Renal Artery Stenosis using different Doppler Parameters: A review study

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Abstract: It is still a matter of debate as to which Doppler parameters should be used for non –invasive diagnosis of renovascular disease by renal Doppler sonography. The accuracy of renal Doppler sonography in detection of renal artery stenosis depends on the parameters which are used for this condition. The purpose of this article is to review the available literature regarding the use of Doppler ultrasound for detection of renal artery stenosis as well as to provide general overview of the best Doppler parameter which has high accuracy in detections of renal artery stenosis. Studies of Doppler ultrasound for detection of renal artery stenosis were identified from a search of the internet scientific databases. The literature was limited to journal articles that were written in English and published after 1990 to ensure that the literature being reviewed was recent and up to date. There were 25 studies were evaluated. The data analysis showed high sensitivity and specifity for all Doppler parameters.The findings of the study illustrate that the combined approach to the main renal artery and to the intrarenal artery seem to be the ideal technique.

[Musa M, Sulieman A, Abdallah A, Ahmed B. **Renal Artery Stenosis using different Doppler Parameters: A review study.** *J Am Sci* 2013;9(4):493-498]. (ISSN: 1545-1003). http://www.jofamericanscience.org. 53

Keywords: Ultrasound; Doppler parameters; Renal artery; artery stenosis

1. Introduction

The initial discovery of the Doppler Effect was begun back in 1843 (Frederick, 2006). Coupled with the introduction into the scientific world of the concept of acoustic wave generation, the first use of the transmission of ultrasound signals and analysis of the return signals through the Doppler equations allows scientist to measure the motions of objects at a distance from the transducers. Imaging ultrasound was first used on humans in 1926. Doppler ultrasound was first incorporated into medical research in 1943 (P.R.Hoskins, 2003). The primary long-standing applications included monitoring of the fetal heart rate during labor and delivery and evaluating blood flow in the carotid artery. Applications that have developed largely in the last two decades have extended its use to virtually all medical specialties including cardiology, neurology, radiology, obstetrics, pediatrics, and surgery. Doppler technology today allows detection of flow even in vessels that are too small to imagine. Non –invasive ultrasound imaging continued to progress through 1970, when the first commercial instruments became available. At the same time, improvements in technology were allowing scientists to incorporate Doppler measurements into non- invasive diagnostic machines. The first commercially available Doppler ultrasound machines were finally introduced in 1976 (Paul L, 2000). It wasn't until the 1980 that ultrasound imaging, coupled with the use of appropriate calibrations system, finally produced quantitatively accurate images. We have now entered a time in the evolutionary process where, with the use of proper calibrations system, Doppler ultrasound can be used to generate highly accurate blood flow data (Mike Stocksley, 2001). When evaluating the various diagnostic techniques available today, it is apparent that ultrasound is truly the technique of the future. It is the safe, effective and lowest in the cost of all the imaging modalities.

For these reasons and despite the wide spread use of computerize tomography and magnetic resonance imaging, ultrasound examinations remains the primary diagnostic technique for evaluations of many disease especially renal pathology. Color duplex ultrasound has added an important dimension to renal ultrasound studies especially for patients with renal artery stenosis (RAS). The benefits of properly performed Doppler ultrasound almost always will provide the directions of blood flow, speed of blood flow and the site of stenosis (William D, 2004).

Renal artery stenosis (RAS) is most often caused by atherosclerosis or fibro muscular dysplasia. The narrowing of the renal artery can impede blood flow to the target kidney. Hypertension and atrophy of the affected kidney may result from (RAS), leading to renal failure if not treated. The etiology of (RAS) is atherosclerosis, which is predominant cause of (RAS) in the majority of patients usually those of a sudden onset of hypertensions at age of 50 years older. Fibro muscular dysplasia is the predominant cause in young patients usually female under 40 years of age (Micheal R, 1998).

A variety of other causes exist, these include renal artery aneurism, anteritise, extrinsic compression, neurofibromatosis and fibrous bands. The prevalence of (RAS) is increasing globally. It is estimated to be between 2% (unselected hypertensive) and 40% (older patients with atherosclerosis). The rate of (RAS) in patients with diabetes mellitus is higher because they have higher prevalence of atherosclerotic vascular lesions (Ugur, 2009).

Renal artery stenosis (RAS) can be diagnosed by angiography or anteriography, computerized tomography, magnetic resonance imaging and ultrasonography. Anteriography is the most invasive procedure, since a catheter or small tube needs to be threaded through the arteries in the grown into the renal artery and contrast injected. Nowadays arteriogram is rarely needed for diagnostic purpose only. CT will show all the blood vessels in the abdomen as well as the other organs. The intravenous contrast used may have potential to cause some kidney damage or deterioration of renal function and the procedure related complications at the site of arterial puncture or catheter induced embolism. Magnetic Resonance Angiography (MRA) produce excellent contrast enhanced angiogram without the risk of contrast media and radiation exposure. It provides accurate information about the number of renal arteries, the size of the kidney and the presence of anatomical variations, but on the other hand, MRA is expensive and its availability is limited. Doppler ultrasound is simple non invasive method which can be used to appropriate the amount of blood flowing through the renal artery to the kidney and to measure the velocity of blood. It has a high sensitivity in expert hands. The benefits and risk of each procedure needs to be assessed for each patient to decide what would be most appropriate in a given situation (Battaglia, 2012).

The application of ultrasound in medical diagnosis show continuous development and growth over several decades. In many areas, ultrasound is now chosen as the first line of investigations before alternative imaging technologies (Matthias,2000). Early primitive display mode such as A- mode and static B-mode, borrowed from radar technologies have given way to high performance, real time imaging. Modern ultrasound system do much more than produce image for unborn babies, however the Doppler effect is used to study motion within the body, particularly that of blood. New ultrasound machines are able to make detailed measurement of blood movement in blood vessels as well as show moving two dimensional images of flow patterns.(Paul L,2000)

The purpose of this article is to review the available literature regarding the use of Doppler ultrasound for detection of renal artery stenosis as well as to provide general overview of the advantages of Doppler parameter which has high accuracy in detections of renal artery stenosis.

2. Material and Methods

A comprehensive literature search was conducted to find studies on the diagnosis of renal artery stenosis in which duplex sonography considered to be the modality of choice and in which sensitivity and specialty were calculated. The research strategy for this particular review used the database pub med, sage and science direct in additional to reference list. Keywords used, alone or in the combination, for this review of the available literature was; renal artery stenosis, Doppler indices, renal sonography and renovascular hypertension. The literature was limited to journal articles that were written in English and published after 1990 to ensure that the literature being reviewed was recent and up to date. There were no restrictions on the country of origin where the publications were produced, which help to provide a range of opinions and experiences. Articles identified from the refined search results were further reviewed on an individual basis for content. Inclusion criteria consisted of the general use of Doppler ultrasound in patients with renal artery stenosis.Other methods of examination which can be used for detection of (RAS) like angiography,CT and MRI were excluded from the research.

3. Results and Discussion

Doppler ultrasound for RAS is a multidirectional method that can vary in its accuracy depending on parameters and indices and their locations of measurement. Although it was not preferred to use one single parameter of Doppler ultrasound for detection of (RAS), all the parameters that were identified in the literature showed a high sensitivity and specifity. These parameters were instrumental in revealing key components to be considered when we make Doppler ultrasound for (RAS). These components being; the types of Doppler indices, the site of measurement and benefits of these indices (Gabrielle,2007).

Doppler Indices:

The technique of Doppler ultrasound for patients with (RAS) depends on the use of Doppler indices. The literature identified many indices which can be used for evaluating (RAS). These indices, together with their normal values are shown in table (1) (Paul L, 2000). They are usually incorporated into the software of ultrasound machines. The first and simple index for evaluating (RAS) is peak systolic velocity (PSV). The common site of measurement of (PSV) is either extra renal, in the main renal artery or intra renal in the interlobar arteries. Renal aortic ratio (RAR) is another type of index focus on the ratio between (PSV) of main renal artery and that of the aorta (Figure1). The literature identified many articles use these two indices; Hoffman etal (1991) used (PSV) greater than (180cm/sec) for main renal artery to discriminate (RAS) with sensitivity of (95%) and specify of (90%). He also used (RAR) of 3.5 and identified (RAS) greater than 60% with sensitivity of (92%) and specifity of (62%). Similar values of sensitivity and specifity were obtained by other authors such as Ali F. Abdurahman etal (2012), who used the (PSV) of the main renal artery and renal aortic ratio. He found a cutoff point equal to 285cm/sec for (PSV) and 3.7 for (RAR).R Zouza de diveria et al (2000), showed a sensitivity of (83%)and specifity of (89%) and a cut off value for (PSV) equal to 150 cm/sec. All these extra renal values was found to have accuracy for (RAS) greater than 60%.Other direct sampling of the extra renal arteries in the literature are shown in table(2). But Li JC et al. (2006) used (PSV) greater than 25cm/sec of the interlobar artery with a sensitivity of (81%) and made ratio between (PSV) of the interlobar artery and (PSV) of the main renal artery, and he found that it was equal to 180cm/sec. in this study a combination of two indices: peak systolic velocity of the main renal artery and that of the interlobar artery (RIR) are used as a ratio and were found to have a sensitivity of (91%) and specifity of (87%) and a cutoff point equal to greater than 5. This combination showed new diagnostic index; (RRR) or (RIR), which was based on the fact that increased blood flow velocity across the stenosis and the immediate post stenotic segment and the observed decreased in the blood flow velocity distal to the stenosis is proportional to the degree of stenosis (Gulgun,2003). Sergio chain etal, (2006) used the new (RAR) and showed a sensitivity of (9 7%), specifity of (96%), positive predictive value of (97%) and negative predictive value of (97%). Because (RRR) used comparative velocity, it increases the diagnostic assurance to the operator, but the problem of this index is that there was little difference between the diameter of the main renal artery and the diameter of the interlobar artery; by contrast (RAR) uses the abdominal aorta, which has much large diameter.

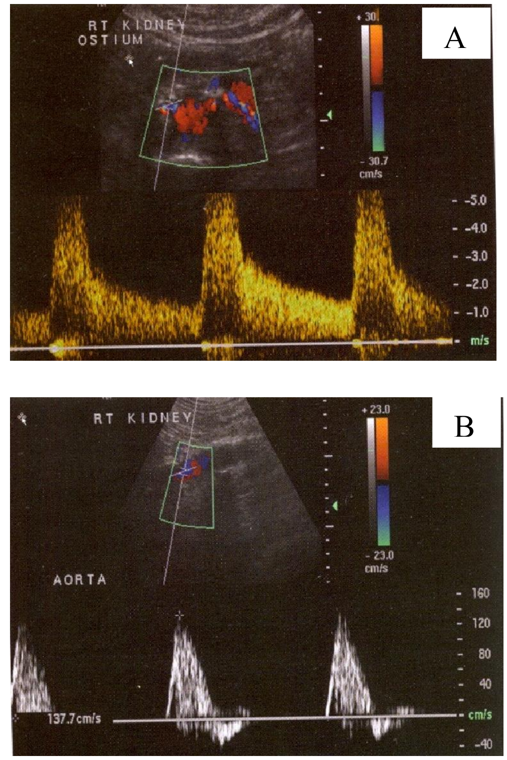

Figure 1. **A:** spectral Doppler sonography of extrarenal artery showed increased velocity ›400cm/sec**. B:** increased aortic velocity (138cm\sec) and increased renal aortic ratio (Barry B,2006)

Resistive index (RI) is the most common type of index which is also used for the assessment of renal artery blood flow. Initially this index was introduced by Pourcelot for the grading of stenosis of the carotid artery (Matthias, 2000). It is independent of beam angle and it can be calculated as: peal systolic velocity minus end diastolic velocity divided by systolic velocity: (Paul L,2000)

PSV-EDV

$$RI = \frac{\left(V_{systole} - V_{diastole}\right)}{V_{systole}}$$

In healthy subject the (RI) values will show minimal differences with one kidney and between the kidneys. A mean value was calculated from the (RI) for each kidney. (RI) also shows a significant dependence on age and area sampled. The values in the main renal artery are higher in the hilar region reaching (0.65±0.7) than in more distal smaller arteries and they are lowest in the interlobar arteries (0.54 ± 0.2). According to the literature the best sampling sites are segmental and interlobar arteries (Bernd,2012). (RI) values are also age dependant: they are higher in elderly patients and they are also increases in hypertensive patients. A further cause of variability in (RI) related to acute renal failure, obstruction in the pelvis, compression, bradycardia and acute rejection (Matthias, 2000). The literature showed that (RI) can be obtained extra renal or intra renal. Santos.S.N. etal, (2010) used (RI) of the main renal artery to predict the outcome of renal revascularization in patients with (RAS). From the total number of patients (106), 25 (24%) have an (RI) less than 0.8 and 81 (76%) were found to have an (R1) greater than 0.8. Gruenewald et al. (2002) introduced the (RI) obtained in the interlobar arteries as a reliable parameter for detecting (RAS). The author calculated the side-to-side difference of intrarenal (RI) greater than (5%) with lower (RI) in the post stenotic area. Sensitivity and specifity were 100 and 94% respectively for moderate to severe (RAS). Rademacher et al.(1998) found that intrarenal (RI) $\geq$ 80 obtained in segmental arteries was highly predictive of treatment failure in patients with atheroschotic (RAS). The Literature also identified several factors influence intarenal (RI); these factors include: the extend of stenosis, the distensibility/stiffness of the cardiovascular system, non-renal factors and the location of intrarenal Doppler measurements (Matthias,2000). Bearing these factors in mind, it might be valid to question whether high intrarenal (RI) is really an indicator of advance morphological damage and is it helpful in predicting the interventional outcome in patients with (RAS)? The above mentioned factors should be considered when intrarenal (RI) was used as parameter to predict interventional success.

Pulsitility index (PI) is another index, which can be used for evaluating (RAS). It was described as peak systolic velocity minus end diastolic velocity divided by mean velocity. It reflects both reverse diastolic flow and a wide range of velocities. Arterial obstruction causes increased pulsitility in portion of the artery proximal to the stenosis. For example with severe obstruction in intrarenal arteries, the Doppler spectrum in the main renal artery has high pulsitility features rather than normal low pulsitility pattern. Bandelli Moreno et al. (1992) used (PI) and he found that it was higher in hypertensive patients without (RAS) and lower in kidneys with significant (RAS) than in kidneys without (RAS).

There are some other parameters which can be used as an indirect method for evaluating (RAS). These parameters include: tandus parvus waveform appearance, accleration time and acceleration index. Tardus parvus waveform appearance is related to the shape of Doppler waveform in (RAS). This appearance results from the slow rise to the peak systolic velocity distal to the site of stenosis. Idetification of the tardus parvus waveform is diagnostic feature of (RAS) (Figure 2). Acceleration time is measured from start of systole to the peak and when it is greater than (0.07) second it is consistent with (RAS) exceeding 60%.The acceleration index was calculated by peak systolic velocity divided by acceleration time (Stish K, 2003). Martin etal. (1991) Investigated the role of acceleration time and acceleration index and he found 87% sensitivity and 98% specifity. Halpern etal. (1995) on the other hand found the acceleration time was the most important parameter to be measured when (RAS) is suspected. Also an abnormally shaped intrarenal artery waveform may indicate for (RAS). Slavros etal. (1992,1994) Found that the loss of the normal early systolic peak (ESP) is adequate to suggest the diagnosis of (RAS) and that this finding was better than other calculation method like peak systolic velocity or acceleration time. Conkbay et al. (2003) showed that indirect parameters did not show better results than the other direct parameters. MA Kliemer et al. (1993) showed that Doppler characterization of the tandus-parvus phenomena in the main renal artery is not an adequate screening method for detection of (RAS).

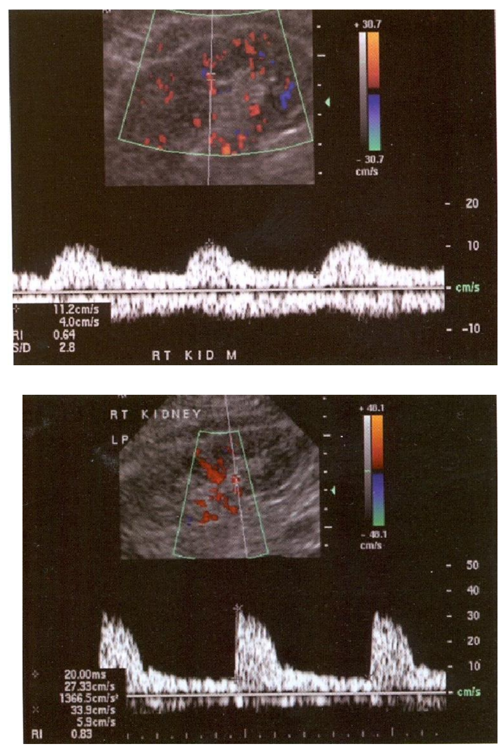

Figure 2: **A**: Tardus parvus waveform in patient with (RAS),**B**: spectral Doppler for the same patient after angioplasty (Barry B,2006)

Table (1): Normal renal artery Doppler indices. (Paul L, 2000)	
Index	Ranges
Pulsatility Index (PI)	0.7 – 1.4
Resistive Index (RI)	0.56 – 0.7
Peak Systolic Velocity (PSV)	60 - 140
Diastolic/Systolic ratio (D/S)	0.26 – 0.4
Renal artery/aortic ratio (RAR)	<3.5
Acceleration Time (AT)	42 – 57ms
Acceleration Index (AI)	250 – 380 m/sec^2

Table 2: Specifity and sensitivity of duplex ultrasoud using direct sampling of extrarenal arteries		
Study	Sensitivity	Specify
Olin,etal (1995)	98	99
Hansen etal (1990)	93	98
Halpern etal (1995)	71	96
Krumm etal (1996)	71	96

Advantages of Doppler indices:

Conventional ultrasound for the kidney is used commonly to depict structural abnormalities. It is limited, however, by the lack of functional and vascular information. Doppler sonography can reduce this limitation of standard sonography quickly and non-invasively. Doppler examinations, although not difficult, must be done properly to obtain useful data. Information regarding the presence and direction of flow in renal vessels can be obtained. Several Doppler indices can identify vascular stenosis in the kidney. Assessment of vascular resistance by resistive index is possible from Doppler waveform analysis. The use of resistive index will provide hemodynamic and predictive information regarding a dilated collecting system identified by conventional ultrasound.

Analysis of resistive index also may provide helpful clinical information in non-obstructive renal disease. In certain clinical setting, such analysis provides diagnostic data not readily available with other clinical and laboratory assessment methods. Although the accuracy of the previously mentioned Doppler parameters in detecting (RAS) is varied, the great numbers of the parameter can help the operator to select the most suitable and combined parameter which can help him in easily diagnosing (RAS).

Limitations:

The major limitation of Doppler ultrasound is that it is highly operator dependant. It needs an operator with high experience and interest to overcome the problems of this technique. The measurements of the different Doppler indices can suffer from aliasing especially if stenosis was detected. This aliasing is going to make misleading in the diagnose of (RAS). Another problem which also limits the diagnose of (RAS) and the measurement taken is the presence of small echoes beside the original one in the spectrum due to the detection of different velocities within the vessel. Increasing pulse repetition frequency (PRF) can reduce aliasing and spectral broading and improve the measurement techniques. Even with this improvement, however, accuracy of Doppler ultrasound depends on the patient status. For obese patients the procedure will be difficult and it will be hard to see the deep vessels and measure the velocity. It is also difficult to obtain the suitable Doppler measurements if the patient is not well prepared. The total reflection of ultrasound from the gases in the abdomen will also make the procedure difficult. Sometimes the weakness of blood flow from obstructed vessel due to small undetectable signal , will make the procedure difficult even we use power Doppler imaging. Combination technique by using more than one velocity parameter is a new technique to overcome these problems and to improve the diagnosis of (RAS).

4.Conclusion

Doppler sonography has been steadily improved over the last years and is now frequently used as first line screening test for patients with suspected renal artery stenosis. In addition, arguments have been presented to indicate that it may also be useful to predict the outcome after revascularization by using Doppler indices. Although there are many Doppler parameters (extrarenal and intrarenal) help in diagnose of (RAS) in the literature, it is important to recognize that isolated use of intrarenal Doppler sonographic parameter may lead to an unacceptably high incidence of false-negative results in the diagnose of this condition. Some single extrarenal parameter like peak systolic velocity of the main renal artery and renal aortic ratio (RAR) has the highest performance characteristics. But the combined approach to the main renal artery, as well as to the intrarenal arteries seem to be the ideal technique to overcome the limitations of this procedure, such as impaired visualization due to bowel movement and obesity. Due to anatomical and environmental variations for the value of Doppler indices, it is suggested that each country should have his own reference value for these indices. Pharmacologically stimulated renal Doppler examination may lead to even great benefits in the future.

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13/3/2013