Stent Placement for Renal Arterial Stenosis: Where Do We Stand? A Meta-analysis[1]

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Index terms:
Arteries, grafts and prostheses, 961.1286
Hypertension, renovascular, 81.72
Renal arteries, stenosis or obstruction, 961.72
Renal arteries, transluminal angioplasty, 961.454
Stents and prostheses, 961.1286

Radiology 2000; 216:78–85

Abbreviation:
PTA = percutaneous transluminal angioplasty

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PURPOSE: To perform a meta-analysis of renal arterial stent placement in comparison with renal percutaneous transluminal angioplasty (PTA) in patients with renal arterial stenosis.

MATERIALS AND METHODS: Studies dealing with renal arterial stent placement (14 articles; 678 patients) and renal PTA (10 articles; 644 patients) published up to August 1998 were selected. A random-effects model was used to pool the data.

RESULTS: Renal arterial stent placement proved highly successful, with an initial adequate performance in 98% and major complications in 11%. The overall cure rate for hypertension was 20%, whereas hypertension was improved in 49%. Renal function improved in 30% and stabilized in 38% of patients. The restenosis rate at follow-up of 6–29 months was 17%. Stent placement had a higher technical success rate and a lower restenosis rate than did renal PTA (98% vs 77% and 17% vs 26%, respectively; $P < .001$). The complication rate was not different between the two treatments. The cure rate for hypertension was higher and the improvement rate for renal function was lower after stent placement than after renal PTA (20% vs 10% and 30% vs 38%, respectively; $P < .001$).

CONCLUSION: Renal arterial stent placement is technically superior and clinically comparable to renal PTA alone.

In 1978, renal percutaneous transluminal angioplasty (PTA) was introduced by Grüntzig et al (1) as an alternative to surgical treatment for renal arterial stenosis. In subsequent years, numerous studies (2) reported the beneficial effect of renal PTA on the management of renovascular hypertension and renal function. Since then, renal PTA has become accepted widely for treating renal arterial stenosis, although a restenosis rate of 27%–100% at follow-up of 6–12 months has been acknowledged as a major limitation of the procedure (3,4). In patients treated for atherosclerotic renal arterial stenosis, the effects on blood pressure were disappointing, but in patients who had renal arterial stenosis owing to fibromuscular dysplasia, renal PTA proved successful, with cure rates for hypertension of 22% versus 83% (5).

With the introduction of self-expanding and balloon-expandable metallic stents, a new treatment that might overcome poor angioplasty results, immediate postangioplasty complications, and restenosis became available for atherosclerotic renal arterial stenosis. Since the early studies (6–8) of renal arterial stent placement in 1991, results of several case series established the successful placement of stents for renal arterial stenosis. The purpose of this study was to present an overview of studies about renal arterial stent placement and to perform a meta-analysis of renal arterial stent placement in comparison with renal PTA in patients with renal arterial stenosis.

MATERIALS AND METHODS

A literature review was performed of studies that deal with renal arterial stent placement and that were identified by means of a MEDLINE search of the English-language medical literature from January 1991 to August 1998. To avoid double counting, data from the most recently published articles from a particular institution were included, thereby ignoring the

TABLE 1
Patient Characteristics, Type of Stents Used, and Initial Angiographic Success Following Renal Arterial Stent Placement

Study	Patients		No. of Arteries	Indication*		Location†		Stent		Initial Angiographic Success		
	No.	Age (y)		HT	RF	Ost	Trunc	No. per Artery	Type	Criterion for PDS‡	Success§	Complications‖
Wilms et al (6)	11	60	12	10	1	6	6	1.25	Wallstent	<20	83	3 (25)
Kuhn et al (7)	10	56	10	9	10	0	10	1.40	Strecker	<20	80	4 (40)
Rees et al (8)	28	66	28	28	14	28	0	1.11	Palmaz	<30	96	5 (18)
Hennequin et al (9)	21	55	21	21	6	7	14	1.19	Wallstent	<30	100	4 (19)
van de Ven et al (10)	24	67	28	24	0	28	0	1.14	Palmaz	<10	100	3 (11)
Henry et al (11)	59	65	64	59	10	34	30	1.00	Palmaz	<20	100	2 (3)
Iannone et al (12)	63	70	83	63	29	51	32	1.00	Palmaz	<30	99	11 (13)
Blum et al (13)	68	60	74	68	20	74	0	1.03	Palmaz	<50	100	0 (0)
Boisclair et al (14)	33	63	35	33	17	19	16	1.00	Palmaz	<30	100	6 (17)
Harden et al (15)	32	67	32	0	32	NM	NM	1.03	Palmaz	<10	100	1 (3)
White et al (16)	100	67	133	100	44	107	26	1.12	Palmaz	<30	99	2 (2)
Rundback et al (17)	45	70	54	0	45	NM	NM	NM	Palmaz	<30	94	5 (9)
Shannon et al (18)	21	63	23	0	21	17	5	1.09	Palmaz	NM	100	2 (9)
Dorros et al (19)	163	67	202	121	95	NM	NM	NM	Palmaz	<50	100	23 (11)
Total or mean	678#	66**	799#	536#	344#	371#	139#	1.07**	NA	NA	98††	11††
95% CI	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	95%, 100%	6%, 16%

Note.—NA = not applicable, NM = not mentioned.
* HT = hypertension, RF = renal failure.
† Ost = ostial, Trunc = truncal.
‡ PDS = percentage of diameter stenosis.
§ Data are the percentage of arteries.
‖ Data are the number of arteries. Data in parentheses are percentages. Hematomas and puncture traumas are excluded.
Total.
** Weighted mean.
†† Mean based on random-effects model.

possible additional information in previously published work. From the 14 articles (678 patients [350 men, 328 women], 799 treated arteries) identified (6–19), when available, the following data were extracted: patient selection criteria, lesion characteristics, procedure, antithrombotic therapy, initial technical success, complications, duration of follow-up, clinical results, and restenosis rate. Patients included in the survey had a mean age of 66 years and an age range from 55 (9) to 70 (12,17) years.

Data extraction was performed by the first author (T.C.L.) and verified by a coauthor (E.J.G.). Discrepancies in the extracted data were resolved by these authors examining the articles simultaneously.

The variables of initial technical success rate, complication rate, clinical results, and restenosis rate across the studies were tested for homogeneity by using the χ^2 test (two-sided, $\alpha = .05$). As these variables were not uniformly defined or measured in identical conditions, a random-effects model, as described by Laird and Mosteller (20) in 1990, was used to combine the data. The mean age of patients, mean number of stents per artery, and mean period of clinical and angiographic follow-up across studies were combined by using weighted means.

The relationship between categoric variables was demonstrated in contingency tables by using the χ^2 test; for continuous variables, the Pearson product moment correlation was calculated (SPSS for Windows, version 7.0; SPSS, Chicago, Ill). Correlation coefficients were determined between patient age and the following variables: lesion characteristics, stents per artery, initial technical success, complication rate, percentage of patients in whom hypertension or renal function was cured or improved, and restenosis rates. Correlation coefficients were considered worth mentioning in the case of *r* values greater than 0.50. Two-sided *P* values of .05 or less were considered statistically significant.

The results of stent placement in patients with renal arterial stenosis were compared with the results of renal PTA in a similar patient group (10 articles, 644 patients [261 men, 218 women, 165 sex not mentioned], 778 arteries). Because the majority of stent studies were published from January 1995 to August 1998, studies dealing with renal PTA for renal arterial stenosis published in the same period were included to obtain contemporary controls (3,21–29). The following parameters were compared between the stent studies and the renal PTA studies: indication for intervention, initial technical success, complication rate, percentage of patients in whom hypertension or renal function was cured or improved, and restenosis rate. Comparison was performed with the use of contingency tables by using the χ^2 test (two-sided, $\alpha = .05$) to test for statistical significance. Patients had a mean age of 64 years and an age range from 59 (28) to 68 (23) years.

RESULTS

Pooled data for all patients who underwent renal arterial stent placement ($n = 678$) are listed in Tables 1 and 2.

Patient Selection Criteria

The criteria used for selecting patients for stent placement varied widely. Clinical indication for intervention was a combination of hypertension and renal failure in all but four articles (10,15,17,18). The number of patients treated for hypertension ($n = 536$) was higher than the number of patients treated for renal function impairment ($n = 344$). In 10 studies (6–9,11,13–17), stent placement was performed after initial or late renal PTA failure. In two studies (12,19), stent placement was the primary intervention, and in the remaining two studies (10,18) stent placement was used as a primary or sec-

TABLE 2
Clinical and Angiographic Follow-up in Patients Who Underwent Renal Arterial Stent Placement

Study	Clinical Follow-up						Angiographic Follow-up			
	Follow-up		Hypertension*		Renal Function*		Follow-up		Restenosis	
	Patients*	Time (mo)	Cured	Improved	Improved	Stabilized	Arteries†	Time (mo)	Criterion for PDS‡	Rate†
Wilms et al (6)	100	7	30	40	0	0	58	7	NM	29
Kuhn et al (7)	80	11	29	43	50	NM	100	7	>50	25
Rees et al (8)	100	7	11	54	36	36	64	8	>50	39
Hennequin et al (9)	100	32	14	86	17	50	95	29	>70	20
van de Ven et al (10)§	92	6	68	5	36	64	82	6	>50	13
Henry et al (11)	92	14	19	57	20	NM	NM	6	>50	9
Iannone et al (12)‖	86	10	4	35	36	45	83	11	>60	14#
Blum et al (13)	100	27	16	62	NM	NM	100	27	>50	11
Boisclair et al (14)	100	13	6	61	41	35	23	NP	>50	NP
Harden et al (15)	100	6	NM	NM	34	34	75	6	>50	13
White et al (16)	100	6	NM	NM	20	NM	60	9	>50	19
Rundback et al (17)	NM	17	NM	NM	NM	NM	52	13	>50	25
Shannon et al (18)§	100	9	NM	NM	43	29	NM	9	>50	0
Dorros et al (19)‖	28	48	3	51	NM	NM	NP	NM	NM	NP
Mean	91**	16††	20‡‡	49‡‡	30‡‡	38‡‡	72**	17††	NA	17‡‡
95% CI	NA	NA	4%, 37%	16%, 83%	22%, 39%	25%, 51%	NA	NA	NA	12%, 23%

Note.—NA = not applicable, NM = not mentioned, NP = not routinely performed.
* Data are percentages of patients.
† Data are percentages.
‡ PDS = percentage of diameter stenosis.
§ Primary and secondary stent placement.
‖ Primary stent placement.
Duplex restenosis.
** Mean.
†† Weighted mean. If the number of patients for follow-up was not reported, the mean was estimated from the number of arteries for follow-up and vice versa. If angiographic follow-up was not reported, the mean was estimated from clinical follow-up data.
‡‡ Mean based on random-effects model.

ondary intervention. The angiographic definition of a hemodynamically significant stenosis ranged from 40% to more than 70% reduction in lumen diameter.

Lesion Characteristics

At angiography, a distinction was made between ostial and truncal lesions and between lesions due to atherosclerosis and lesions due to fibromuscular dysplasia. Ostial lesions were defined as stenoses of the renal artery within 2 mm (18), 4 mm (17), or 5 mm (10,13) of the aortic lumen. In one study (11), an ostial lesion was defined as a stenosis without a nondiseased renal arterial segment between the lesion and the aorta. More ostial lesions (n = 371) than truncal lesions (n = 139) were treated. In seven articles (6,9,11,12,14,16,18), either ostial or truncal lesions were treated. In three studies (8,10,13), only ostial lesions were treated, and in one study (7), only truncal lesions were involved. In the remaining three studies (15,17,19), the location of the lesion was not mentioned. Renal arterial stenoses were atherosclerotic in origin in the majority of cases. Patients also were included with renal arterial stenosis due to fibromuscular dysplasia (n = 6), Takayasu arteritis (n = 2), and/or posttransplantation stenosis (n = 4) (6,7,9,11,14).

Procedure

In 11 studies (6–14,17,18), the femoral approach was used for access; the brachial approach was used in the remainder (15,16,19). Stent placement was preceded by predilation or balloon angioplasty in all but one study (19). The reason for predilation was given in two studies: in one study (8) to decrease the inflation pressure required for stent expansion and in the other study (16) to ensure that full expansion of the lesion was possible. In one study (7), the lesion was overdilated up to 120% of the original vessel size before stent placement. In the majority of studies (n = 11), the authors did not describe the method used for vessel sizing. In the remaining three studies (11, 12,16), digital angiographic analysis was used. In 11 studies, the Palmaz stent was used; in two studies (6,9), the Wallstent; and in one study (7), the Strecker stent.

In four studies, overdilation of the stent up to 110% (8,16) or 120% (13) of the original vessel size or 0.5–1.0 mm larger than the original vessel was performed (7). The reason for this overdilation was "to compensate for neointimal growth and to prevent the stent from migrating" (7). For ostial lesions, a slight protrusion of the stent into the aorta was recommended in five studies (10,11,13,14,18). In addition, in one study (11) the part of the stent protruding into the aorta was reshaped with the use of a larger balloon.

Antithrombotic Therapy

Prophylaxis against thrombosis during the procedure was used in all studies, but the regimens varied. These included a 2,000–10,000-IU bolus of heparin calcium (6,7,9–11,13,16); a 1,000–5,000-IU bolus of heparin calcium and 100–400 μg of nitroglycerin (8,14,17,18); or a combination of 75 mg of dipyridamole, 325 mg of acetylsalicylic acid, and mannitol hexanitrate (10% solution injected intravenously at a rate of 100 mL/h for 5 hours) (19).

In seven studies (6,7,9–11,13,14), heparin calcium was used intravenously for anticoagulation the 1st days after renal arterial stent placement and was titrated to obtain a partial thromboplastin time two to three times normal. The anticoagu-

TABLE 3
Definitions Used to Describe Improvement of Blood Pressure Following Renal Arterial Stent Placement

Study	Definition
Wilms et al (6)	Diastolic blood pressure decreased 15% or more and was greater than 90 mm Hg but less than 110 mm Hg
Kuhn et al (7)	Decrease in systolic and diastolic blood pressure of 10 mm Hg or more, the same or less medication
Rees et al (8)	Diastolic blood pressure decreased 15 mm Hg or more with the same or less medication, less medication, or diastolic blood pressure decreased 15% or more and was greater than 90 mm Hg but less than 110 mm Hg with the same or less medication
Hennequin et al (9)	Diastolic blood pressure was less than 90 mm Hg with the same or less medication, or diastolic blood pressure decreased 15% or more and was greater than 90 mm Hg but less than 110 mm Hg with the same or less medication
van de Ven et al (10)	Decrease in mean arterial pressure of 20% or more
Henry et al (11)	Diastolic blood pressure decreased 15% or more with the same or less medication
Iannone et al (12)	Diastolic blood pressure was less than 90 mm Hg and less medication, or diastolic blood pressure was greater than 90 mm Hg and decreased 10 mm Hg more with less medication
Blum et al (13)	Diastolic blood pressure of 91–110 mm Hg and a decrease of 15% or more; or diastolic blood pressure of 91–110 mm Hg, a decrease of 10% or more, and one or more fewer medications
Boisclair et al (14)	Diastolic blood pressure was less than 90 mm Hg or 90–110 mm Hg, a decrease of 15% or more with the same or less medication
Harden et al (15)	Not mentioned
White et al (16)	Systolic blood pressure was less than 150 mm Hg and diastolic blood pressure was less than 90 mm Hg with the same or less medication
Rundback et al (17)	Not mentioned
Shannon et al (18)	Not mentioned
Dorros et al (19)	Systolic or diastolic blood pressure decreased 10% or more or 15% or more with the same medication, or systolic or diastolic blood pressure remained the same or decreased less than 10% or less than 15% with less medication

lation regimen at patient discharge was changed to 100–300 mg of acetylsalicylic acid per day (6,9–11), 660 mg of acetylsalicylic acid per day and 150 mg of dipyridamole per day (7), 100 mg of acetylsalicylic acid per day or 250 mg of ticlopidine hydrochloride per day (13), or warfarin potassium (14). In other studies, patients used only 75–300 mg of acetylsalicylic acid per day (18) or warfarin potassium (international normalized ratio of 2.0–2.5, 1–3 months) (16), or they used a combination of acetylsalicylic acid, dipyridamole, and warfarin potassium (19). Patients in two studies (8,17) did not use anticoagulation therapy routinely after renal arterial stent placement, and the authors of two other studies (12,15) did not report the anticoagulation regimen.

Initial Technical Success

The initial technical success of the procedure reported was not significantly different among the studies. In two of the earlier studies, successful stent placement was achieved in 83% (6) and 80% (7) of arteries, followed by success rates ranging from 94% to 100% in subsequent studies (Table 1). It should be noted, however, that the definitions for technical success ranged from less than 10% residual stenosis (10,15) to less than 50% residual stenosis (13,19).

Complications

Of the complications encountered, the most frequently reported ($n = 40$) were hematoma formation and puncture trauma. More severe complications in 71 (9%) of the 799 treated arteries included renal failure ($n = 34$; three fatal), segmental renal infarction ($n = 9$), perinephric hematoma ($n = 9$; two fatal), renal arterial thrombosis or occlusion ($n = 6$), stent misplacement ($n = 5$), proteinuria ($n = 2$), sepsis ($n = 1$), brachial arterial occlusion ($n = 1$), mismatch of stent and vessel ($n = 1$), cholesterol embolism to the lower extremities ($n = 1$), dissection of the iliac artery ($n = 1$), and brachial arterial bleeding ($n = 1$; fatal). The mean mortality rate related to the procedure was 1% (95% CI: 0%, 2%). The mortality rate usually included deaths directly or indirectly related to the procedure within the 1st month after stent placement (8,12,15,18). In one study (18), the mortality rate included a patient who died 6 months after stent placement owing to rupture of a pseudoaneurysm caused by the intervention. In one study (19), the authors did not mention the postprocedural period in which the mortality rate was calculated; therefore, data from this study were not included in the mortality rate. In addition, six other patients died of causes described as not related to the procedure. The complication rate varied significantly across the studies ($P < .001$) and was significantly lower in studies in which Palmaz stents were used than those in which other stent types were used (8% vs 25%; $P < .001$); the mean complication rate was 11% (95% CI: 6%, 16%) (Table 1).

Duration of Follow-up

The clinical follow-up period ranged from 6 months (10,15,16) to 48 months (19); for angiographic follow-up, 6 months was the shortest interval (10,11,15), whereas the longest follow-up was 29 months (9).

Clinical Results

The clinical effect of renal arterial stent placement on blood pressure was expressed in terms of cure and improvement, although neither classification was defined uniformly. In most studies, ''cure'' was defined as a diastolic blood pressure of 90 mm Hg or less without medication (6,8,9,11–14). Other definitions of ''cure'' included blood pressure less than 160/95 mm Hg (10), blood pressure less than 160/95 mm Hg without medication (7), and systolic blood pressure less than 160 mm Hg and/or diastolic blood pressure less than 90 mm Hg without medication (19). In addition, in one study (16) clinical success was reported as systolic blood pressure less than 150 mm Hg and diastolic blood pressure less than 90 mm Hg with the same or less medication than the patient used before stent placement. Definitions used to describe improvement of hypertension varied widely and are summarized in Table 3.

More uniform criteria were used to define the effect of renal arterial stent placement on renal function in terms of improvement, stabilization, and deterioration. Renal function was considered improved when the serum creatinine values decreased more than 20% (10,11,15,17,18), more than 15% (8,12,14), or more than 18 μmol/L (19). Renal function was considered stabilized when the change in serum creatinine values was

TABLE 4
Patient Characteristics and Initial Angiographic Success Following Renal PTA

Study	Patients		No. of Arteries	Indication*		Location†		Initial Angiographic Success		
	No.	Age (y)		HT	RF	Ost	Trunc	Criterion for PDS‡	Success§	Complications‖
Karagiannis et al (21)	62	65	76	62	27	NM	NM	<50	72	3 (4)
Jensen et al (22)	107	63	147	NM	NM	NM	NM	NM	82	8 (5)
Eldrup-Jorgensen et al (23)	52	68	60	10	42	NM	NM	NM	92	3 (5)
Bonelli et al (24)	190	64	242	NM	NM	53	189	<30	82	56 (23)
von Knorring et al (25)	38#	60	38	38	0	9	29	NM	NM	NM
Tullis et al (26)	41	65	52	41	0	29	23	<60**	75	NM
Baumgartner et al (27)	56	60	63	25	25	NM	NM	<60**	NA	NM
Hoffman et al (3)	50	66	52	46	36	52	0	<30	58	9 (17)
Plouin et al (28)	23	59	23	23	0	7	16	NM	NM	6 (26)
Webster et al (29)	25	60	25	25	0	13	12	NM	NM	3 (12)
Total or mean	644††	64‡‡	778††	270††	130††	163††	269††	NA	77§§	13§§
95% CI	NA	NA	NA	NA	NA	NA	NA	NA	68%, 86%	6%, 19%

Note.—NA = not applicable, NM = not mentioned.
* HT = hypertension, RF = renal failure.
† Ost = ostial, Trunc = truncal.
‡ PDS = percentage of diameter stenosis.
§ Data are the percentage of arteries.
‖ Data are the number of arteries. Data in parentheses are percentages. Hematomas and puncture traumas are excluded.
Only patients with atherosclerotic renal arterial stenosis are included.
** Based on duplex US.
†† Total.
‡‡ Weighted mean.
§§ Mean based on random-effects model.

less than these values and deteriorated when serum creatinine values increased according to these values. In five studies (6,7,9,13,16), no criteria for change in renal function were provided.

The percentage of patients in whom hypertension was cured (20%; 95% CI: 4%, 37%) was not uniform among the studies ($P < .001$) (Table 2). The percentage of patients in whom hypertension improved as a result of renal arterial stent placement was higher (49%; 95% CI: 16%, 83%) and differed significantly among the studies ($P < .001$). No study results showed a significant decrease in overall serum creatinine values after stent placement. Renal function in patients with renal failure was improved in 30% (95% CI: 22%, 39%) and stabilized in 38% (95% CI: 25%, 51%) of patients. These results did not vary significantly across the studies (improvement, $P = .13$; stabilization, $P = .11$) (Table 2).

Restenosis Rate

Angiographic follow-up was performed in all but three studies: In two studies (14,19), follow-up angiography was not performed routinely, and in one study (12), duplex ultrasonography (US) was used for detection of restenosis. The definitions used for restenosis were not uniform among the studies. The criterion of stenosis of more than 50% of the diameter was used for restenosis in most studies. Stenosis of more than 60% (12) and stenosis of more than 70% (9) were also criteria for restenosis. Unclear, however, was whether the percentages were calculated at the stent site (local stenosis) or were calculated in comparison with the reference site (relative stenosis). This may have caused considerable variation among the reviewed studies. The overall restenosis rate after renal arterial stent placement, depending on the angiographic definition, was 17% (95% CI: 12%, 23%) and ranged from 0% (18) to 39% (8) ($P = .04$).

Relationship between Variables

Calculation of correlation between variables showed that older patients had more ostial lesions ($r = 0.61$; $P = .05$), significantly fewer stents per artery ($r = -0.65$; $P = .02$), and a significantly lower complication rate ($r = -0.56$; $P = .04$) than did younger patients. Patient age was significantly related with success rate for hypertension: the older the patient, the smaller the effect on blood pressure ($r = -0.77$; $P = .009$).

Comparison with Renal PTA

Renal PTA data are given in Tables 4 and 5. The patient groups for stent placement and renal PTA showed significant differences in indication for intervention and the location of the lesion involved. In the stent studies, more patients with renal failure and more ostial lesions were included than in the renal PTA studies ($P < .02$ and $P < .001$, respectively). The technical success rate was significantly higher after stent placement compared with that after renal PTA alone (98% and 77%, respectively; $P < .001$). The complication rate was not significantly different between stent placement and renal PTA alone (11% and 13%, respectively; $.2 < P < .3$).

The proportion of patients in whom hypertension was cured was significantly different: 20% after stent placement and 10% after renal PTA ($P < .001$). The proportion of patients with improvement of hypertension was similar for both treatment strategies (49% and 53%, respectively; $.1 < P < .2$). The percentage of patients with improved renal function was significantly lower for stent placement than for renal PTA (30% vs 38%, respectively; $P < .001$). Restenosis rates, however, were significantly lower after stent placement than after renal PTA alone (17% and 26%, respectively; $P < .001$).

DISCUSSION

Review of 14 articles concerning patients with hypertension, renal failure, or both indicated that renal arterial stent place-

TABLE 5
Clinical and Angiographic Follow-up in Patients Who Underwent Renal PTA

	Clinical Follow-up						Angiographic Follow-up			
	Follow-up		Hypertension*		Renal Function*		Follow-up		Restenosis	
Study	Patients*	Time (mo)	Cured	Improved	Improved	Stabilized	Arteries†	Time (mo)	Criterion for PDS‡	Rate†§
Karagiannis et al (21)	48	40	19	52	22	50	NM	NM	NM	NP
Jensen et al (22)	78	12	12	40	NM	NM	77	12	>75	9
Eldrup-Jorgensen et al (23)	NM	28	NM	NM	NM	NM	NM	NM	NM	NP
Bonelli et al (24)	NM	33	8	62	NM	NM	NM	22	>70	NP
von Knorring et al (25)	71	48	11	74	NM	NM	NM	48	NM	NM
Tullis et al (26)	35	28	11	33	50	40	35	24	>60	55
Baumgartner et al (27)	70	13	9	46	48	36	NM	13	>60‖	28
Hoffman et al (3)	49	21	2	64	32	36	50	11	>50	27
Plouin et al (28)	23	6	NM	NM	NM	NM	100	6	>50	13
Webster et al (29)	25	NM	NM	NM	NM	NM	35	12	NM	NM
Mean	50#	22**	10††	53††	38††	41††	59#	19**‡‡	NA	26††
95% CI	NA	NA	7%, 14%	42%, 63%	25%, 51%	35%, 48%	NA	NA	NA	11%, 42%

Note.—NA = not applicable, NM = not mentioned.
* Data are percentages of patients.
† Data are percentages.
‡ PDS = percentage of diameter stenosis.
§ NP = not standardly performed.
‖ Based on duplex US.
Mean.
** Weighted mean.
†† Mean based on random-effects model.
‡‡ If the number of patients for follow-up was not reported, the mean was estimated from the number of arteries for follow-up and vice versa. If clinical follow-up was not reported, the mean was estimated from angiographic follow-up data.

ment is an attractive treatment with a high initial success rate (98%) and a mean restenosis rate of 17% at a mean follow-up of 17 months. At clinical follow-up of 6–48 months, hypertension was cured in 20% of the patients and improved in 49%. Renal function in the patients with impaired renal function was improved in 30% and stabilized in 38%.

In the early studies, most of the patients were included in order to assess the effects on blood pressure. In later studies (15,17,18), the authors assessed the effect on renal function in patients with renal failure, regardless of the presence of hypertension. Although the minority of patients with chronic renal failure have renovascular disease, intervention by means of renal PTA or stent placement in renal failure associated with renovascular disease seems worthwhile, since stenosis of the renal artery is one of the few correctable causes of renal failure.

In most of the reviewed studies, secondary renal arterial stent placement was performed (ie, after initial or late failure of renal PTA). In some studies, however, primary stent placement or combined primary or secondary stent placement was performed. Patients undergoing secondary stent placement after unsuccessful renal PTA may have more severe renal arterial disease and are therefore perhaps more difficult to treat with stent placement than patients undergoing primary stent placement. This phenomenon could have caused a selection bias and makes comparison between studies of technical and clinical results difficult.

The majority of patients selected had atherosclerotic renal arterial stenosis. According to the literature, the outcome of renal PTA for renal arterial stenoses due to fibromuscular dysplasia appears to be much better than that for atherosclerotic stenoses (2). No conclusions could be drawn about the value of stent placement for fibromuscular dysplasia because these patients were underrepresented in this review.

Most investigators used the Palmaz stent; the authors of only three studies (6,7,9) used other stent types. Clinical success and restenosis rates in these series did not differ substantially from those reported with Palmaz stents. Complication rates, however, were higher in the studies in which Palmaz stents were not used, but these results have to be interpreted with caution because other stent types were used in only three studies. In the studies (6,9) in which Wallstents were used, problems were encountered with stent visibility at fluoroscopy. This is of utmost importance for correct stent placement, especially when the selected stent is short. The femoral approach for access into the renal artery was used commonly in the reviewed studies and seemed to be safer than the brachial approach, which is illustrated by the case of the patient who died owing to uncontrolled bleeding from a brachial puncture site (15).

In the reviewed studies, no specific relation was found between the antithrombotic therapy used and the outcome and complications of the intervention. Antithrombotic therapy is warranted to prevent thrombosis, but at the same time substantial bleeding complications should be avoided.

The initial technical success of renal arterial stent placement was high and agreed with success rates of stent placement in coronary arteries (30,31). However, the difference in angiographic definitions used for technical success made adequate comparison difficult. We used intravascular US following angiographically successful renal arterial stent placement and found that intravascular US data warranted further increase of vessel dimensions in 33% (six of 18) of patients (32). Results of future studies will show whether renal arterial stent placement guided by intravascular US is beneficial for the long-term outcome.

The initial technical success rate of stent placement was consistently high (>80%). The complication rate encountered (11%) varied among the studies reviewed. The cause of the difference in complication rates between the studies (0%–40%) remains speculative. The mortality rate due to renal arterial stent placement was the same as that previously reported after coronary arterial stent placement (1% [three of 259]) (33).

After review of the results of renal arterial stent placement for renovascular disease, it appears that there is no universally accepted reporting standard. Although all articles describe a decrease in systolic and diastolic blood pressure after stent placement, there is much variation in definitions for ''cure'' and ''improvement'' of hypertension. This aspect hampered adequate comparison between the studies and may explain the difference in clinical results achieved.

In addition, the adjustment of antihypertensive drugs after stent placement was not sufficiently described and quantified. The actual effect of stent placement on blood pressure in these uncontrolled studies, therefore, remains elusive, especially when one bears in mind that blood pressure also can be lowered by means of medication alone (28). Reporting all actual blood pressure data, as well as the amount and type of antihypertensive drugs used, may allow a more accurate comparison of the results of various studies. The best way to express the amount of antihypertensive drugs is, to our knowledge, the calculation of defined daily doses, or DDDs, according to the World Health Organization, to reflect both the number and doses of the prescribed drugs (34).

In agreement with results obtained after renal PTA, a beneficial effect of renal arterial stent placement on renal function has not been established convincingly. Nevertheless, renal function in 30% of the patients with renal failure was regarded as improved and in 38%, as stabilized, which may indicate that the effect of stent placement on renal function may be stabilization rather than statistically significant improvement.

It is noteworthy that the most recent studies (15,17,18) focused on the effect of renal arterial stent placement on the management of renal function, whereas the effects on hypertension seemed to be of less importance. This shift of focus from hypertension to renal function seems unjustified in regard to the blood pressure and renal function data among the studies reviewed. It should be noted, however, that hypertension was the subject of numerous previous studies, and renal function has been ignored somewhat, which may have been corrected in the later studies.

The mean restenosis rate of 17% (range, 0%–39%) after follow-up of 6–29 months after renal arterial stent placement agreed with restenosis rates in coronary arteries (35). Restenosis rates after stent placement were significantly lower than those after renal PTA alone, although a randomized trial is warranted to investigate this topic in more detail. The cause of the different restenosis rates among the studies was not established clearly, nor were the mechanisms related to restenosis.

Calculation of correlations between the different variables revealed that older patients had less benefit from stent placement with regard to hypertension than did younger patients. This may reflect the coexistence of essential hypertension and irreversible arteriolosclerosis in older patients. A serious limitation associated with the calculation of correlations between the different variables across the studies is the absence of raw data. The fact that, for example, one patient may have undergone two stent placement procedures could not be taken into account in an analysis as presented in this study. Therefore, conclusions must be interpreted carefully. For the same reason, we were unable to perform a multivariate regression analysis, which might have established the prediction of intervention outcome on the basis of patient or lesion characteristics. The results of our study, however, demonstrate that such an analysis would be interesting to perform.

Comparison between stent placement and renal PTA showed higher initial success rates and lower restenosis rates after stent placement. The percentage of patients in whom hypertension was cured tended to be higher after stent placement than after renal PTA. The results as presented here were in accordance with the results of the randomized trial in which renal arterial stent placement was compared with renal PTA (36). In that study (36), renal arterial stent placement was a better technique than renal PTA to achieve vessel patency with higher technical success and lower restenosis rates (88% vs 57% and 14% vs 48%, respectively). The clinical outcome, however, was not significantly different between stent placement and renal PTA. In the meta-analysis presented here, stent placement was associated with a lower percentage of patients with improved renal function. This may be because the stent studies included more patients with impaired renal function instead of hypertension, which may affect the clinical outcome in terms of renal function.

The major limitation of the present study is that it is not a randomized controlled clinical trial. Although randomized controlled clinical trials are the superior mode for evaluating and comparing therapeutic interventions, they also have limitations (37). First, a randomized trial, performed in an ideal setting with a selected, usually small, patient population, may hamper generalization of the results. Second, these trials are costly and often have a short follow-up period for both practical and ethical reasons. Meta-analysis of cohort studies, on the other hand, may reflect the general clinical practice, is cheaper, supplies additional data about a larger number of patients, and may be a reasonable alternative to a randomized controlled clinical trial. However, a meta-analysis as presented here has well-known deficits, including unequal numbers of patients and different end points in the studies. A multicenter trial with uniform patient entry criteria and outcome measurements would provide valuable results.

The following issues need to be addressed in future studies: (*a*) The assessment of the outcome of renal PTA, stent placement, and optimal medical therapy in a randomized controlled setting. (*b*) The long-term effects of treatments on blood pressure, renal function, and restenosis rates. Accurate monitoring of the amount of antihypertensive medication in defined daily doses is of critical importance, since inaccuracies blur the outcome of the intervention. (*c*) Optimal depiction of the effect of endovascular renovascular intervention. Possible modalities are intravascular US (32) and magnetic resonance angiography (38).

Renal arterial stent placement appears to be superior, regarding initial success and restenosis rates, and clinically comparable to renal PTA alone. Future studies are needed to focus on the prevention of complications and on the assessment of long-term benefit, as well as on the factors determining success or clinical failure of the intervention.

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