

Extracting Quantitative Parameters From a Mathematical Model Fitted to Renal Artery Blood Flow Data obtained by Magnetic Resonance Angiography

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Introduction

Renal artery stenosis is a well-known cause of high blood pressure, but it may also be a cause of impaired renal function. 3-D gadolinium-enhanced magnetic resonance angiography (3D-Gd-MRA) can describe arterial morphology in three dimensions, and functional information regarding blood flow can be obtained in the same examination. Reduced mean flow is a potential marker for detecting renal artery stenosis¹. However, due to the autoregulatory capacity of the kidney, the mean flow remains constant even for severe stenosis². An alternate approach is analysis of blood flow profile curves³. As the analysis is mostly carried out visually, it is subject to interobserver variability. The aim of this study was to investigate whether it is feasible to extract from a mathematical model fitted to renal blood flow profile data quantitative parameters that may prove useful for diagnosis of renal artery stenosis.

Materials and methods

Eight patients with significant renal arterial stenosis verified by CT angiography and 5 without stenosis were investigated in a 1.5 T scanner (Philips Achieva). Quantitative flow measurements were performed in the abdominal aorta and in each renal artery using an ECG-triggered 2D phase-contrast sequence ($v_{enc} = 200$ cm/s, 32 cardiac phases). The velocity maps were then transferred to a workstation (Philips ViewForum), and flow curves corresponding to each vessel were obtained. The data were then transferred to a curve-fitting program on a PC/Windows workstation (WinCurveFit 1.1.8, Kevin Raner Software). The program uses a simple mathematical model relating flow (Q) to time within the cardiac cycle (t) (Eqn. 1 and Fig. 1) and performs non-linear regression, selecting the values of the seven parameters that result in the closest fit to measured data in the least-square sense. The model was fitted to the aortic and renal artery blood flow data for each patient and the fit was evaluated with the R^2 value.

Results

In total, 13 patients with 3 data sets each were analyzed. Three data sets yielded R^2 values less than 0.80 and were considered unreliable for parameter extraction and excluded. In all, 29 out of 39 flow curves yielded R^2 values exceeding 0.90. An example of curves fitted to renal blood flow data is given in figure 2. Estimated values of the parameters in the two groups of patients are shown in Table 1.

Discussion

The results of this feasibility study suggest that it is possible to use a mathematical model to extract quantitative parameters from renal blood flow data. It should be noted that no physiological assumptions have been made concerning the renal blood flow profile, and that the model simply describes the shape of the curve. As no correlation between the flow curves and the clinical degree of renal artery stenosis was made, it remains to investigate what conclusions can be drawn from the estimated parameters.

The use of a mathematical model fitted to the entire renal blood flow curve favors extraction of several parameters at once, and the sensitivity to noise in the curve is expected to be less when the extracted parameters are not determined by one or two values, as in previous studies, but by the entire curve.

The curve fitting software requires the user to enter initial values for each parameter and an initial curve is plotted, thus showing whether these values produce a curve running close to the data points or not. This means that our method is not completely free of subjective elements.

In conclusion, the results of this study suggest that it is technically feasible to use a mathematical model describing the shape of MR flow curves to extract quantitative parameters. However, further studies are needed to evaluate whether these parameters may be clinically useful as a tool in diagnosing renal artery stenosis.

Table 1. The mean (standard deviation) parameter values of flow curves from patients with significant renal artery stenosis (S) and patients without stenosis (N). In group S, the artery with significant stenosis was used in the calculations. In group N, the right renal artery was used.

Group	Parameter							
	<i>a</i>	<i>b</i>	<i>c</i>	<i>d</i>	<i>e</i>	<i>f</i>	<i>g</i>	<i>h</i>
S (<i>n</i> =7)	1.2 (3.6)	9.3 (13.9)	88.9 (61.8)	85.6 (149.0)	360.2 (166.5)	229.0 (254.8)	2.3 (4.1)	541.2 (331.0)
N (<i>n</i> =5)	3.6 (2.5)	6.8 (2.8)	103.3 (25.1)	19.3 (13.6)	350.8 (221.5)	145.5 (59.6)	-1.5 (4.7)	455.1 (138.4)

References

1. de Haan MW, van Engelshoven JMA, Houben AJHM, et al. Phase-Contrast Magnetic Resonance Flow Quantification in Renal Arteries – Comparison with ¹³³Xenon Washout Measurements. *Hypertension*. 2003;41:114-118.
2. May AG, de Weese JA, Rob CG. Hemodynamic effects of arterial stenosis. *Surgery* 1963;53:513-524.
3. Schoenberg SO, Knopp MV, Bock M, et al. Renal Artery Stenosis: Grading of Hemodynamic Changes with Cine Phase-Contrast MR Blood Flow Measurements. *Radiology*. 1997;203:45-53.

$$Q(t) = a + b \times \tanh\left(\frac{t-c}{d}\right) - b \times \tanh\left(\frac{t-e}{f}\right) - \frac{g}{(t-h)^2 + 1}$$

Equation 1

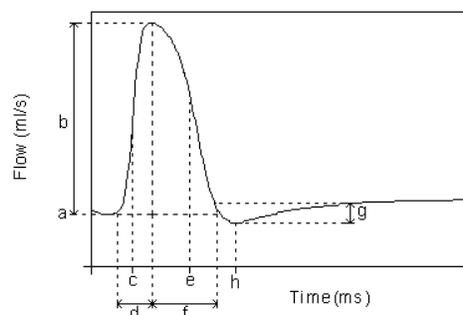


Figure 1. Graphical illustration of the meaning of each parameter. *a* denotes the base-line flow; *b* the height of the systolic peak, *c* the position in time of the acceleration; *d* its duration; *e* the position in time of the deceleration, *f* its duration; *g* the depth of the post-systolic incisure, and *h* its position in time.

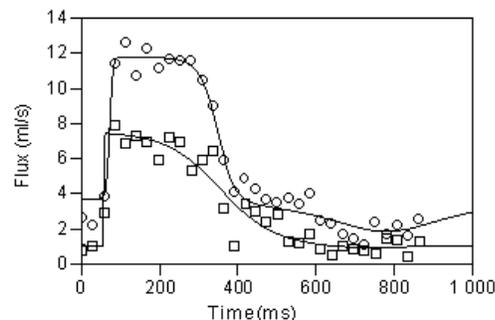


Figure 2. Example of curves fitted to renal artery blood flow data from the normal right (circles) and stenotic left (squares) renal artery in a patient with a significant stenosis (>50% diameter reduction) of the left renal artery.