REVIEW ARTICLE

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# SONOGRAPHIC DIAGNOSTIC CRITERIA IN THE EVALUATION OF SUSPECTED RENAL ARTERY STENOSIS

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## ABSTRACT

*INTRODUCTION: With the increase in life expectancy and the incidence of atheromatous disease, diabetes and hypertension in the population, the diagnosis for the adequate management of renal stenosis tends to become increasingly important. This trend is evidenced by the increase in the number of patients on dialysis.*

*METHODS: In this review, comparative studies were collected on diagnostic criteria for Doppler ultrasound of renal artery stenosis published in the following databases: MEDLINE, LILACS and SciELO, according to criteria of impact, citation and visualization between the years 1973 and 2021.*

*RESULTS: We selected 30 articles. We separated by diagnostic criteria for renal stenosis according to indirect and direct criteria, additional criteria and combination of criteria for their respective analyses.*

*DISCUSSION: The criteria with better accuracy and greater support in works are the peak systolic velocity of the stenosis; the renal-aortic relationship and the combination of these two criteria.*

*CONCLUSION: Although there is no consensus regarding the best way to diagnose renal artery stenosis on Doppler, it is evident that there is still room for its use as a population screening as well as for improving its accuracy.*

*KEYWORDS: STENOSIS, RENAL ARTERY, DOPPLER, ULTRASOUND, DIAGNOSIS*

## INTRODUCTION

Renal artery stenosis (RAS) refers to the narrowing or partial obstruction of flow in the renal arterial bed. Its etiology can be fibromuscular dysplasia, arteritis of large and medium vessels (such as Takayasu's arteritis), trauma, dissection. However, the most common cause is atherosclerosis, responsible for 90% of cases.

As a cause of secondary arterial hypertension, RAS is considered the most common, reaching 5% of the total cases of hypertension, as in the English study by Connolly. [1]

The work of Dean and Foster suggested that the natural evolution of renovascular disease was a decrease in renal mass and glomerular filtration. Its natural history, therefore, evolves to renal failure.[2]

The term ischemic nephropathy was introduced by Jacobson and Breyer in 1993. It can be defined as a decrease in glomerular filtration rate (GFR) due to hemodynamically significant renovascular disease.

Other names for this entity include ischemic chronic kidney disease, azotemic renovascular disease, or renal failure from renovascular hypertension.

Proper diagnosis in suspected cases provides proper treatment and reduces hospitalizations and treatments for associated morbidities. Therefore, its identification and adequate treatment allow a reduction in costs and hospitalizations. Another challenge is found in the group of patients where the stenosis is asymptomatic until the appearance of its complications. The fact that it is a correctable form of renal ischemic disease makes it the object of some therapeutic studies.

The Brazilian Society of Nephrology has collected annually for more than 20 years the important Brazilian Census of dialysis. These data show that in 1994, 24,000 patients were maintained on a dialysis programme. In 2006 this number surpassed 70,000 patients, 89% of them treated by the Unified Health System. In 2019 this number reached 139,691. [3-5]

As for the profile of patients in the last census, 58% were male in the age group of 45 to 64 years, with 36% of patients over 65 years. In the underlying disease, hypertensive nephrosclerosis is the main cause with 34% of patients, followed by diabetic nephropathy with 32%.

Works such as those by Conlon proposed a prevalence of 11 to 23% of RAS in patients with documented coronary artery disease (CAD). Plouin et al in 2001 found a prevalence of 16% in suspected patients for patients evaluated for CAD through coronary angiography in a study conducted in France. Imori et al, in 2014, in a study carried out in Japan, showed the statistical relationship between CAD, RAS, carotid stenosis and peripheral artery disease, recording a 7% prevalence of RAS in patients suspected of having CAD. This prevalence rose to 9%

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in patients with confirmed CAD. [6-8]

In 2005, Kalra et al conducted a population sample of 1 million people in the United States. The prevalence of renovascular disease was 0.5%. In the chronic kidney disease subgroup, the prevalence of ischemic nephropathy reached 5.5%. In this study, the relationship between renal artery stenosis and atherosclerotic disease was also evidenced. In patients with renovascular disease, 67% had concomitant CAD, 37% had cerebrovascular disease and 56% had peripheral arterial disease. [9]

It is important to note that life expectancy in the US at the time of this work was 77 years. And in 2008 it reached 78 years. This is the importance of the subject that we will deal with.

## METHODS

A search was carried out in the main available databases, MEDLINE, LILACS and SciELO using the keywords "renovascular hypertension", "stenosis", "doppler ultrasound" and "renal artery", in the search title field.

From 588 articles returned by the search, we excluded duplicate references. In addition to selecting articles in English and Portuguese, we prioritize open access articles with good or excellent degrees of impact, citation and visualization. Of these, comparative clinical studies were selected whose control group underwent angiography of the renal arteries.

The result was 30 articles that were divided into the direct, indirect, additional and a combination of criteria for their proper analysis.

## RESULTS

The following tables show the articles found according to the diagnostic criteria.

| Indirect diagnostic criteria (16) | References: |
|---|---|
| Interlobar artery systolic peak velocity index iaPSV | 12, 13 |
| Resistance index difference RId | 14-16 |
| Acceleration time AT | 17-21 |
| Acceleration Index AI | 17-19; 21-24 |

**Table 1. Distribution of references by indirect diagnostic criteria**

| Direct diagnostic criteria (18) | References |
|---|---|
| End-diastolic velocity EDV | 14, 16, 25, 26 |
| Peak systolic velocity PSV | 13, 16, 20, 24, 25, 28-32 |
| Renal-aortic ratio RAR | 13, 16, 20, 24, 25, 28, 33-36 |
| Reno-renal ratio RRR | 13, 37 |

**Table 2. Distribution of references by right diagnostic criteria**

| Additional diagnostic criteria (3) | References |
|---|---|
| Renal-segmental ratio RSR | 24 |
| Renal-interlobar ratio RIR | 12,13 |
| Critérios diagnósticos combinados (6) | |
| PSVe + RAR | 20, 26, 27, 35, 38, 39 |

**Table 3. Distribution of references by additional and combined diagnostic criteria**

## DISCUSSION

Diagnostic criteria on Doppler

Several methods have been tested and developed over the last 40 years to assess renal stenosis. The works referenced here carried out their studies on RAS, in the vast majority of them, with lesions due to atherosclerosis. Therefore, the use of the indices and values mentioned here in other causes of RAS such as FMD, dissection or others, must be done with caution, due to their virtual lack of validation for these situations.

The techniques and criteria used in Doppler are separated by most authors as indirect and direct.

The indirect method parameters are measurements and calculations taken from the entire renal vascular tree, except the point of stenosis and the renal artery. Therefore, in most studies, they are flowmetric measurements of samples at the height of the hilum or more distally in segmental arteries.

Direct diagnostic methods use measurements from the sample of the stenosis point, either just the sample from this point, as in the isolated measurement of peak systolic velocity, or in comparison with the sample from other segments of the arterial tree, as in the renal-aortic ratio or in the renal-renal ratio.

Indirect criteria

The indirect diagnostic methods evaluated in this review are:

- The resistance index (RI);
- The pulsatility index (PI);
- The interlobar artery systolic peak velocity index (iaPSV);
- The Resistance index difference (RId);
- The acceleration time (AT);
- The Acceleration Index (AI) and its variations.

Indirect diagnostic criteria were created as the first form of evaluation. Mainly in a time without filters and with low processing machines, it became an immense challenge to evaluate arteries in greater depth. Therefore, in patients where it was not possible to assess the stenosis site directly, the indirect criteria were more reproducible. The speed in obtaining these criteria is also something mentioned with advantage in some works. Currently, some studies suggest their use as important adjuvants in confirming direct assessments of stenoses.

The pulsatility index and the resistance index showed low positive (PPV) and negative (NPV) predictive values during the studies evaluated, being consistently classified as inadequate for population screening, which is why they will only be briefly discussed here.

Despite the low correlation of RI with the diagnosis of RAS, there are studies that support a reference value of RI=0.8 or more as a predictor of response to interventional correction of RAS, be it angioplasty, angioplasty with stent or surgery. In some publications, the index is referred to as the resistivity index, the only difference in its formula in relation to the conventional one being its multiplication by 100 in these works. Therefore, their reference value is 80. Both Radermacher et al in 2001 and Santos et al in 2010 found a better response to the intervention, with regard to renal function and hypertensive disease in patients with RI less than 0.80. [10,11]

Interlobar artery systolic peak velocity index

This index was evaluated during the work of Li et al in 2006, obtaining it as part of the calculation of the renal-interlobar ratio that will be discussed later. During the work they evaluated interlobar arteries in the superior, middle and inferior pole. As they were analyzing findings from previous works, they used the pyramids as an anatomical marker for their work, mainly because they thought that even a stenosis in the distal portion of the renal artery would have already lost the effect of turbulence and increased peak systolic velocity (PSV) in this segment. The renal-interlobar ratio showed good sensitivity and specificity in severe stenosis, helping in cases of post-stent stenosis and stenosis in the middle third. However, the PSV of the interlobar artery, as an isolated diagnostic criterion, proved to be insufficient, with low sensitivity and specificity. No other work evaluating this criterion was found. [12,13]

The resistance index difference

The resistance index (RI) alone may have shown low accuracy, but the RId has shown evidence to support the diagnosis of RAS. This index is calculated through the RI difference in hilar samples. In the cited works, an evaluation of this value can be seen ranging from 0.01 to 0.007. There is a body of evidence in favor of 0.05 as the cutoff point for hemodynamically significant stenosis (HSS), usually 70% or greater. A reduction of 0.05 or more in one of the hila suggests ipsilateral HSS. As with all criteria, it is suggested that it be measured more than once to increase the reliability of this finding. Figure 1 shows an example of a patient with HSS in the left renal artery confirmed by angiographic control.

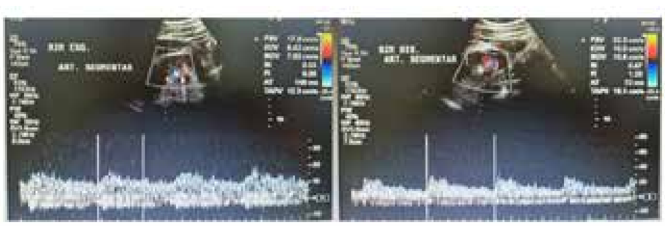

**Figure 1: Intrarenal vascular assessment. Note RId which is calculated at 0.67-0.53=0.14, indicating a hemodynamically significant stenosis to the left. It is also important to note the difference in wave morphology and AT.**

Zeller et al in 2001 presented a sensitivity of 77% and specificity of up to 99% for a stenosis of 70%. [14]

Ripollés et al in 2001 obtained a sensitivity of 50% and specificity of 90%. However, what was most interesting in this study was the difference in sensitivity and specificity reported for patients over and under 50 years of age. Patients younger than 50 years had better sensitivity and specificity in this criterion, suggesting a probable age interference in the compliance of these arteries and therefore interference in the use of this criterion.[15]

In 2007, Staub et al carried out an extensive retrospective study on the diagnostic criteria in 49 patients diagnosed with renal artery stenosis by Doppler and referred for confirmation by angiography and measurement of intra-arterial pressure. For a 70% stenosis, a RId of 0.05 had a sensitivity of 42%, specificity of 91%, PPV of 69%, NPV of 77%, and overall accuracy of 76%. For a 50% stenosis, the same RId value showed a sensitivity of 31%, specificity of 97%, PPV of 93%, NPV of 50% and accuracy of 58%. [16]

Table 4 summarizes the studies on the RId criterion with regard to their findings.

| Author | YP | St. | PC | Sens. | Spec. | PPV | NPV |
|---|---|---|---|---|---|---|---|
| Zeller et al | 2001 | 70% | 0.05 | 77% | 99% | 69% | 92% |
| Ripollés et al | 2001 | 75% | 0.05 | 50% | 96% | 69% | 92% |
| Staub et al | 2007 | 50% | 0.05 | 31% | 97% | 93% | 50% |
| Staub et al | 2007 | 70% | 0.05 | 42% | 91% | 69% | 77% |
| Staub et al | 2007 | 70% | 0.07 | 35% | 95% | 75% | 76% |

**Table 4: Year of publication (YP), degree of stenosis (St.), cutoff point (CP), sensitivity (Sens.), specificity (Spec.), positive predictive value (PPV), negative predictive value (NPV) .**

The acceleration time

This index showed good reproducibility of its methodology in the evaluated works. Of the indirect indices, it presented the highest number of works with its evaluation. It is the time from the beginning of the acceleration ramp to the maximum systolic peak. As a cutoff point, values from 70 to 100ms were used.

In 1988, studies by Handa et al were published showing the use of acceleration time and AI with good sensitivity and specificity for stenosis of 60% or more. Perhaps the first work to evaluate AT. As a cutoff point they suggest 0.07s. [17,18]

Stavros et al published in 1992 their findings in a prospective study with 56 patients having angiography as a control. Using 0.07s or more as a cutoff point for a stenosis of 60% or more, they found a sensitivity of 78%, a specificity of 94%, a PPV of 85%, a NPV of 91% and an overall accuracy of 89 %.[19]

In 1999, House et al published their prospective study with 63 patients, finding a sensitivity of 41% and specificity of 85% for an AT greater than 70ms as a criterion for an RAS of 60% or more. [20]

Bardelli et al in 2006 suggested 80ms as the best cutoff point, with a sensitivity of 93%, specificity of 65, PPV of 51% and NPV of 96% for a stenosis of 60% or more. [21]

Table 5 summarizes the findings on the AT criterion.

| Author | YP | St. | PC | Sens. | Spec. | PPV | NPV |
|---|---|---|---|---|---|---|---|
| Handa et al | 1988 | 60% | 0.07s | 100% | 83% | 66% | 100% |
| Stavros et al | 1992 | 60% | 0.07s | 78% | 94% | 85% | 91% |
| House et al | 1999 | 60% | 70ms | 41% | 85% | 36% | 88% |
| Motew et al | 2000 | 60% | 58ms | 58% | 96% | 97% | 52% |
| Motew et al | 2000 | 60% | 100ms | 32% | 100% | 100% | 41% |
| Ripollés et al | 2001 | 75% | 80ms | 89% | 99% | 94% | 98% |
| Bardelli et al | 2006 | 60% | 80ms | 93% | 65% | 51% | 96% |

Note the change in units (0.07s=70ms).

**Table 5 summarizes the findings on the AT criterion.**
**Note the change in units (0.07s=70ms).**

The acceleration index

This is perhaps the most confusing indirect criteria in reproducibility. There are different methodologies for calculating this index. Including works where the loss of the early systolic peak is the result of the morphological analysis of the wave, reflecting a drop in acceleration. The result of this are the different cut-off values and measurement units cited by the sources in this review, such as 3.78KHz/s/MHz, 4m/s2, 300cm/s2 and 9s-1. Figure 2 is an example of evaluating the acceleration index in a renal artery without stenosis.

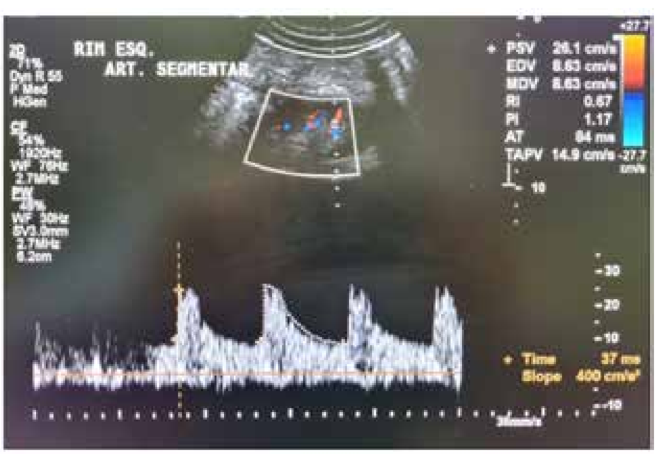


**Figure 2: Note that during image post-processing, the slope or acceleration was calculated, which is within normal limits with a value of 400cm/s2.**

The first article found by this review dealing with this index is that of Handa et al in 1986. In it, two parameters of flowmetry in the bilateral renal arteries of eight control patients, 19 patients with essential hypertension and 8 with renovascular hypertension are evaluated using echodoppler. The two parameters are the acceleration index and the ratio S (peak systolic)/D (end-diastolic velocity). The study does not define a unit for the acceleration index, but the calculation is shown as the ratio of the tangential slope calculated in KHz by the acceleration ramp in 1 second and divided by the emitted frequency in MHz. It is inferred as KHz/s/MHz unit. This measurement is made in the hilar region. Therefore, it is a technical way of characterizing a tardus parvus flow wave. A cutoff point of 2.5 or less is suggested during the presentation of results. And the average value of the controls revolve around 8.1 and 8.5. In 1988, Handa et al again evaluated AI. In these works, the measurement unit is defined and the best cutoff point is 3.78KHz/s/MHz, with an accuracy of 95%, sensitivity of 100% and specificity of 93%.[17,18,22]

One difficulty with this type of index is finding Doppler machines that perform this calculation, leaving the operator to perform it. It's easier to find machines that do slope calculations, or in Portuguese declive. This function calculates acceleration in cm/s2 or m/s2. So this is another formula for calculating the acceleration ramp.

The presence of one or two kidneys, age, systemic hypertension, atherosclerosis or diabetes affecting the compliance of the renal arterial tree, in addition to heart valve disease, left heart failure and cardiovascular medications are some of the factors that can affect the AI assessment[17,21, 22].

As the AI is an attempt to characterize the wave, it is common for studies to evaluate it in conjunction with other indices, such as acceleration time and loss of early systolic peak.

During the review of articles, the most cited value as a limit for acceleration was 300cm/s2 (also cited as 3m/s2). Therefore, values lower than 300cm/s2 suggest hemodynamically significant RAS. Some studies, such as that by Miralles et al, did not even discuss the AI results, suggesting a low accuracy obtained during the study compared to other indices.

In 1992, Stavros et al attest to an acceleration of less than 3m/s2 (or 300cm/s2), as a cutoff point for stenosis of 60% or more, a sensitivity of 89%, a specificity of 83%, a PPV of 69 , a NPV of 95% and an overall accuracy of 85%. In his methodology, the curve for this index was collected from the segmental arteries of the upper and lower poles. House et al in 1999 also published in their study for the same acceleration value in a stenosis of 60% or more a sensitivity of 56% and specificity of 62%, with an accuracy of 47%. Note that in the methodology of House et al, this index was collected outside the renal parenchyma in the main branch or in the renal artery itself.[19, 20]

In the study by Souza de Oliveira in 2000, the acceleration index was collected in segmental arteries of the three anatomical groups: upper, middle and lower. Angiographic control was used as a control for stenoses equal to or greater than 50%. They were analyzed as a cutoff point of 1-6m/s2. However, none of them presented satisfactory overall accuracy. [24]

The AI presented, throughout some works, varied sensitivities and specificities. Bardelli et al in 2006 evaluated the use of some indirect criteria such as acceleration time and acceleration. Realizing the loss of the early systolic peak, they propose two new indirect indices based on acceleration: the maximum systolic acceleration (ACCmax) and the maximum acceleration index (AImax). The calculation of the first is made by using the acceleration curve towards the largest PSV, divided by the smallest AT until there is a significant change in the velocity curve. At work it is called maximum acceleration time (ATmax). The AImax calculation is considered a correction for the absolute flow regime. It is calculated by dividing the ACCmax by the maximum systolic peak (PSVmax).[23]

In this study with 200 kidneys and 56 of them with stenosis of 60% or more, indices such as PI (pulsatility index), RI (resistance index), TA, ACCsys (medical systolic acceleration or simply acceleration), ACCmax (maximal systolic acceleration) and AImax. As a result, they report failure of PI and RI independently to reach a suitable NPV for screening. Among the indices that have adequate NPV and PPV values, they point out that AImax reached the highest NPV and the highest PPV among the individually evaluated indirect indices. In their work, the values of 80ms for AT, 4m/s2 (or 400cm/s2) for ACCsys, 4m/s2 for ACCmax and 9s-1 for AImax are evidenced as the best cutoff for RAS graded at 60% or more. . In this cutoff, AImax achieved a sensitivity and specificity of 93% and 84% for a 60% stenosis. Therefore, it was an interesting finding, but no new studies were identified in our research using this form of acceleration calculation. The ACCsys of 400cm/s2 had a sensitivity of 93%, specificity of 56%, PPV of 56% and NPV of 95%.[23]

| Author | YP | St. | PC | Sens. | Spec. | PPV | NPV |
|---|---|---|---|---|---|---|---|
| Handa et al | 1988 | 50% | AI 3,78 | 100% | 93% | 83% | 100% |
| Stavros et al | 1992 | 60% | Ac 3m/s$^2$ | 89% | 83% | 69% | 95% |
| House et al | 1999 | 60% | Ac 3m/s$^2$ | 56% | 62% | 23% | 87% |
| Souza de Oliveira et al | 2000 | 50% | ESA 4,0 | 40% | 22% | 20% | 43% |
| Ripollés et al | 2001 | 75% | Ac 1m/s$^2$ | 89% | 98% | 89% | 98% |
| Ripollés et al | 2001 | 75% | Ac 3m/s$^2$ | 100% | 51% | 26% | 100% |
| Bardelli et al | 2006 | 60% | ACCsys 4,0 | 93% | 56% | 45% | 95% |
| Bardelli et al | 2006 | 60% | ACCmax 4,0 | 94% | 75% | 60% | 97% |
| Bardelli et al | 2006 | 60% | AImax 9,0 | 93% | 84% | 70% | 97% |

**Table 6 gathers the findings of the works on the AI criterion.**

Direct criteria

In general, the direct criteria, when feasible, obtained better overall accuracy in relation to the indirect ones. However, technically, it may be difficult to obtain these indices due to the interposition of gases or in some degrees of obesity.

Direct criteria are considered:

- Morphological assessment of stenosis
- End-diastolic velocity (EDV)
- Peak Systolic Velocity sor stenosis (PSVe)
- Renal-aortic ratio (RAR)
- Renal Renal Ratio (RRR)

Morphological evaluation

Of the direct criteria, the morphological assessment of the stenosis is not performed transabdominally. The frequency required for the evaluation lacks linear resolution, so there are no works on this form of diagnosis. In order to maintain good accuracy with this method, it is necessary to resort to an invasive method: the IVUS. However, intravascular ultrasound loses some of the advantages of the transabdominal technique, with complications similar to those of invasive procedures.

Therefore, IVUS is not considered a method for screening and diagnosing RAS in the population. However, it is a method for confirming RAS and helping to make therapeutic decisions prior to the procedure, during the procedure and post-procedure.

End-diastolic velocity

Of the direct criteria already evaluated by the transabdominal route, this one has been abandoned by articles of prospective and review studies. It is a measure provided automatically when the velocity curve is enveloped in flowmetry.

The first study found by this review was that of Miralles et al in 1996. However, it is discussed that PSV was found as the best parameter for suspecting stenosis of 60% or more, followed by RAR and EDV. The mean value of EDV in these stenoses was 72.9cm/s against a mean value of 39.9cm/s for minor stenoses or absence. However, the work does not propose a cutoff point for the EDV, much less an assessment of its accuracy. [25]

In 2005, in the work by Engelhorn et al, a speed of 48 cm/s was proposed as a cutoff point for the EDV for stenosis of 60% or more. The sensitivity found was 70% and the specificity 72%, with an accuracy of 70%.[26]

In the 2007 work by Staub et al, they achieved an accuracy of 83% for a stenosis of 70% or more in the angiographic control, using an EDV of 90cm/s or more as the cutoff point. Sensitivity was 77%, specificity 87%, PPV 74%, and NPV 88%. It was the best performance of this criterion in prospective studies.[16]

Zeller et al, in 2008, commented on the increase in RI in the progression of kidney disease, which would reduce the EDV, and ultimately render the use of this criterion useless. Therefore, we must remember that low EDV values cannot exclude the possibility of stenosis. Its dependence on heart rate and peripheral resistance also compromise its use.[27]

In some studies, the EDV was part of the calculation of the end-diastolic ratio through the division of the EDV by PSVe. It was an attempt to find the patients who could respond better to a surgical intervention on the stenosis, but it was abandoned due to the low statistical correlation.

Stenosis systolic velocity peak

With the introduction of low-frequency transducers, the improvement of the ultrasound technique and, consequently, of flowmetric samples, the techniques for direct assessment of the lesion began to show greater overall accuracy in the published studies. Many works until the 90's deal exclusively with indirect methods. At the end of the 1980s, publications appeared on direct methods, and this trend only increased in the following decades. Some authors emphasize the importance of indirect techniques as more feasible, even in obese patients or those with inadequate preparation. However, over the years, authors cited in this review have been observed suggesting the use of direct techniques whenever possible.

The evaluation of the peak systolic velocity at the greatest point of stenosis is aided by color Doppler both to determine the greatest point of stenosis and to correct the sample angle. Even the decrease in the variability of the values used as a cutoff point from 100 to 220cm/s to 180 to 200cm/s throughout the published works is justified by the review articles as a consequence of this assistance. We see an example in Figure 3 of an PSVe compatible with HSS in the right renal artery and confirmed by angiography.

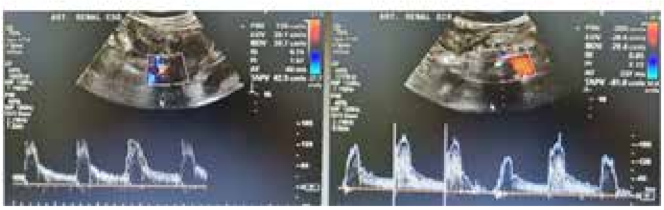

**Figure 3: Evaluation of peak systolic velocity demonstrating stenosis of the right renal artery. Observe PSV of 129cm/s on the left and 200cm/s on the right. Observe laminar flow on the left and swirl on the right.**

The oldest work using PSVe found by this review was that of Hoffmann et al in 1991. We analyzed 74 renal arteries in 41 patients using angiography as a control. In this work, the sensitivity of this criterion was 95% and the specificity 90%, for a cutoff point of 180cm/s in stenoses of 60% or more in the control. The estimated PPV was 98% and the NPV 75%.[28]

Miralles et al, in 1996, did a study comparing direct and indirect indices prospectively. Of 78 patients, 142 renal arteries were analyzed. In the PSV evaluation, a velocity of 198cm/s was identified as the best cutoff point for a stenosis of 60% or more. A sensitivity of 87% and a specificity of 92% were identified with this value.[25]

House et al in 1999 published a prospective study with 63 patients where a control angiography was available. For a stenosis of 60% or more on angiography, the velocity 180cm/s provided a sensitivity of 80%, a specificity of 77%, a PPV of 43% and a NPV of 95%. The most interesting part of this work was the combination of criteria, an item that will be discussed later. [20]

In 2000, Motew et al published a prospective study on 41 patients with angiography as a control for a stenosis of 60% or more. It compares direct and indirect criteria. As a cutoff point for PSVe, 2m/s or 200cm/s was used, obtaining a sensitivity of 91%, a specificity of 96%, a PPV of 98%, a NPV of 83%, with an overall accuracy of 92%. The superiority of this criterion in relation to AT is evidenced in the work. However, with a high specificity and PPV, the auxiliary importance of this indirect criterion is also suggested.[29]

The first Brazilian study on diagnostic criteria identified by this review was from 2000. Souza de Oliveira et al published a prospective series of 96 renal arteries, excluding nine due to technical difficulties. In this work, angiographic stenosis of 50% or more is a control for the Doppler exam. A PSVe of 150cm/s has a sensitivity of 83% and a sensitivity of 89.47cm/s. A PSVe of 170cm/s had 70% and 98% respectively for the same degree of stenosis. [24]

In 2005, Engelhorn et al published a paper on the importance of validating diagnostic criteria. They even report on the variability of the direct criteria, with the PSV cutoff of 100 to 200cm/s and the RAR between 3.2 and 3.5 in different references. In this work, he individually analyzes the direct criteria used, suggesting a speed of 252cm/s as the best cutoff point for PSV, with sensitivity of 83%, specificity of 92% and accuracy of 87%. [26]

Cardoso et al, in 2006, obtained better accuracies with PSVe, when compared with RAR or even with the combination of criteria. Even when the cutoff point was corrected by the ROC curve. PSVe corrected to 189cm/s obtained the highest accuracy of the work, which was calculated at 97%. [39]

Staub et al, in 2007, carried out a prospective study with 49 patients resulting in an analysis of 98 renal arteries, where the doppler criteria had angiography and the intra-arterial pressure gradient as controls for stenoses of 50% or more and for stenoses of 70 % or more. These cutoff choices had an implication on therapeutic decisions. At the time, several studies indicated the need for intervention for stenoses of 70% or more, but there was disagreement about intervening in stenoses of 60% or more. Therefore, a 50% stenosis would indicate a need for more frequent monitoring of the patient, while a 70% or more stenosis would already indicate the need for intervention. They demonstrated that stenoses above 50% already caused a difference in intra-arterial pressure gradient pre- and post-injury of 20mmHg or more. [16]

In this work, they recorded a sensitivity of 96%, a specificity of 69%, a PPV of 81%, a NPV of 93% and an accuracy of 85% for a PSVe of 180cm/s for stenoses of 50% or more. A PSVe of 200cm/s resulted in a sensitivity of 92%, a specificity of 81%, a PPV of 87% and a NPV of 88%, with an accuracy of 87% for the same degree of stenosis. For a PSVe of 250cm/s, a sensitivity of 78%, specificity of 92%, a PPV of 93%, a NPV of 75% were found, with an accuracy of 84%. Therefore, the best accuracy was with a PSVe at 200cm/s for a stenosis of 50% or more.[16]

In the same study, for a stenosis of 70% or more, the overall accuracy improvement, calculated at 84%, was found with a cutoff point of 300cm/s.

In 2008, Li et al published a prospective study with 77 patients and 153 renal arteries with control angiography for stenoses of 50% or more. PSVe, RId and renal-segmental ratio were the best criteria in this work. The value of 170cm/s had a sensitivity of 90%, specificity of 90%, PPV of 88% and NPV of 91%. An interesting point of this work was the discussion of how the aortic stenosis in [8] patients influenced the direct indices and how

PSVe still achieved good accuracy in this scenario.[13]

Abu Rahma et al in 2012 recorded a sensitivity of 89%, a specificity of 54%, a PPV of 56%, a NPV of 88% and an accuracy of 68% for a PSVe of 200cm/s for a stenosis of 60% or more.[31]

| Author | YP | St. | PC | Sens. | Spec. | PPV | NPV |
|---|---|---|---|---|---|---|---|
| Hoffmann et al | 1991 | 60% | 180cm/s | 95% | 90% | 98% | 75% |
| Miralles et al | 1996 | 60% | 198cm/s | 87% | 92% | 86% | 92% |
| House et al | 1999 | 60% | 180cm/s | 80% | 77% | 43% | 95% |
| Motew | 2000 | 60% | 180cm/s | 94% | 88% | 94% | 88% |
| Motew | 2000 | 60% | 200cm/s | 91% | 96% | 98% | 83% |
| Souza de Oliveira et al | 2000 | 50% | 150cm/s | 83% | 90% | 80% | 92% |
| Souza de Oliveira et al | 2000 | 50% | 170cm/s | 70% | 98% | 95% | 87% |
| Engolhorn et al | 2005 | 60% | 252cm/s | 83% | 92% | | |
| Cardoso et al | 2005 | 60% | 189cm/s | 100% | 87% | 96% | 100% |
| Cardoso et al | 2005 | 60% | 180cm/s | 100% | 81% | 94% | 100% |
| Staub et al | 2007 | 50% | 200cm/s | 92% | 81% | 87% | 88% |
| Staub et al | 2007 | 50% | 180cm/s | 96% | 69% | 81% | 93% |
| Staub et al | 2007 | 70% | 300cm/s | 89% | 81% | 69% | 94% |
| Staub et al | 2007 | 70% | 250cm/s | 89% | 70% | 58% | 93% |
| Li et al | 2008 | 50% | 170cm/s | 90% | 90% | 88% | 91% |
| Abu Rahma et al | 2012 | 60% | 200cm/s | 89% | 54% | 56% | 88% |

**Renal-aortic ratio**

**Table 7 shows the findings in the works related to the PSVe criterion.**

Obtaining the index by dividing the PSV of the renal artery stenosis by the PSV of the aorta between the superior mesenteric and renal ostium is a correction for the patient's hemodynamic regime. This correction may have problems, as suggested by some studies, such as a drop in the aortic PSV as its caliber increases, which may occur with advancing patient age and with the presence of aneurysms; or even with the presence of hemodynamically significant stenoses in the aorta. Figure 4 exemplifies an RAR compatible with HSS of the right renal artery, confirmed by angiography.

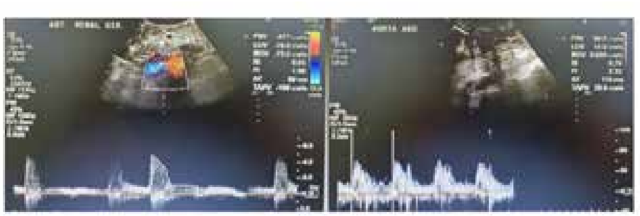

**Figure 4: Observe PSV of 471cm/s and a PSV in the aorta of 88.9cm/s. A RAR of 5.29 is calculated. Therefore, in this case, there are 2 indices indicative of hemodynamically significant stenosis: PSVe and RAR. A swirling flow is also observed.**

The first study identified by this review was that of Kohler et al in 1986. In it, they retrospectively evaluated 158 patients, and the angiogram of only 43 renal arteries was available as a control. With a sensitivity of 91% and a specificity of 95% for a stenosis of 60% or more, the authors talk about the need for prospective studies to better assess the RAR.[33]

Therefore, in 1988, Taylor et al published a prospective study on this index. Fifty-eight arteries in 29 patients are analyzed with angiography as control. They obtained a sensitivity of 84%, sensitivity of 97%, a PPV of 94% and a NPV of 90% for a stenosis of 60% or more. It is important to note in the methodology that in addition to the change in the RAR, it was necessary to have a focal increase in velocity with downstream turbulence in the color Doppler. A curious fact about this work was the presence of authors such as Strandness Jr., Moneta, and Kohler himself.[34]

The 1990 work by Strandness Jr is a revisitation of the 1988 work with greater details on the technique employed and the methodology, with a new analysis on sensitivity and specificity.[35]

Hansen et al, in 1990, published a prospective study, where 74 patients had control angiography with patent arteries. Of these patients, six Doppler scans were inadequate due to obesity or the presence of gas in the loop, resulting in 142 arteries being comparatively evaluated. A RAR greater than or equal to 3.5 and the presence of turbulent flow in the lesion or downstream for stenoses of 60% or greater on angiography were used as criteria on the Doppler. They then publish a sensitivity of 93%, a specificity of 98%, a PPV of 98% and a NPV of 94%. They report that these indices were obtained from kidneys with only one main artery and in the discussion they refer that a PSVe of 2m/s (200cm/s) was able to predict the presence of stenosis as well as the RAR of [3.5,36]

In the 1991 work by Hoffmann et al, the index of 3.5 demonstrated a sensitivity of 92%, a specificity of 62%, a PPV of 81% and a NPV of 80%.[28]

In 1996, Miralles et al, for a RAR of 3.3, which was identified as the best cutoff point for a stenosis of 60% or more, obtained a sensitivity of 76%, a specificity of 92%, a PPV of 86% and a NPV of 87%.[25]

In the 1999 work by House et al, a sensitivity of 50%, a specificity of 88%, a PPV of 50% and a NPV of 88% were obtained with an index of 3.5 for a 60% stenosis in the angiography. A ratio of 3.0, on the other hand, obtained a sensitivity of 70%, a specificity of 80%, a PPV of 46% and a NPV of 92%.[20]

The work by Souza de Oliveira et al in 2000 obtained for a stenosis of 50% or more in the angiographic control, using an optimized RAR of 1.8 in the Doppler evaluation, a sensitivity of 83% and specificity of 79%.[24]

Engelhorn et al published in 2005 a RAR of 3.27 as an ideal cut-off point for their sample of 137 arteries, with a sensitivity of 85%, a specificity of 86%, with an accuracy of 86%.[26]

Staub et al, in 2007, for a stenosis of 50% or more on angiography, obtained the best overall accuracy for a RAR of 2.5 and 3.0, with a sensitivity of 92%, specificity of 79%, PPV of 86% and NPV of 87% for the first value and 83%, 91%, 93% and 80% respectively for the second value. Both having accuracy calculated at 87%. An accuracy similar to the PSVe criterion of 200cm/s for the same degree of stenosis in the same study. [16]

In the same study, for a 70% stenosis, the RAR of 3.5 had a sensitivity of 84%, specificity of 72%, PPV of 57% and NPV of 91%, with an accuracy of 76%. For the same degree of stenosis, the RAR of 4.0 showed values of 60%, 84%, 63% and 83% respectively. With a cutoff point of 4.5 for the RAR, they obtained a calculated accuracy of 77%, similar to the cutoff point of 4.0, but penalizing the sensitivity.

In 2008, Li et al identified in their prospective work, for a stenosis of 50% or more on angiography with an optimized RAR cutoff value of 2.3, a sensitivity of 76%, a specificity of 89%, a 85% PPV, an 82% NPV, and an overall accuracy of 83%.[13]

| Author | YP | St. | PC | Sens. | Spec. | PPV | NPV |
|---|---|---|---|---|---|---|---|
| Kohler et al | 1986 | 60% | 3.5 | 91% | 95% | 93% | 94% |
| Taylor et al | 1988 | 60% | 3.5 | 84% | 97% | 94% | 90% |
| Hansen et al | 1990 | 60% | 3.5 | 93% | 98% | 98% | 94% |
| Strandness et al | 1990 | 60% | 3.5 | 84% | 97% | 94% | 90% |
| Hoffmann et al | 1991 | 60% | 3.5 | 92% | 62% | 81% | 80% |
| Miralles et al | 1996 | 60% | 3.3 | 76% | 92% | 86% | 87% |
| House et al | 1999 | 60% | 3.5 | 50% | 88% | 50% | 88% |
| House et al | 1999 | 60% | 3.0 | 50% | 88% | 50% | 88% |
| Souza de Oliveira et al | 2000 | 50% | 1.8 | 83% | 79% | 66% | 91% |
| Engolhorn et al | 2005 | 60% | 3.27 | 85% | 86% | | |
| Cardoso et al | 2006 | 60% | 3.5 | 79% | 93% | 97% | 60% |
| Cardoso et al | 2006 | 60% | 2.6 | 96% | 87% | 96% | 87% |
| Staub et al | 2007 | 50% | 2.5 | 92% | 79% | 86% | 87% |
| Staub et al | 2007 | 50% | 3.0 | 83% | 91% | 93% | 80% |
| Staub et al | 2007 | 70% | 3.5 | 84% | 72% | 57% | 91% |
| Staub et al | 2007 | 70% | 4.0 | 60% | 84% | 63% | 83% |
| Li et al | 2008 | 50% | 2.3 | 76,5% | 89% | 85,3% | 82% |

**Table 8 summarizes the diagnostic tests on the RAR criterion.**

Reno-renal ratio

The first work to be published on the reno-renal ratio (RRR) was Chain et al in 2006. The index is a division of the PSV of the lesion by the PSV distal to the lesion in the same main artery.[37]

The first work to be published on the reno-renal ratio (RRR) was Chain et al in 2006. The index is a division of the PSV of the lesion by the PSV distal to the lesion in the same main artery.[37]

In the aforementioned work, criteria such as RAR and PSVe were evaluated, in addition to RRR. To this end, a prospective evaluation was conducted in 34 patients suspected of having RAS, using angiography as a control for a stenosis of 50% or more. The best cutoff point found for the RRR was 2.7, with a sensitivity of 97%, specificity of 96%, PPV of 97% and NPV of 96%. At work, this criterion obtained better overall accuracy in relation to the other two.

In the 2008 study by Li et al, the best cutoff point for the RRR was 2.0 for stenoses of 50% or more in angiographic control, with a sensitivity of 76%, specificity of 93%, PPV of 90% and NPV of 83, with an overall accuracy lower than the PSVe.

| Author | YP | St. | PC | Sens. | Spec. | PPV | NPV |
|---|---|---|---|---|---|---|---|
| Chain et al | 2006 | 50% | 2.7 | 97% | 96% | 97% | 96% |
| Li et al | 2008 | 50% | 2.0 | 77% | 93% | 90% | 83% |

**Table 9 shows the statistics on the RRR criterion.**

Additional criteria

There are two criteria cited by three papers that were not identified in the other prospective or revisionist papers. They are classified as indirect criteria in some works, but they also have characteristics of direct criteria. Therefore, in view of the classification dilemma, these criteria were set aside. They are:

- Renal-segmental ratio (RSR)
- Renal-interlobar ratio (RIR)

Renal-segmental ratio

The renal-segmental ratio was explored in the work by Souza de Oliveira et al in 2000. It is an extensive work in which criteria such as early systolic acceleration, PSVe and RAR are also evaluated. Early systolic acceleration was measured in segmental arteries, which makes sense as it would have been influenced by a proximal stenosis, but had low overall accuracy (below 50%). The RSR value is obtained by dividing the PSV of the origin or proximal portion of the renal artery by the PSV of the segmental artery evaluated in the upper, middle and lower anatomical groups. In the prospective study they used control angiography for stenosis greater than or equal to 50%. The best cutoff point found was RSR=5 with sensitivity ranging from 80 to 93% in anatomical segments, and specificity from 84% to 94%. It is also the one that presents the best accuracy in the ROC curve in the evaluation of the inferior segmental artery in relation to the middle and superior segmental arteries. The second best accuracy is for PSVe at 150cm/s with sensitivity of 83% and sensitivity of 90%. [24]

| Author | YP | St. | PC | Sens. | Spec. | PPV | NPV |
|---|---|---|---|---|---|---|---|
| Souza de Oliveira et al | 2000 | 50% | 5.0 segm. sup. | 80% | 84% | | |
| Souza de Oliveira et al | 2000 | 50% | 5.0 segm. med. | 90% | 95% | | |
| Souza de Oliveira et al | 2000 | 50% | 5.0 segm. inf. | 93% | 90% | | |
| Li et al | 2008 | 50% | 4.0 | 84% | 92% | 98% | 87% |

**Table 10 shows the findings regarding the RRR criterion.**

Renal-interlobar ratio

Li et al in 2006, propose an evolution of the previous criterion. To prevent a stenosis in the middle or distal portion of the renal artery from increasing the hilar or segmental velocity, they collect the PSV from the interlobar artery, using the pyramid as an anatomical reference. They chose the PSV of the interlobar artery with the best flowmetry appearance. Therefore, the PSV of the lesion was divided by the PSV of the chosen interlobar artery. The best cutoff point identified was PSV=5 for a stenosis greater than or equal to 50% in the angiographic control. Sensitivity was 88%, specificity 88%, PPV 91% and NPV 84%.[12]

In 2008, Li et al published a study comparing direct indices, RIR and RSR. In a prospective series where 150 renal arteries were evaluated, having their angiographic control available for classification of stenosis at 50% or more. An important detail in their methodology is that they evaluated the upper, middle and lower segments and used that segment that showed signs of change in the waveform to collect the indices. If none of the segments showed suspicious alteration, indices were collected from the middle segment. The best cutoff point for the RIR was 5.5 with a sensitivity of 85%, specificity of 90%, PPV of 88% and NPV of 88%. The RSR, on the other hand, had its best cutoff point at 4.0, with a sensitivity of 84%, specificity of 91%, PPV of 98% and NPV of 87%.[13]

In the same work, they refer to a case where the stenosis was well advanced in the control angiography, but PSVe and RAR were within normal limits, with the RIR indicating HSS. Similar findings have already been reported for stenoses above 90% in other sites, such as the carotid, where there is a reduction in PSV in more advanced stenoses. This may suggest an advantage in using the RIR.

The criteria cited here were not found in other studies, but the publications found so far are promising. And they should be included in future work.

| Author | YP | St. | PC | Sens. | Spec. | PPV | PNV |
|---|---|---|---|---|---|---|---|
| Li et al | 2006 | 50% | 5 | 88% | 88% | 91% | 84% |
| Li et al | 2008 | 50% | 5.5 | 85% | 90% | 88% | 88% |

**Table 11 summarizes the statistics related to the RIR criterion.**

Combination of criteria

In some works, the study design allowed both the individual assessment of the criterion and their combined use. Other works only published their combination.

In two works, evaluation details were added that can be described as extra criteria, but with a more subjective aspect in their evaluation. Such as the identification of turbulence in the flow of the lesion, the loss of the early systolic peak, or even the identification of curves with the aspect of tardus parvus without using flowmetric criteria. Despite being somewhat subjective aspects, experience in the field would allow us to reproduce such aspects during the evaluation.

The first work to suggest the combination of criteria as a way to achieve better accuracy was that of Strandness in 1990, with PSVe and RAR.[35]

In 1996, Krumme et al used as criteria a PSVe greater than 200cm/s and a RId equal to or greater than 0.05 for stenoses equal to or greater than 70% in the angiographic control. It obtained a sensitivity of 89%, a specificity of 92%, a PPV of 92% and a NPV of 88%. It was the first work found by this review to combine criteria.[38]

The first study found by this review to evaluate the combination of direct criteria was that of House et al in 1999. In it, PSVe greater than 180cm/s together with an RAR greater than 3.5 for a stenosis of 60% or more in angiography it obtained a sensitivity of 80%, a specificity of 78%, a PPV of 45% and a NPV of 95%. A PSVe of 180cm/s with an RAR greater than 3.0 yielded a sensitivity of 85%, a specificity of 76%, a PPV of 44% and a NPV of 96%. They report better overall accuracy with the combination of criteria than with the criteria alone.[20]

In 2004 we have a Brazilian work on diagnostic criteria. Engelhorn et al published a prospective study with 137 renal arteries of 69 adult patients, with a positive angiography for stenosis of 60% or more as a control. In this study, stenoses of 60% or more were considered positive when velocities of 180cm/s or more were observed in conjunction with an RAR greater than 3.5. Therefore, the sensitivity of 95%, the specificity of 88%, the PPV of 90%, the NPV of 95% and the overall accuracy of 92% come from the combination of the two right criteria. [30]

Engelhorn et al in 2005, based on a cut of 180cm/s of PSV and 3.5 of RAR for a stenosis of 60% or more in the angiographic control, found a sensitivity of 93%, a specificity of 84%, a PPV of 88% and a 90% NPV. In this work, the combination of criteria obtained the highest overall accuracy, closely followed by PSVe, then by RAR and then by EDV.[26]

Cardoso et al in 2006, in a prospective study, used PSVe greater than 189cm/s and a RAR greater than 3.5 as criteria in a study with 127 renal arteries in 62 patients. Angiography was used as a control for a stenosis greater than 60%. They achieved a sensitivity of 79%, a specificity of 97%, a PPV of 99% and a NPV of 61%. When they optimized the cutoff values to 189cm/s and RAR of 2.6, after ROC curve analysis they obtained 96%, 94%, 98%, and 89% respectively as results. Something important to highlight in this work was that greater overall accuracy was not achieved with the combination of criteria, but with the use of PSVe alone. With a cut-off point of 189cm/s, they achieved results of 100%, 87%, 96% and 100% respectively.[39]

In the 2006 study, Li et al proposed two new combinations of criteria for detecting a stenosis of 50% or more. One of them using PSVe with RIR; and another using the RIR with the systolic peak of the interlobar artery (IL PSV), the latter being positive for stenosis when less than 15cm/s. Both with good accuracy.[12]

In 2008, Zeller et al used cutoff points of 3.5 for the RAR and 0.05 for the RId in detecting stenoses equal to or greater than 70% on angiography. They found a sensitivity of 76%, a specificity of 97%, a PPV of 97% and a NPV of 76%. They justified the low sensitivity to the presence of bilateral stenosis in 22% of the patients, which influenced the RId. It is interesting to note the low sensitivity as a probable limitation of this criterion, as it is necessary for there to be laterality of an HSS in only one renal artery. It may not influence criteria such as RIR and RSR, but further studies would be needed. [27]

In 2013 another Brazilian work was published. Borelli et al published a prospective study with 61 patients with suspected RAS. They were submitted to doppler, renal scintigraphy with Tc-99m DTPA and renal angiotomography, with renal angiography as control. For stenoses above 60% or more in controls, PSVe equal to or greater than 180cm/s associated with a RAR equal to or greater than 3.5 were used as a criterion. That is, if the patient had a PSVe equal to or greater than 180cm/s, but with a RAR of less than 3.5, it would be considered a stenosis of less than 60%. As a result, they obtained a sensitivity of 83%, a specificity of 70%, a PPV of 85% and a NPV of 67%. [32]

| Author | YP | St. | PC | Sens. | Spec. | PPV | NPV |
|---|---|---|---|---|---|---|---|
| Krummer | 1996 | 70% | PSVe 200cm/s; RId 0.05 | 89% | 92% | 92% | 88% |
| House et al | 1999 | 60% | PSVe 180cm/s; RAR 3.5 | 80% | 78% | 45% | 95% |
| House et al | 1999 | 60% | PSVe 180cm/s; RAR 3.0 | 85% | 76% | 44% | 96% |
| Engelhorn et al | 2004 | 60% | PSVe 180cm/s; RAR 3.5 | 95% | 88% | 90% | 95% |
| Engelhorn et al | 2005 | 60% | PSVe 180cm/s; RAR 3.5 | 93% | 83,6% | 88% | 90% |
| Cardoso et al | 2006 | 60% | PSVe 189cm/s; RAR 3.5 | 79% | 97% | 99% | 61% |
| Cardoso et al | 2006 | 60% | PSVe 189cm/s; RAR 2.6 | 96% | 94% | 98% | 89% |
| Li et al | 2006 | 50% | PSVe 150cm/s; RAR 2 | 82% | 91% | 93% | 79% |
| Li et al | 2006 | 50% | PSVe 150cm/s; RIR 5 | 89% | 88% | 91% | 85% |
| Li et al | 2006 | 50% | RIR 5; aiPSV 15cm/s | 91% | 87% | 90% | 88% |
| Li et al | 2008 | 50% | PSVe 190cm/s; RSR 5,0 | 90% | 92% | 89% | 92% |
| Zeller et al | 2008 | 70% | RAR 3,5; RId 0.05 | 76% | 97% | 97% | 76% |
| Borelli et al | 2013 | 60% | PSVe 180cm/s; RAR 3.5 | 83% | 70% | 85% | 67% |

**Table 12 summarizes the diagnostic tests on combinations of criteria.**

Types of lesion

The work by Hansen et al in 1990 presented 6 arteries with characteristics compatible with fibromuscular dysplasia of 147 evaluated renal arteries.

Hoffmann et al, in their work published in 1991, excluded arteries suspected of having FMD, which leads us to conclude that the lesions found must be of atherosclerotic origin.

House et al in 1999 found in 125 arteries analyzed, two with lesions typical of FMD. Both in the same patient, therefore, a case of bilateral stenosis.

In 2000, Motew et al, in their work on 81 renal arteries, observed 5 lesions compatible with FMD, 2 of them in the same patient.

In the work by Bardelli in 2006, indirect criteria were evaluated and one of the most interesting points of the work were the classifications of the stenosis site and the etiology of the stenoses. Of the 72 stenoses evaluated, 16 were cited as etiology by fibromuscular dysplasia and 56 were by atherosclerosis.

Cardoso et al in 2006, had in their sample 55 patients with atherosclerotic etiology and seven patients with fibromuscular dysplasia (FMD).

The 2006 work by Li et al had an interesting etiologic population. Of the 93 stenoses, 42 were due to atherosclerosis, 30 due to Takayasu's arteritis and 21 due to FMD. This distribution may have influenced his work mainly in relation to PSVe and RAR, as some patients with Takayasu had both aortic and multisegmental involvement.

In his 2009 work, of the 68 renal artery stenoses, 40 were due to atherosclerosis, [17] due to Takayasu, nine due to FMD and two due to pheochromocytoma and polyarteritis nodosa. Here we make the same caveat regarding patients with Takayasu who may have multisegmental involvement, altering the use of some indices. In this work, the authors reaffirm how aortic stenoses can affect the diagnostic indexes, which is not a demerit of the work, but a warning for any examiner who is not aware of the possibility of stenosis in the aorta or even in another segment of the arterial tree kidney during the performance of your Doppler.

The other studies did not specify the etiology, but the description in most of them suggests that it is probably an atherosclerotic etiology.

## CONCLUSION

In the following tables we show the arithmetic mean of each statistic of the diagnostic tests of the works according to each diagnostic criterion. Caution is needed when analyzing the average achieved, because the cutoff points differ between studies and the degree of stenosis as well. In some studies where the PPV and NPV were not published, it was calculated based on the prevalence of the sample, sensitivity and specificity.

| Mean between papers for the RId criterion. | Sens. | Spec. | PPV | NPV |
|---|---|---|---|---|
| | 47% | 96% | 75% | 77% |

Table 13

| Mean between works for the AT criterion. | Sens. | Spec. | PPV | NPV |
|---|---|---|---|---|
| | 70% | 89% | 76% | 81% |

Table 14

| Mean between works for the AI criterion. | Sens. | Spec. | PPV | NVP |
|---|---|---|---|---|
| | 84% | 69% | 54% | 90% |

Table 15

| Mean between works for the PSVe criterion. | Sens. | Spec. | PPV | NVP |
|---|---|---|---|---|
| | 89% | 83% | 82% | 91% |

Table 16

| Mean between papers for the RAR criterion. | Sens. | Spec. | PPV | NVP |
|---|---|---|---|---|
| | 80% | 87% | 81% | 86% |

Table 17

| Author | YP | St. | PC | Sens | Spec. | PPv | NPV |
|---|---|---|---|---|---|---|---|
| House et al | 1999 | 60% | PSVe 180cm/s; RAR 3.5 | 80% | 78% | 45% | 95% |
| House et al | 1999 | 60% | PSVe 180cm/s; RAR 3.0 | 85% | 76% | 44% | 96% |
| Engelhorn et al | 2004 | 60% | PSVe 180cm/s; RAR 3.5 | 95% | 88% | 90% | 95% |
| Engelhorn et al | 2005 | 60% | PSVe 180cm/s; RAR 3.5 | 93% | 84% | 88% | 90% |
| Cardoso et al | 2006 | 60% | PSVe 189cm/s; RAR 3.5 | 79% | 97% | 99% | 61% |
| Cardoso et al | 2006 | 60% | PSVe 189cm/s; RAR 2.6 | 96% | 94% | 98% | 89% |
| Li et al | 2006 | 50% | PSVe 150cm/s; RAR 2 | 82% | 91% | 93% | 79% |
| Borelli et al | 2013 | 60% | PSVe 180cm/s; RAR 3.5 | 83% | 70% | 85% | 67% |
| Média | | | | 87% | 85% | 80% | 84% |

**Table 18: in this table, studies with a combination of different criteria were excluded; however, it is important to note the different cutoff points despite the same combination of criteria.**

Some more recent works that dealt with indirect criteria mentioned some limitations of the technique. Li et al[12] describes the difficulty of using RId in bilateral stenosis. And Staub el al[16] specifies the difficulty of using indirect criteria in situations such as bilateral stenoses, single kidneys, unilateral renal parenchymal disease, arrhythmia, aortic regurgitation and presence of arteriovenous fistulas.

The direct criteria also have some limitations related to the use of the technique, but when feasible, they proved to be more reproducible and with better overall accuracy compared to the indirect criteria. The works where there were indirect criteria being evaluated together with the direct criteria referred to a better performance of the direct criteria in relation to sensitivity, specificity, PPV and NPV.

Therefore, it is not surprising that review studies, especially the most recent ones, not only confirm the greater reproducibility of direct criteria, but also strongly suggest their use for the diagnosis of renal artery stenosis. Among the direct criteria, PSVe has been the most recommended. And, if necessary, the use of RAR for confirmation. The use of indirect criteria as an adjuvant for diagnosis is also suggested. However, the limitations of indirect criteria must be borne in mind.

It would be interesting in the future to see works on criteria such as RRR, RSR and RIR. The last two in particular have shown promise as diagnostic criteria. Furthermore, these indices would theoretically not be influenced by bilateral stenosis, single kidney, arrhythmia, aortic regurgitation or arteriovenous fistulas. On the other hand, renal parenchymal disease could theoretically influence the latter two. However, further studies are needed to investigate these possibilities.

A detail in the evaluation of these criteria is that the best accuracy does not always define the best cut-off point. As the renal artery Doppler is a screening test, it might be interesting to have a higher sensitivity to actually determine those who should continue the investigation.

With regard to stenosis of non-atherosclerotic origin, it seems necessary to create a collaborative effort between the centers so that a reliable criterion can be established for renal artery stenosis due to other etiologies, mainly due to the low number of patients in the studies presented.

In conclusion, at the current stage of work and knowledge built, it is comfortable to suggest the use of PSVe as a diagnostic criterion for renal artery stenosis, with RAR being an important adjuvant. The use of indirect criteria should be done with caution, always keeping in mind the examiner's familiarity with a tardus parvus wave, with his ultrasound device and the acquisition of several measurements for greater reliability.

Future work should continue to evaluate the contrast-enhanced ultrasound (CEUS) technique in the case of RAS. This technique has been under development since 1996, showing significant improvements with second-generation contrast agents. However, it contains a risk inherent to minimally invasive procedures, since the intravenous injection of a contrasting agent is required. Another drawback has been the cost of contrast in developing countries. However, promising results have emerged in the evaluation of RAS and in the evaluation of other renal and intra-abdominal pathologies.

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