidney Injury in Horses. Journal of Equine Veterinary Science 103, 103662. https://doi.org/10.1016/j.jevs.2021.103662.

Song, J., Wu, W., He, Y., Lin, S., Zhu, D., Zhong, M., 2018. Value of the combination of renal resistance index and central venous pressure in the early prediction of sepsis-induced acute kidney injury. Journal of Critical Care 45, 204–208. https://doi.org/10.1016/j.jcrc.2018.03.016.

Terry, J.D., Rysavy, J.A., Frick, M.P., 1992. Intrarenal Doppler: Characteristics of aging kidneys. Journal of Ultrasound in Medicine Official Journal of the American Institute of Ultrasound in Medicine 11 (12), 647–651. https://doi.org/10.7863/jum.1992.11.12.647.

Theertha, K.C., Das, S.K., Shetty, M.S., 2023. Renal Resistive Index: Revisited. Cureus 15 (3). https://doi.org/10.7759/cureus.36091.

Tublin, M.E., Bude, R.O., Platt, J.F., 2003. The Resistive Index in Renal Doppler Sonography: Where Do We Stand? Article 4. American Journal of Roentgenology 180 (4). https://doi.org/10.2214/ajr.180.4.1800885.

Viazzi, F., Leoncini, G., Derchi, L.E., Pontremoli, R., 2014. Ultrasound Doppler renal resistive index: A useful tool for the management of the hypertensive patient. Article 1. Journal of Hypertension 32 (1). https://doi.org/10.1097/hjh.0b013e328365b29c.

Wybraniec, M.T., Bożentowicz-Wikarek, M., Chudek, J., Mizia-Stec, K., 2017. Pre-procedural renal resistive index accurately predicts contrast-induced acute kidney injury in patients with preserved renal function submitted to coronary angiography. Article 5. The International Journal of Cardiovascular Imaging 33 (5). https://doi.org/10.1007/s10554-016-1039-1.