Kidney International, Vol. 53 (1998), pp. 1795–1800

Effects of balloon angioplasty and stent implantation on intrarenal echo-Doppler velocimetric indices

IVANA MARANA, FLAVIO AIROLDI, LARRY BURDICK, CRISTINA ALBERTI, ANDREA LOVARIA, SILVIA SACCHERI, GABRIELLA GAZZANO, SIMONE PALATRESI, BARBARA NADOR, LUCIA TUROLO, and ALBERTO MORGANTI

Istituto di Clinica Medica Generale e Terapia Medica and Centro di Fisiologia Clinica e Ipertensione, Università di Milano, and Servizio di Radiologia IRCCS, Ospedale Maggiore, Milano, Italy

Effects of balloon angioplasty and stent implantation on intrarenal echo-Doppler velocimetric indices. This study was aimed at examining whether four intrarenal echo-Doppler velocimetric indices (pulsatility and resistive indices, acceleration and acceleration time) can be useful for assessing the effects of renal artery dilation obtained with either angioplasty or stent implantation. Echo-Doppler studies were performed in 63 hypertensive patients with 68 renal artery stenoses (39 atherosclerotic and 29 fibromuscular) prior to and within five days after the dilation procedures (55 angioplasties, 13 stent implantations), which resulted in an average reduction of arterial narrowing from 79% to 20%. In 24 patients, the velocimetric indices were also examined in relationship to the venoarterial differences of plasma renin activity and of angiotensin II across the stenotic kidneys. We found that after dilation the values of the four indices had returned within the normal range in all but three arteries (one false negative for resistive index and two for acceleration time). However, decrements in acceleration time was the only factor to be significantly correlated with the reduction of arterial narrowing. Moreover, post-dilation values of this index were, on average, slightly but significantly higher in arteries that at follow-up developed restenosis rather than in those that remained patent. For similar reductions in arterial narrowing the absolute changes of all indices were similar in atherosclerotic and fibromuscular stenotic arteries and, in a subset of the atheromatous arteries, were also similar after angioplasty and stent implantation. No relationship was found with the changes in the venoarterial differences of plasma renin activity and angiotensin II. It appears that these intrarenal velocimetric indices and, in particular, acceleration time reliably reflect the technical success of renal artery dilation. The acceleration time index may also be valuable for predicting the restenosis of the dilated vessel. None of the indices, however, mirrors the functional consequences of removal of renal artery stenosis as expressed through the changes in transrenal gradients of the components of the renin-angiotensin system.

Among the screening tests currently available for diagnosing renal artery stenosis, the Doppler ultrasound scanning test is increasingly appreciated not only because of its ability of visualizing the arterial narrowing, but it offers the possibility of estimating the consequences of arterial narrowing on renal blood flow through the evaluation of the echo-Doppler velocimetric indices [1]. Moreover, as this technique is noninvasive, its repeatability and relatively low cost make it ideally suited to assess the effects of stenosis removal [2] and in long-term studies reveal its recurrence [3].

Several studies have examined how a technically successful renal angioplasty affects some echo-Doppler velocimetric indices [4–8], but none has thoroughly investigated the so-called distal or intrarenal indices, which in our experience [9] and in that of others [10–12], are the most accurate in detecting renal artery stenosis. Also, to our knowledge, no studies have comparatively examined the effects of balloon angioplasty and stent implantation on these indices. Such data may be relevant in view of increasing application of the latter procedure for treating renal artery disease [3]. In this study we attempted to establish which index (if any) among the pulsatility and resistive indices, acceleration and acceleration time, best reflects the changes in arterial caliber induced by these two dilation procedures. In doing so we separately examined the atherosclerotic and the fibromuscular renal artery stenosis because it is known that the absolute values of velocimetric indices are markedly affected by the etiology of the lesion [9, 13, 14]. We also attempted to correlate baseline velocimetric indices and their changes after dilation to those in the venoarterial differences of plasma renin activity (PRA) and of angiotensin II (Ang II) across the stenotic kidney, these latter levels being taken as the humoral markers of the functional consequences of the stenosis [15, 16].

METHODS

Patients

Sixty-three patients (37 males and 26 females, mean age 47 years, range 16 to 82) admitted for evaluation of moderate to severe hypertension participated in the study. All but 8 of them were on treatment with antihypertensive agents that included calcium antagonists ($N = 34$), beta-blockers ($N = 9$), angiotensin converting enzyme inhibitors ($N = 22$), alpha-blockers ($N = 4$) and diuretics ($N = 3$), either alone or in combination. In the course of their diagnostic work-up all patients underwent a conventional angiography that revealed 39 atherosclerotic renal artery stenoses (33 unilateral, 2 bilateral and 1 case with two stenotic arteries on one side) and 29 fibromuscular dysplasias (25 unilateral, 2 bilateral); nine occluded arteries were also found, however, they were excluded from the analysis for the purposes of

Key words: atherosclerotic stenosis, fibromuscular renal artery stenosis, plasma renin activity, angiotensin II.

Received for publication September 29, 1997
and in revised form January 12, 1998
Accepted for publication January 15, 1998

this study. Patients with atherosclerotic stenosis were older (58 ± 2 vs. 33 ± 2 years, $P < 0.01$), had higher values of serum creatinine (1.43 ± 0.1 vs. 0.96 ± 0.05 mg/dl, $P < 0.01$) and had lower values of diastolic blood pressure than patients with fibromuscular stenosis (88 ± 2 vs. 97 ± 2 mm Hg, $P < 0.05$), whereas systolic blood pressure was similar in the two groups (155 ± 3 and 153 ± 3 mm Hg, respectively). After the dilation procedures patients were kept in the hospital for at least five days for blood pressure and renal function monitoring. Adjustments in the antihypertensive regimen were modified according to the clinical needs and were entirely withdrawn in six patients. During this time patients underwent the echo-Doppler control studies. Patients were then discharged and entered a follow-up protocol that included a periodical physical examination, an evaluation of renal arteries patency by echo-Doppler and, whenever clinically advisable, an angiographic control study.

Angiographic grading of stenosis, ballon angioplasty and stent implantation techniques

To evaluate the severity of the stenosis, two or more views of all arteriograms were taken. The degree of arterial narrowing was estimated visually by one of our vascular radiologists (A.L. or S.S.), who compared the caliber of the vessel at its narrowest point with that distal to the stenosis just before the bifurcation. Accordingly, the stenosis was judged to be in the range 50 to 59% in 9 arteries, 60 to 80% in 33 arteries and greater than 80% in 26 arteries. Because of the clinical suspicion of renovascular hypertension, all patients initially underwent a balloon percutaneous transluminal angioplasty that was performed according to the conventional technique described by Tegtmeyer and Sos [17]. The technical outcome was immediately evaluated with a control angiogram that resulted in a reduction of arterial narrowing to less than 50% of the caliber of the vessel (on average 20%) in 55 arteries, 26 of which with atherosclerotic and 29 with fibromuscular lesions. In the former group the residual stenosis was 0 to 20% in 7 cases, 21 to 40% in 7 cases and 41 to 50% in the remaining 12 cases, whereas in the latter group the corresponding numbers were 11, 12 and 6. In the remaining 13 atherosclerotic stenoses in which the results of angioplasty were considered unsatisfactory, that is, when the resudual stenosis was greater than 50%, a Palmaz stent was implanted. The stent was delivered through the same angioplasty balloon previously used for angioplasty, and its length was selected in order to cover entirely the atheromatous lesions. The stent was fitted to protrude by 1 to 2 mm into the aortic lumen and its correct positioning was verified with a final control angiography. The residual stenosis after stent implantation was evaluated by the same radiologist who performed the angioplasty and it was always found less than 25%. Antiplatelet medication was given to all patients after the procedure, except in nine in whom it was contraindicated.

Humoral measurements

These determinations were carried out in 24 patients (10 with atherosclerotic and 14 with fibromuscular stenosis) who were not on treatment with angiotensin converting enzyme inhibitors. Prior to renal angioplasty, via catheterization of the femoral vein blood samples were collected from the renal veins and simultaneously from the aorta for the measurements of PRA and of Ang II. This collection was repeated 60 minutes after the completion of the dilating procedures. The venoarterial differences of PRA and of AngII across the stenotic and the normal kidneys were calculated according to the formula

$$\frac{V - A}{A}$$

where V and A are the values of PRA and Ang II in the renal veins and in the aorta, respectively. For PRA values of this ratio ≥ 0.5 and ≤ 0 indicate a lateralization and a suppression of renin secretion, respectively, and are suggestive of a functionally significant renal artery stenosis [15]. PRA was measured with the enzymatic method using a radioimmunoassay, quantifying the amount of angiotensin I generated during one to three hours of incubation of plasma at 37°C and pH 5.7. The sensitivity of the entire assay was 0.25 ng/ml/hr and its interassay reproducibility was 11% [18]. Angiotensin II was measured by radioimmunoassay after extraction of the peptide from plasma as described in detail elsewhere [19]; the sensitivity of the method is 1.25 pg/ml and its interassay reproducibility 16%.

Renal Duplex technique and calculation of velocimetric indices

Ultrasound evaluations prior to and after dilation were always performed by one of us (L.B., I.M. or F.A.) who was unaware of the technical outcome of the procedure. Studies were carried out with an Ultramark 9HDI apparatus (Advanced Technology Laboratories, Bothell, WA, USA) employing a 3 MHz phased array probe and color flow mapping in order to speed up the identification of renal arteries. The examinations were carried out in fasting patients as described in detail elsewhere [9]. In brief, renal arteries were always interrogated in their distal portion or in the interlobar branches in order to optimize the quantitation of the velocity changes. Also, particular care was taken in obtaining the best possible angle of insonation of the artery, that is, close as possible to 0°. From analysis of at least three homogeneous Doppler spectra the following parameters were then derived: maximum systolic velocity (V_{max}), minimum diastolic velocity (V_{min}), mean velocity (V_{mean}) and the time from beginning of systole to first inflection point or first peak (t). From these parameters the following indices were calculated:

$$\text{Pulsatility index} = \frac{V_{max} - V_{min}}{V_{mean}}$$

$$\text{Resistive index} = \frac{V_{max} - V_{min}}{V_{min}}$$

$$\text{Acceleration} = V_{max/t}\ (\text{m/sec}^2)$$

$$\text{Acceleration time} = t\ (\text{msec})$$

In our hands the intraobserver reproducibilities obtained in normal arteries for the four indices were 7%, 5%, 12% and 11%, respectively.

Statistical analysis

Values of all parameters observed prior to dilation were compared to those observed after it using a Student's *t*-test for paired data. A P value < 0.05 was considered statistically significant. The least squares analysis was used to determine the correlation coefficient between two variables.

Table 1. Effects of dilation (angioplasty or stent implantation) on velocimetric indices in renal arteries with atherosclerotic and fibromuscular stenoses and in contralateral normal arteries

	Patients with atherosclerotic arteries				Patients with fibromuscular stenosis			
	Stenotic arteries		Contralateral normal arteries		Stenotic arteries		Contralateral normal arteries	
	(%) Before	(%) After	Before	After	(%) Before	(%) After	Before	After
Pulsatility index	(78) 1.0 ± 0.06[c] (39)	(20)[a] 1.5 ± 0.06[ac] (39)	1.4 ± 0.07[bc] (25)	1.4 ± 0.08[c] (23)	(79) 0.7 ± 0.05 (29)	(21)[a] 1.2 ± 0.08[a] (29)	1.1 ± 0.06[b] (21)	1.1 ± 0.06 (15)
Resistive index	(78) 0.59 ± 0.02[c] (33)	(17)[a] 0.71 ± 0.02[ac] (33)	0.68 ± 0.02[bc] (21)	0.70 ± 0.02[c] (15)	(90) 0.50 ± 0.02 (25)	(19)[a] 0.63 ± 0.02[a] (25)	0.61 ± 0.02[b] (19)	0.61 ± 0.02 (10)
Acceleration *m/sec²*	(79) 4.1 ± 0.5 (33)	(19)[a] 14.8 ± 1.0[a] (33)	16.8 ± 1.7[b] (21)	17.3 ± 1.5 (15)	(81) 3.6 ± 0.8 (24)	(19)[a] 15.9 ± 1.2[a] (24)	17.2 ± 1.6[b] (19)	17.1 ± 1.2 (10)
Acceleration time *msec*	(79) 117 ± 9 (33)	(19)[a] 40 ± 2[a] (33)	49 ± 6[b] (21)	41 ± 2 (15)	(81) 145 ± 10 (24)	(19)[a] 46 ± 4[a] (24)	43 ± 3[b] (19)	41 ± 3 (10)

Values observed before and after dilation are expressed as means ± SEM. % indicates the mean degree of narrowing of stenotic arteries and *N* in parentesis the number of Doppler evaluations carried out for each index.
[a] $P < 0.05$ after vs. before dilation
[b] $P < 0.05$ stenotic vs. contralateral arteries prior to dilation
[c] $P < 0.05$ normal and stenotic atherosclerotic arteries vs. correspondent fibromuscular arteries both before and after dilation

RESULTS

Effects of dilation on arterial narrowing and on blood pressure

Prior to angioplasty or stent implantation arteries with atherosclerotic and fibromuscular stenosis had a similar degree of narrowing (78 ± 2% and 79 ± 2%, respectively), which was significantly and similarly reduced after the procedures (respectively to 20 ± 3% and 21 ± 3%, $P < 0.01$ for both groups). During the following five days the mean systolic and diastolic blood pressures were reduced by 11/5 mm Hg and by 17/11 mm Hg, respectively, in the two groups ($P < 0.05$ or more for all these changes), and this depressor effect was greater in patients with fibromuscular stenosis than in those with atherosclerotic stenosis for both systolic and diastolic pressures ($P < 0.05$).

Effects on velocimetric indices

At baseline all indices were significantly altered in stenotic with respect to normal arteries (Table 1). Pulsatility and resistive indices, but not acceleration and acceleration time, were significantly higher in atherosclerotic than in fibromuscular stenotic arteries. This difference was also evident in the contralateral normal arteries of the two groups.

The reduction in arterial narrowing induced by the dilation procedures was associated with significant increments in the pulsatility and resistive indices and in acceleration, but with significant decrements in acceleration time. In the normal arteries all indices were unchanged. As a result of these modifications all indices were, on average, similar in dilated and normal arteries.

If the individual values of the four indices observed after dilation were evaluated with respect to the mean ± 2 SD of those previously found in a larger series of normal arteries [9] and set for pulsatility and resistive indices (acceleration and acceleration time respectively at 0.67, 0.53, 3.4 m/sec^2 and 65 msec for atherosclerotic arteries and at 0.61, 0.48, 2.8 m/sec^2 and 65 msec for fibromuscular arteries), it appeared that they had always returned within the normal limits, except in three cases of fibromuscular stenosis in which one abnormal value for resistive index and two abnormal values for acceleration time were observed.

When data were examined taking into account the side to side differences (Δ) between the stenotic and the contralateral normal arteries prior to dilation, the Δ of all indices were found to be consistently higher than those previously observed by us in patients with essential hypertension [9], whereas after dilation they were, on average, normalized (Table 2). However, when the individual changes of Δ were examined with respect to the mean ± 2 SD of the side differences found in patients with essential hypertension [9] and set at 0.55, 0.11, 13.1 m/sec^2 and 29 msec, respectively, for pulsatility and resistive indices, acceleration and acceleration time, it appeared that in 8 cases (4, 3 and 1 cases for pulsatility and resistive indices and acceleration time, respectively) the Δ failed to return within the normal limits.

In a subset of 13 patients with atherosclerotic stenosis in whom a Palmaz stent was implanted, the changes in the four indices were similar to those observed in a group of 12 patients, also with atherosclerotic stenosis, in whom angioplasty was technically successful and resulted in a comparable reduction of arterial narrowing of between 0 and 25% (0.5, 0.11, 11.5 m/sec^2 and 83 msec vs. 0.6, 0.11, 11.3 m/sec^2 and 73 msec for pulsatility and resistive indices, acceleration and acceleration time, respectively). Finally, in ten patients who had angiographic evidence of restenosis of the dilated artery at follow-up, we found that only acceleration time values were significantly higher, after dilation, than those found in arteries that subsequently did not develop restenosis (53 ± 9 vs. 41 ± 2 msec, $P < 0.02$; Table 3).

Humoral effects

Prior to dilation the venoarterial differences of PRA were 1.1 ± 0.3 and 0.8 ± 0.2 in kidneys with atherosclerotic and fibromuscular stenosis, respectively, and these values were higher than those found in the contralateral normal kidneys (0.23 ± 0.08 and 0.04 ± 0.04, respectively; Fig. 1). After dilation the lateralization of renin secretion tended to disappear, in that 60 minutes after the completion of the procedures the venoarterial differences across the dilated kidneys were 0.42 ± 0.1 and 0.38 ± 0.1, whereas the suppression in the contralateral kidney was still present. However, by that time the absolute values of PRA in the aorta had declined from 6.9 ± 1.6 to 5.2 ± 1.4 ng/ml/hr and 5.4 ± 2.6 to 3.7 ± 1.3 ng/ml/hr in patients with atherosclerotic and with fibromuscular

Table 2. Effects of dilatation on side to side differences (Δ) of velocimetric indices in patients with atherosclerotic and fibromuscular stenoses

	Patients with atherosclerotic arteries		Patients with fibromuscular stenosis	
	(%) Before	(%) After	(%) Before	(%) After
Pulsatility index	(79) 0.51 ± 0.08 (22)	(20)[a] 0.24 ± 0.06[a] (22)	(80) 0.49 ± 0.05 (15)	(18)[a] 0.29 ± 0.09[a] (15)
Resistive index	(78) 0.15 ± 0.04 (14)	(16)[a] 0.04 ± 0.004[a] (14)	(84) 0.18 ± 0.3 (9)	(16)[a] 0.09 ± 0.03[a] (10)
Acceleration *m/sec*^{2}	(78) 14.4 ± 1.9 (13)	(15)[a] 6.1 ± 1.0[a] (13)	(84) 16.5 ± 2.3 (10)	(15)[a] 6.6 ± 1.1[a] (10)
Acceleration time *msec*	(78) 74 ± 14 (13)	(15)[a] 8 ± 2[a] (13)	(84) 104 ± 17 (10)	(15)[a] 15 ± 4[a] (10)

Values are expressed as means ± SEM before and after dilatation. Patients with bilateral stenosis were excluded from this analysis. As in Table 1, % indicates the mean degree of narrowing of stenotic arteries and *N* in parentesis the number of Doppler evaluations carried out for each index. The number of calculated Δ is less than that of stenotic arteries (see Table 1) because in same contralateral arteries the indices were not collected prior to dilation.

[a] $P < 0.05$ after vs. before dilation

Table 3. Velocimetric indices before and after angioplasty or stent implantation in arteries that, at follow-up, did and did not develop restenosis

	Before dilation		After dilation	
	No restenosis ($N = 58$)	Restenosis ($N = 10$)	No restenosis ($N = 58$)	Restenosis ($N = 10$)
Pulsatility index	0.9 ± 0.04	0.8 ± 0.13	1.4 ± 0.06	1.4 ± 0.13
Resistive index	0.56 ± 0.01	0.47 ± 0.06	0.68 ± 0.01	0.63 ± 0.05
Acceleration *m/sec*^{2}	3.7 ± 0.5	4.9 ± 1.3	15.7 ± 0.8	12.5 ± 1.7
Acceleration time *msec*	131 ± 7	121 ± 16	41 ± 2	53 ± 9[a]

Among the arteries with restenosis 6 were atherosclerotic and 4 fibromuscular. All were treated with angioplasty, after which the degree of arterial narrowing was similar to that observed in arteries that had no restenosis (25 ± 5% vs. 20 ± 2%, respectively). During follow-up, the absence of restenosis was established on a clinical basis and with negative echo-Doppler studies.

[a] $P < 0.02$ arteries with restenosis vs. without

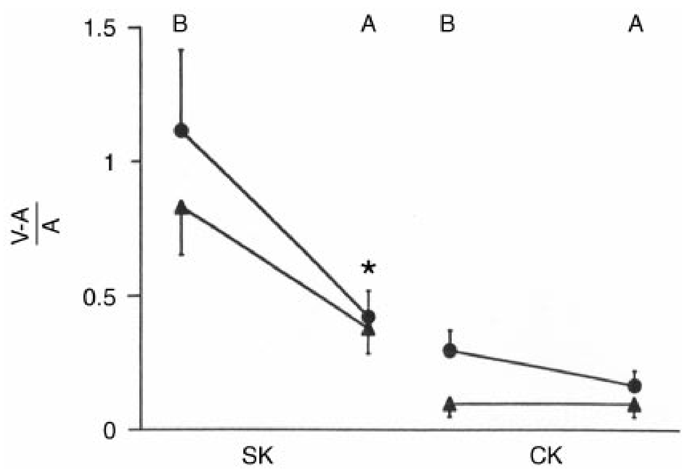

Fig. 1. Venoarterial differences (V-A/A) of plasma renin activity across the kidney with the stenotic artery (SK) and the contralateral normal artery (CK) before (*B*) and after (*A*) balloon angioplasty or stent implantation. Symbols are: (●) patients with atherosclerotic stenosis ($N = 10$); (▲) patients with fibromuscular stenosis ($N = 14$). *$P < 0.05$ for values after versus before dilation.

stenosis, respectively ($P < 0.05$ for both). In the stenotic kidneys the venoarterial differences of Ang II had somewhat similar trends to those of PRA in that after dilation they declined from neutral or slightly positive values to negative values (Fig. 2), whereas in the contralateral kidney the venoarterial differences were already negative at baseline and tended to further decrease afterwards. The aortic values of Ang II were unchanged after dilation (from 17.3 ± 8.6 to 14.4 ± 6.8 pg/ml and from 6.2 ± 1.1 to 8.9 ± 1.3 pg/ml for patients with atherosclerotic and fibromuscular stenosis, respectively).

Regression analysis

Prior to dilation in arteries with atherosclerotic stenosis, no correlation was found between the degree of arterial narrowing and any of the velocimetric indices or the venoarterial differences of PRA and Ang II. In contrast, in arteries with fibromuscular stenosis the degree of narrowing was significantly correlated with the absolute values of acceleration time ($r = 0.48$, $P < 0.01$) and with the side difference of this index ($r = 0.54$, $P < 0.02$). In kidneys with fibromuscular stenosis the degree of narrowing was also significantly correlated with the venoarterial difference of PRA ($r = 0.68$, $P < 0.01$). As to the effects of dilation, the changes in the degree of narrowing induced by this maneuver were slightly related only to the changes in acceleration time ($r = 0.22$, $P < 0.05$) when atherosclerotic and fibromuscular stenosis were considered together. In this respect stratification of velocimetric indices according to the degree of residual stenosis from 0 to 50% showed no significant differences either for atherosclerotic or fibromuscular arteries (Table 4). Finally, no relationship was found between the changes in any of the velocimetric indices or their Δ and those in PRA and Ang II in the dilated and contralateral kidneys as well as with the changes in blood pressure. Equally not significant were the correlations between the changes in blood pressure and those in the degree of improvement of the stenosis and in systemic PRA.

DISCUSSION

In a previous study we showed that the four intrarenal velocimetric indices examined in the current study are quite accurate indicators of a greater than 50% renal artery stenosis [9]. In this study we extended our observation to the effects of removal of the stenosis achieved either with balloon angioplasty or with stent

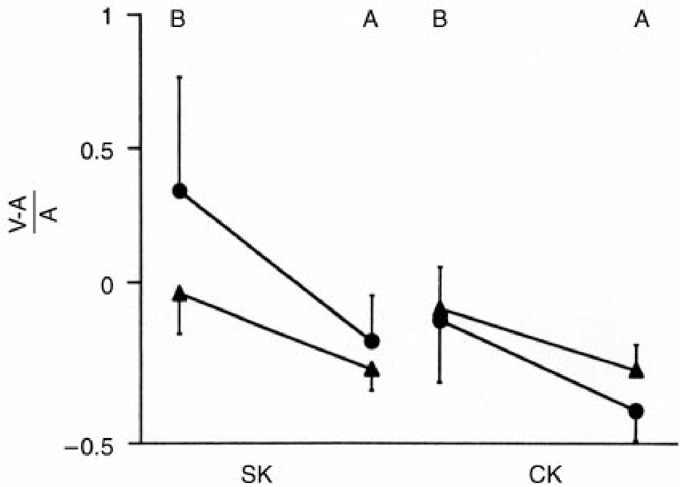

Fig. 2. Venoarterial differences of angiotensin II across the kidney with the stenotic artery and the contralateral normal kidney before and after angioplasty or stent implantation. Symbols are: (●) patients with atherosclerotic stenosis ($N = 9$); (▲) patients with fibromuscular stenosis ($N = 13$). $^*P < 0.05$ for values after versus before dilation.

implantation and found that a reduction of the arterial narrowing to an average of 20% was associated with the normalization of these indices in practically all instances. Indeed, after the intervention procedures only three arteries out of 68 failed to return to the normal range of the indices. These modifications were observed within a relatively short time after the dilation, yet they are likely to reflect the definitive effects of this procedure in that their magnitude, at least for resistive index and acceleration time, were similar to that reported by others in investigations carried out at variable times apart from dilation [3, 7, 8].

To further improve the accuracy in evaluating the outcome of angioplasty, some authors have proposed comparing the side to side differences of these indices and of the resistive index, in particular [3, 14]. Indeed, in comparative studies this index was found to have the advantage of a low inter- and intraobserver variability [20]. However, from our data this approach does not appear convenient in that, even excluding from the analysis the patients with bilateral stenosis that may be an obvious cause of false negative results, in our series there were eight cases in which the Δ failed to normalize after dilation, and in three this was because of the resistive index.

Previous investigations have shown that the absolute values of pulsatility and resistive indices are dependent upon the age of the patient cohort [3, 9, 21, 22]. However, this does not appear to be a limiting factor in their use to assess the effects of dilation, that is, the absolute changes of these two indices as well as those of acceleration and acceleration time after the procedures were, on average, similar in older patients with atherosclerotic stenosis and in the younger ones with fibromuscular stenosis. Thus, for clinical purposes these four intrarenal indices are equally valid for assessing the effects of dilation irrespective of the techniques used to achieve it. Yet acceleration time appears particularly useful in that the observation of values of this index on the high side of normalcy after dilation may help in discriminating which arteries will subsequently develop restenosis.

Our data also provide some insight as to the mechanisms responsible for the changes in the velocimetric indices observed after removal of the stenosis. In addition to the changes in blood flow they could have been due to the reduction in systemic blood pressure that followed the dilation, as well as to the modification of the antihypertensive treatment that patients were assuming prior to dilation [22, 23]. It is unlikely, however, that these two factors played a major role in determining the changes in velocimetric indices in dilated arteries because their values were unmodified in the contralateral normal arteries, which represent the internal control of this study. If the modifications of the indices were essentially due to the increments in renal blood flow and it is assumed that these were proportional to the reduction of the arterial narrowing, then one may wonder why only the changes of acceleration time were found to be correlated with the changes in the arterial caliber. There are several possible explanations for this finding. One is that an accurate estimation of the degree of the stenosis and even more of its changes after dilation may be cumbersome in some arteries [24]. In addition, our own data and those of others [6] indicate that velocimetric indices cannot properly discriminate between normal arteries and arteries with less than 50% stenosis. Finally, it is becoming increasingly clear that Doppler arterial waveforms, from which the velocimetric indices are derived, are a complex phenomenon that largely depend from vessel compliance and intrarenal impedance [25, 26]. These factors, which are mostly relevant in aged patients with atherosclerotic arteries and altered renal function, may interfere with the mere effects of the changes in blood flow. This may particularly apply to the measurement of pulsatility and resistive indices because vascular compliance and impedance are the main determinants of the minimum diastolic velocity (V_{min}) that specifically affect the ratios from which these indices are derived (**Methods** section). These confounding factors may be less relevant for the determination of acceleration time because it is directly derived from the time to peak systolic velocity. Indeed, the possibility that this index may better reflect blood flow and its changes is also supported by the finding that it was the only one to be found significantly correlated, prior to dilation, not only with

Table 4. Velocimetric indices stratified according to the degree of residual stenosis after angioplasty in atherosclerotic and fibromuscular arteries

	Residual stenosis after angioplasty					
	0–20%		20–40%		40–50%	
	Atherosclerotic	Fibromuscular	Atherosclerotic	Fibromuscular	Atherosclerotic	Fibromuscular
N	7	11	7	12	12	6
Pulsatility index	1.3 ± 0.1	1.1 ± 0.08	1.4 ± 0.1	1.3 ± 0.2	1.5 ± 0.1	1.1 ± 0.1
Resistive index	0.66 ± 0.03	0.59 ± 0.02	0.68 ± 0.04	0.66 ± 0.04	0.70 ± 0.04	0.66 ± 0.05
Acceleration *m/sec²*	14.8 ± 2.3	16.3 ± 2.0	15.3 ± 2.1	15.6 ± 2.5	13.2 ± 1.3	16.0 ± 1.6
Acceleration time *msec*	42.5 ± 7.2	45.5 ± 4.6	44.3 ± 1.7	49.4 ± 10.2	40.0 ± 3.6	44.0 ± 6.8

the degree of arterial narrowing, but also with the venoarterial difference of PRA in patients with fibromuscular stenosis. In contrast, no correlations were found between the changes in any of the velocimetric indices and those in the venoarterial differences of PRA and Ang II. There are two possible explanations for this finding: one is the discrepancy in time at which the humoral determinations and the echo Doppler studies were performed. The former were made immediately after the termination of the procedures, whereas the latter evaluations were carried out within five days after the dilatation. Another explanation is that the changes in the venoarterial gradients of PRA and Ang II are also complex phenomenon resulting not only from the modifications in renal blood flow and in renin secretion, but also from those in renin and Ang II uptake within the renal circulation [16].

Reprint requests to Prof. Alberto Morganti, Centro Fisiologia Clinica e Ipertensione Via F. Sforza 35 20122 Milano, Italy.
E-mail: Zanchetti@imiucca.csi.unimi.it

REFERENCES

1. Olin JW: Role of duplex ultrasonography in screening for significant renal artery disease. *Urol Clin North Am* 21:215–226, 1994
2. Strandness DE: Doppler ultrasound diagnosis of renovascular hypertension. *J Nephrol* 7:195–199, 1994
3. Blum U, Krumme B, Flugel P, Gabelmann A, Lahnert T, Buitrago-Tellez C, Schollmeyer P, Langer M: Treatment of ostial artery stenosis with vascular endoprostheses after unsuccessful balloon angioplasty. *N Engl J Med* 336:459–465, 1997
4. Soulen MC, Benenati JF, Sheth S, Merton D, Rothget J: Changes in renal artery doppler indexes following renal angioplasty. *J Vasc Interv Radiol* 2:457–462, 1991
5. Edwards JM, Zaccardi MJ, Strandness DE: A preliminary study of the role of duplex scanning in defining the adequacy of treatment of patients with renal artery fibromuscular dysplasia. *J Vasc Surg* 15:604–611, 1992
6. Schwerk WB, Restrepo IK, Stellwag M, Klose KJ, Shade-Brittenger C: Renal artery stenosis: Grading with image-directed Doppler ultrasound evaluation of renal resistive index. *Radiology* 190:785–790, 1994
7. Stravos TA, Parker SH, Yakes WF, Chantelois AE, Burke BJ, Meyers PR, Schenck JJ: Segmental stenosis of the renal artery: Pattern recognition of tardus and parvus abnormalities with duplex sonography. *Radiology* 184:487–492, 1992
8. Schürmann K, Ruekforth J, Kilbinger M, Gunther RW: Intrarenal duplex sonography for detecting flow changes due to renal PTA. *Fortschr Röntgenstr* 163:67–72, 1995
9. Burdick L, Airoldi F, Marana I, Giussani M, Alberti C, Cianci M, Lovaria A, Saccheri S, Gazzano G, Morganti A: Superiority of acceleration and acceleration time over pulsatility and resistance indices as screening tests for renal artery stenosis. *J Hypertens* 14: 1229–1235, 1996
10. Kamada T: Efficacy of echodoppler examination for the evaluation of renovascular disease. *Ultrasound Med Biol* 14:1–5, 1988
11. Martin RL, Nanra RS, Wlodarczyk J, Desieva A, Bray AE: Renal hilar doppler analysis in the detection of renal artery stenosis. *J Vasc Technol* 15:173–180, 1991
12. Middleton W: Doppler US evaluation of renal artery stenosis: Past, present and future. *Radiology* 184:307–308, 1992
13. Windeck P, Labs KH, Taeger KA: How useful are acceleration and deceleration based doppler indices: A trial on patients with percutaneous transluminal angioplasty. *Ultrasound Med Biol* 18:525–534, 1992
14. Krumme B, Blum U, Schwertfeger E, Flugel P, Hollstin F, Schollmeyer P, Rump LC: Diagnosis of renovascular disease by intra- and extrarenal Doppler scanning. *Kidney Int* 50:1288–1292, 1996
15. Pickering TG, Sos TA, Vaughan ED, Case DB, Sealey JE, Harshfield GA, Laragh JH: Predictive value and changes of renin secretion in hypertensive patients with unilateral renovascular disease undergoing successful renal angioplasty. *Am J Med* 76:398–404, 1984
16. Webb DT, Cumming AMM, Adams FC, Hodsmann GP, Leckie BJ, Lever AF, Morton JJ, Murray GD, Robertson JIS: Changes in active and inactive renin and in angiotensin II across the kidney in essential hypertension and renal artery stenosis. *J Hypertens* 2:605–614, 1984
17. Tegtmeyer CJ, Sos TA: Techniques of renal angioplasty. *Radiology* 161:577–586, 1990
18. Sealey JE, Laragh JH: How to do a plasma renin assay. *Cardiovasc Med* 2:1079–1092, 1977
19. Morganti A, Grassi G, Giannattasio C, Bolla G, Turolo L, Saino A: Effects of angiotensin converting enzyme inhibition on cardiovascular regulation during reflex sympathetic activation in sodium replete patients with essential hypertension. *J Hypertens* 7:825–836, 1989
20. Gottlieb RH, Snitzer EL, Hartley DF, Fultz PJ, Rubens DJ: Interobserver and intraobserver variation in determining intrarenal parameters by Doppler sonography. *Am J Radiol* 168:627–631, 1997
21. Bardelli M, Jensen G, Volkmann R, Aurell M: Non invasive ultrasound assessment of renal artery stenosis by means of the Gosling pulsatility index. *J Hypertens* 10:985–989, 1992
22. Veglio F, Frascisco M, Melchio R, Provera E, Rabbia F, Oliva S: Assessment of renal resistance index after captopril test by Doppler in essential and renovascular hypertension. *Kidney Int* 48:1611–1616, 1995
23. René PC, Oliva BJ, Froment D, Harel C, Nicolet V: Renal artery stenosis: Evaluation of doppler US after inhibition of angiotensin converting enzyme. *Radiology* 196:675–679, 1995
24. Plouin PF, Darné B, Chatellier G, Pannier I, Battaglia C, Raynaud A, Azizi M: Restenosis after a first percutaneous transluminal renal angioplasty. *Hypertension* 21:89–96, 1993
25. Halpern EJ, Deane CR, Needleman L, Merton DA, East SA: Normal artery spectral doppler waveform: A closer look. *Radiology* 196:667–673, 1995
26. Bude RO, Rubin JM: Detection of renal artery stenosis with doppler sonography: It is more complicated than originally thought. *Radiology* 196:612–613, 1995