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CLINICAL INVESTIGATION ARTERIAL INTERVENTIONS

Comparing Percutaneous Transluminal Angioplasty and Stent Placement for Treatment of Subclavian Arterial Occlusive Disease: A Systematic Review and Meta-Analysis

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Abstract

Background and Purpose Subclavian artery occlusive disease (SAOD) is often associated with cerebrovascular symptoms such as subclavian steal syndrome and stroke. We conducted a systematic review and meta-analysis to compare percutaneous transluminal angioplasty (PTA) and stent placement for the treatment of SAOD.

Materials and Methods We searched Medline, EMBASE, Cochrane Central Register of Controlled Trials, Cochrane Database of Systematic Reviews, and Scopus through October 16, 2014. From each study, we abstracted baseline patient characteristics, study design variables, and outcome data including rates of technical success, primary patency ($\leq$2 and >2 years follow-up), symptom resolution, and complications. Meta-analysis was performed using a random-effects model.

Results A total of 35 non-comparative studies with 1726 patients were included. Technical success rate was significantly higher in the stent group than the PTA group (92.8 vs 86.8 %, $p = 0.007$). Long-term primary patency rates (76.9 vs 79.6 %, $p = 0.729$) and symptom resolution rates (82.2 vs 73.0 %, $p = 0.327$) were not statistically different. There was no statistically significant difference in the rates of stroke or death.

Conclusion Stent placement for treatment of SAOD may be associated with higher rates of technical success but similar rates of symptom resolution and long-term outcomes. The confidence in the available estimates is low. Further comparative studies are needed to guide patients and clinicians in shared decision making.

Keywords Neurointerventions · Arterial intervention · Venous intervention · Diagnostic · Endovascular Aneurysm Repair/Endovascular Aortic Repair (EVAR) · Endovascular treatment · Inferior Vena Cava Filter (IVC) placement · Venous intervention

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Introduction

Subclavian artery occlusive disease (SAOD) is often associated with cerebrovascular symptoms such as subclavian steal syndrome, arm claudication, distal embolization, and stroke [1–4]. Multiple modalities have been used in the treatment of SAOD including surgical and endovascular approaches [5–7]. Over the past 20 years, endovascular approaches such as percutaneous transluminal angioplasty (PTA) and stent placement have emerged as the primary approach due to high rates of technical success, long-term patency, and low complication rates demonstrated in case series reporting on patients receiving one of the two approaches [8–13]. No comparative studies are available.

Currently, little is known as to whether there are any significant differences in outcomes and complications between PTA and stenting for treatment of SAOD [14–20]. We conducted a systematic review and meta-analysis of the available literature comparing outcomes and complications of PTA and stent placement for the treatment of subclavian artery occlusive disease.

Materials and Methods

The authors created a priori protocol for this systematic review and meta-analysis. The population criteria, description of interventions, comparisons, and the outcomes of interest were predefined in the protocol. This report is consistent with the suggestions from the Preferred Reporting Items for Systematic Reviews and Meta-examinations (PRISMA) statement [21].

Literature Search

A comprehensive literature search was carried out by a librarian experienced in the literature searches for systematic reviews. The databases included Ovid Medline In-Process & Other Non-Indexed Citations, Ovid MEDLINE, Ovid EMBASE, Ovid Cochrane Central Register of Controlled Trials, Ovid Cochrane Database of Systematic Reviews, and Scopus. The databases were searched from the date of their earliest inception to October 16, 2014. Controlled vocabulary supplemented with keywords was used to search for studies such as "stenting," "angioplasty," and "subclavian artery occlusive disease." The search strategy is shown in Table 4 in Appendix. In addition, a manual search was performed by searching bibliographies of included studies and previous review articles.

Study Selection

Study selection was performed through two levels of study screening. At 1st level of screening, titles and abstracts were screened for the following exclusion criteria: (a) case reports, letters, comments, and reviews; animal or in vitro studies; fewer than 10 patients in the study; and languages other than English. Two reviewers independently (A.A. and K.M.) screened title and abstract for relevant studies; any disagreements were resolved by a third reviewer (W.B.). Relevant studies were retrieved for full-text screening.

At 2nd level, full-text screening was conducted using the following inclusion criteria: (1) original controlled and uncontrolled studies (prospective and retrospective) that enrolled consecutive series of patients with subclavian artery stenosis or occlusion that received either percutaneous transluminal angioplasty (PTA) without stent placement or stent placement, (2) studies reporting one or more of outcomes of interest as described below, (3) studies including at least 10 patients, and (4) studies published in English. Studies that did not meet all four inclusion criteria were excluded. Full-text screening was reviewed independently by two reviewers (A.A. and K.M.); any disagreements were resolved by a third reviewer (W.B.). Web-based software DistillerSR (Evidence Partners Inc) was used for screening and data extraction. DistillerSR is web-based software specifically designed to conduct systematic reviews. Agreement between reviewers was calculated using chance-adjusted agreement statistics [22].

Outcomes

Patients were divided into two groups: (1) those who underwent primary stenting and (2) those who underwent primary angioplasty without stenting. If an angioplasty patient underwent secondary stenting due to failure of angioplasty or for retreatment, they were still included in the angioplasty arm. Primary outcomes included technical success, short-term primary patency (<24 months), long-term primary patency (>24 months), symptom resolution, and retreatment. Technical success was defined as a residual stenosis following the procedure of less than 30 % and an intraarterial systolic pressure gradient across the obstruction less than 10 mm Hg. Secondary outcomes included perioperative outcomes (outcomes <30 days post-op) including in-stent stenosis and occlusion, periprocedural "mortality, stroke, transient ischemic attack, dissection, fistula formation, and distal embolization."

Statistical Analysis

Using DerSimonian and Laird random-effects model [23], we pooled log-transformed event rates and estimated 95 % confidence intervals (CI). Random effect subgroup model was used to compare outcomes between PTA and stent intervention. To measure the overall heterogeneity across the included studies, we used the I2 statistic, in which I2 greater than 50 % suggests high heterogeneity [22]. We used STATA version 13 (StataCorp LP, College Station, Texas) for data analysis. Some of the studies reported the number of vessels treated instead of number of patients. However, a very small number of patients had treatment for more than one vessel (17/1726, <1 %). Therefore, the overlap was minimal and we report our results as per patient treated.

Results

Initial literature search yielded 281 citations of which 35 studies were eligible for analysis. The detailed selection process is described in Fig. 1. The weighted average kappa to evaluate concordance of independent reviewers for study selection was 0.80. Table 1 summarizes the included studies. Of the total 1726 patients included in this study, 57 % were males. Mean age was 59 years, and the mean follow-up duration was 32 months. 397 (23 %) patients had subclavian steal syndrome, 347 (20 %) had subclavian artery occlusion without subclavian steal, and 874 (51 %) had subclavian artery stenosis without subclavian steal. 374 patients in 11 studies received PTA and 1352 patients in 27 studies received stenting.

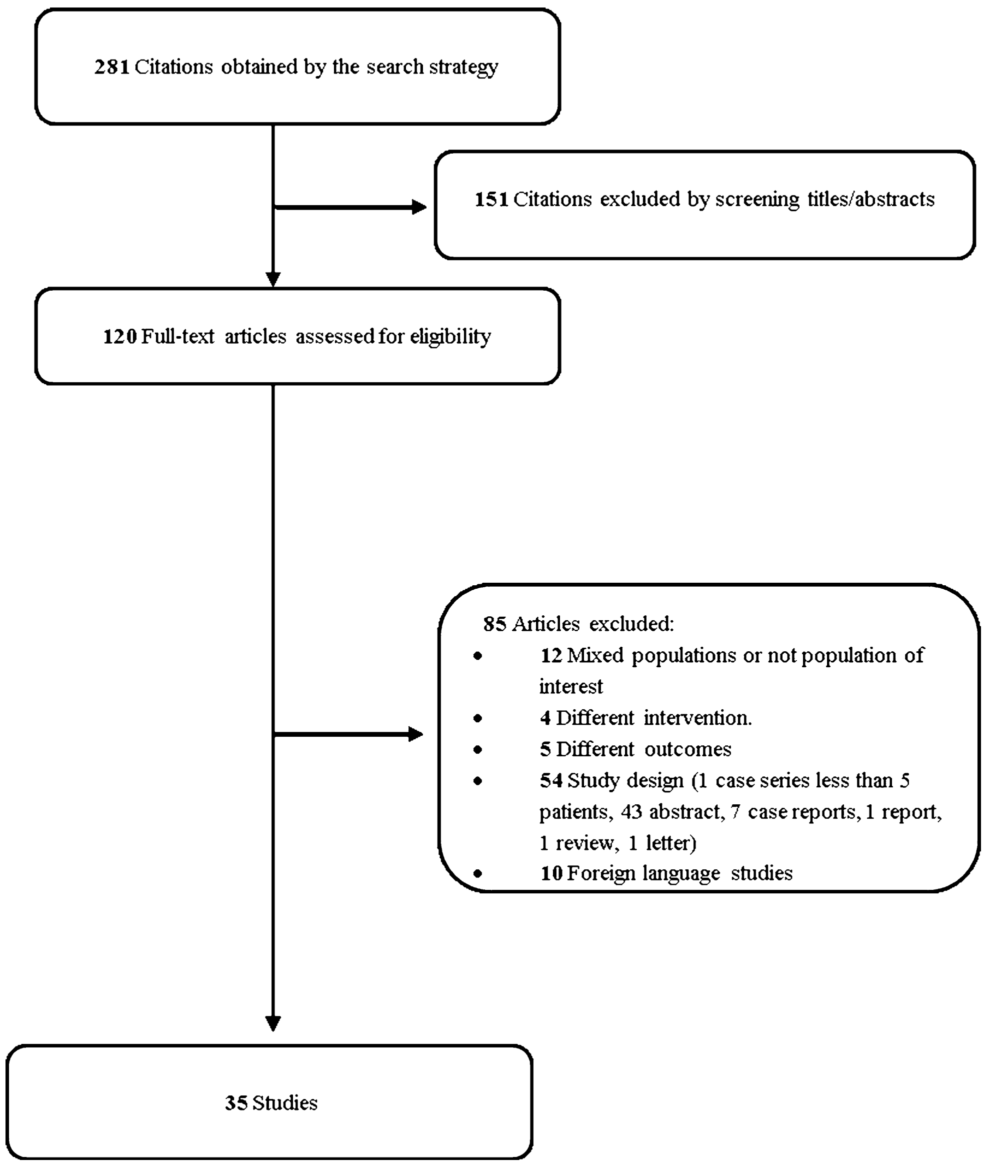


Fig. 1 Flow chart shows the literature search yield and selected studies

Table 1 Characteristics of the included studies

Author name, year	Intervention	Number of patients	Age mean ± SD (years)	Male %	Mean follow-up (months)	Type of lesion (n)	Subclavian steal syndrome[a]
Przewlocki, 2006 [31]	PTA	75	60 ± 8.6	58.7	24.4 ± 15.5	Occlusion [18] Stenosis [58]	46
Higashimori, 2013 [32]	Stent	59	68 ± 10	71.2	49 ± 26	Occlusion [14] Stenosis [46]	21
Li, 2012 [33]	Stent	20	62.3 ± 9	70	27	Occlusion [2] Stenosis [18]	14
Babic, 2011 [34]	Stent	56	58 ± 8	44.6	40 ± 26	Occlusion [56]	NR
Song, 2012 [35]	Stent	148	62.9 ± 6.8	66.9	67	Occlusion [16]	NR
Wang, 2010 [36]	Stent	59	61.9 ± 11	78	40.7 ± 34.9	Occlusion [15] Stenosis [46]	NR
Sixt, 2009 [25]	PTA	14	68 ± 12	50	29	Occlusion [2] Stenosis [12]	NR
	Stent	90	66 ± 9	48		Occlusion [24] Stenosis (66)	NR
Linni, 2008 [37]	Stent	40	61.1 ± 11	52	52	Occlusion [25] Stenosis [15]	NR
Sixt, 2008 [38]	PTA	16	63 ± 16	50	28	Occlusion [3] Stenosis [13]	NR
	Stent	78	65 ± 9	47		Occlusion [23] Stenosis [55]	NR
Palchik, 2008 [39]	Stent	67	63 ± 11	33	48	NR	NR
Van Noord, 2007 [40]	PTA	5	67.6	48.8	12	Stenosis or occlusion [40]	12
	Stent	38					
AbuRahma, 2007 [7]	Stent	121	63	36	40.8	Occlusion [25] Stenosis (96)	NR
Filippo, 2006 [41]	Stent	42	62.64 ± 11	NR	60		42
De Vries, 2005 [42]	Stent	110	62	NR	34	Occlusion [20] Stenosis (90)	NR
Modarai, 2004 [43]	Stent	41	62	NR	48	NR	NR
Angle, 2003 [44]	Stent	21	62.4	52	27	Stenosis [21]	NR
Schillinger, 2002 [45]	PTA	109	59	NR	46 median	Occlusion [27] Stenosis (80)	83
Takach, 2001 [46]	Stent	10	61.5	NR	37.2 months/ patient	NR	NR
Korner, 1999 [17]	Stent	37	58 ± 11	NR	24	NR	14
Rodriguez-Lopez, 1999 [14]	Stent	69	67	52	13	Stenosis [53]	33
Martinez, 1997 [47]	Stent	17	64	NR	19.4	NR	15
Millaire, 1993 [11]	PTA	50	55 ± 11	76	41.2	NR	30
Cook, 1989 [48]	PTA	6	58.3 ± 9.2	50	11.2	Stenosis [6]	NR
Jaschke, 1989 [49]	Stent	9	54	NR	12	NR	9
Burke, 1987 [50]	PTA	27	56.4	NR	25	NR	11
Wilms, 1987 [51]	Stent	22	56	NR	13	NR	NR
Lowman, 1983 [52]	PTA	9	13	NR	30.6	Stenosis [9]	NR
Miyakoshi, 2012 [53]	Stent	36	68.6	72	30.9	Occlusion [7] Stenosis [23]	NR

Table 1 continued

Author name, year	Intervention	Number of patients	Age mean ± SD (years)	Male %	Mean follow-up (months)	Type of lesion (*n*)	Subclavian steal syndrome[a]
Yu, 2010 [54]	Stent	14	67 ± 10	35.7	12	Occlusion [5]	4
						Stenosis [14]	
Sakai, 2007 [55]	Stent	26	62.7	69.2	24	Occlusion [26]	NR
Amor, 2004 [56]	Stent	86	67.8 ± 10	55.1	42.12	Occlusion [13]	44
						Stenosis (76)	
Gonzalez, 2002 [57]	Stent	9	55	100	37.4	Occlusion [9]	8
Kumar, 1995 [58]	Stent	27	60 ± 11	37	NR	Occlusion [8]	11
						Stenosis [23]	
Perrault, 1993 [59]	PTA	11	57 ± 9	72.7	38	Stenosis [11]	NR
Hebrang, 1991 [60]	PTA	52	57	NR	29	Occlusion [9]	NR
						Stenosis [43]	

[a] Subclavian steal syndrome: The term subclavian steal is characterized by specific signs and symptoms due to retrograde blood flow in the vertebral artery associated with proximal ipsilateral subclavian artery stenosis or occlusion usually the occlusion is proximal to the origin of the vertebral artery

Risk of Bias

All studies included were single-arm cohort studies. No comparative studies (randomized or non-randomized) were available. The risk of bias in the included studies was generally high due to unclear description of the included cohort, inadequate outcomes ascertainment, or attrition. None performed adjustment for confounding variables. Detailed risk of bias assessment is described in Table 2.

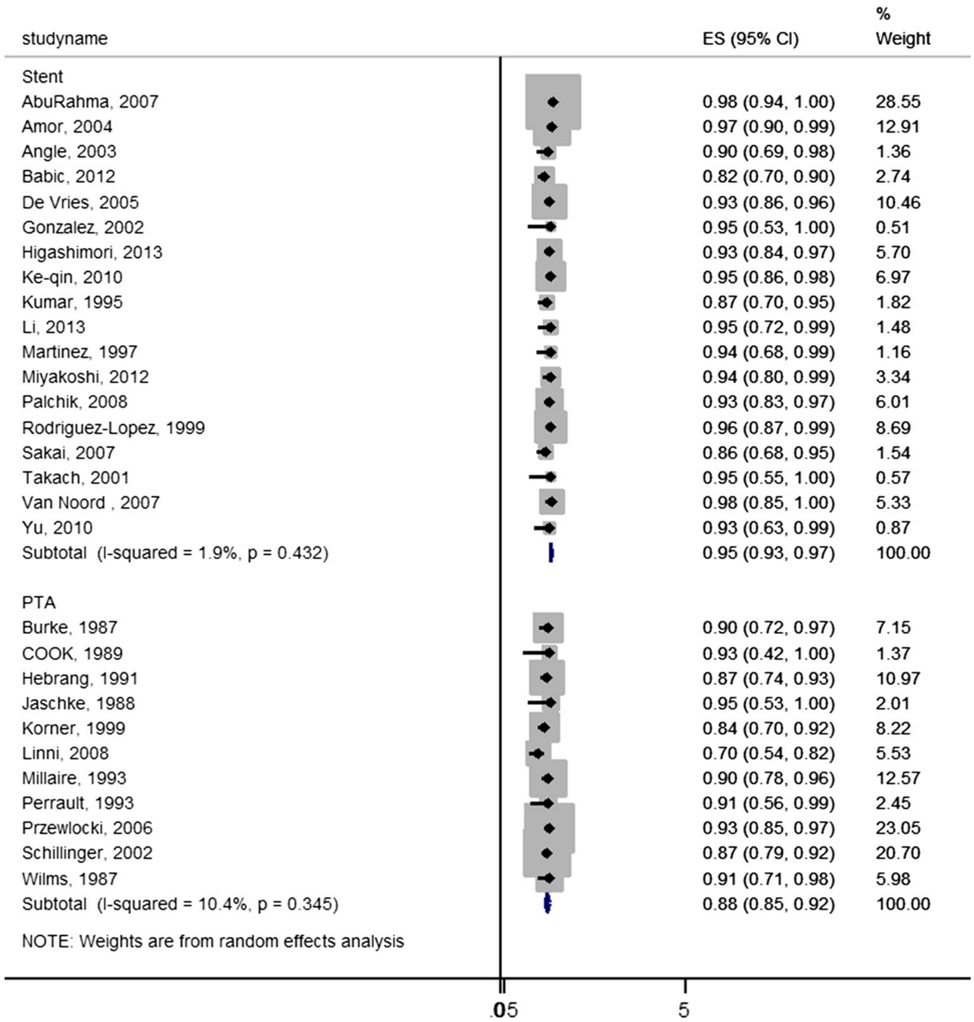
Table 2 Risk of bias assessment of the included studies

	Selection of cohort/patients	Adjusting for confounders	Outcome ascertainment was adequate?	Adequate follow-up period
Przewlocki, 2006 [31]	Selected/non-consecutive patients, i.e., patients were chosen because of specific criteria	None or not clear	Yes	Adequate
Higashimori, 2013 [32]	Consecutive, i.e., patients were not selected based on a criteria but were chosen the order they presented	None or not clear	Yes	Adequate
Li, 2012 [33]	Consecutive, i.e., patients were not selected based on a criteria but were chosen the order they presented	None or not clear	Yes	Adequate
Babic, 2011 [34]	Consecutive, i.e., patients were not selected based on a criteria but were chosen the order they presented	None or not clear	Yes	Adequate
Song, 2012 [35]	Consecutive, i.e., patients were not selected based on a criteria but were chosen the order they presented	None or not clear	Yes	Adequate
Wang, 2010 [36]	Selected/non-consecutive patients, i.e., patients were chosen because of specific criteria	None or not clear	Yes	Adequate
Sixt, 2009 [25]	Selected/non-consecutive patients, i.e., patients were chosen because of specific criteria	None or not clear	Yes	Adequate
Linni, 2008 [37]	Selected/non-consecutive patients, i.e., patients were chosen because of specific criteria	None or not clear	Yes	Adequate
Sixt, 2008 [25]	Consecutive, i.e., patients were not selected based on a criteria but were chosen the order they presented	None or not clear	Yes	Adequate

Table 2 continued

	Selection of cohort/patients	Adjusting for confounders	Outcome ascertainment was adequate?	Adequate follow-up period
Palchik, 2008 [39]	Not reported	None or not clear	Yes	Adequate
Van Noord, 2007 [40]	Consecutive, i.e., patients were not selected based on a criteria but were chosen the order they presented	None or not clear	Yes	Not Adequate
AbuRahma, 2007 [7]	Selected/non-consecutive patients, i.e., patients were chosen because of specific criteria	None or not clear	Yes	Adequate
Filippo, 2006 [41]	Selected/non-consecutive patients, i.e., patients were chosen because of specific criteria	None or not clear	Yes	Adequate
De Vries, 2005 [42]	Selected/non-consecutive patients, i.e., patients were chosen because of specific criteria	None or not clear	Yes	Adequate
Modarai, 2004 [43]	Selected/non-consecutive patients, i.e., patients were chosen because of specific criteria	None or not clear	Yes	Adequate
Angle, 2003 [44]	Consecutive, i.e., patients were not selected based on a criteria but were chosen the order they presented	None or not clear	Yes	Adequate
Schillinger, 2002 [45]	Consecutive, i.e., patients were not selected based on a criteria but were chosen the order they presented	None or not clear	Yes	Adequate
Takach, 2001 [46]	Selected/non-consecutive patients, i.e., patients were chosen because of specific criteria	None or not clear	Yes	Adequate
Korner, 1999 [17]	Selected/non-consecutive patients, i.e., patients were chosen because of specific criteria	None or not clear	Yes	Adequate
Rodriguez-Lopez, 1999 [14]	Consecutive, i.e., patients were not selected based on a criteria but were chosen the order they presented	None or not clear	Yes	Adequate
Martinez, 1997 [47]	Selected/non-consecutive patients, i.e., patients were chosen because of specific criteria	None or not clear	Yes	Adequate
Millaire, 1993 [11]	Consecutive, i.e., patients were not selected based on a criteria but were chosen the order they presented	None or not clear	Yes	Adequate
Cook, 1989 [48]	Selected/non-consecutive patients, i.e., patients were chosen because of specific criteria	None or not clear	Yes	Not Adequate
Jaschke, 1989 [49]	Selected/non-consecutive patients, i.e., patients were chosen because of specific criteria	None or not clear	Yes	Not Adequate
Burke, 1987 [50]	Selected/non-consecutive patients, i.e., patients were chosen because of specific criteria	None or not clear	Yes	Adequate
Wilms, 1987 [51]	Selected/non-consecutive patients, i.e., patients were chosen because of specific criteria	None or not clear	Yes	Adequate
Lowman, 1983 [52]	Selected/non-consecutive patients, i.e., patients were chosen because of specific criteria	None or not clear	Yes	Adequate
Miyakoshi, 2012 [53]	Selected/non-consecutive patients, i.e., patients were chosen because of specific criteria	None or not clear	Yes	Adequate
Yu, 2010 [54]	Selected/non-consecutive patients, i.e., patients were chosen because of specific criteria	None or not clear	Yes	Not Adequate
Sakai, 2007 [55]	Selected/non-consecutive patients, i.e., patients were chosen because of specific criteria	None or not clear	Yes	Adequate
Amor, 2004 [56]	Selected/non-consecutive patients, i.e., patients were chosen because of specific criteria	None or not clear	Yes	Adequate
Gonzalez, 2002 [57]	Selected/non-consecutive patients, i.e., patients were chosen because of specific criteria	None or not clear	Yes	Adequate
Kumar, 1995 [58]	Consecutive, i.e., patients were not selected based on a criteria but were chosen the order they presented	None or not clear	Yes	Unclear or not reported
Perrault, 1993 [59]	Selected/non-consecutive patients, i.e., patients were chosen because of specific criteria	None or not clear	Yes	Adequate
Hebrang, 1991 [60]	Selected/non-consecutive patients, i.e., patients were chosen because of specific criteria	None or not clear	Yes	Adequate

Fig. 2 Meta-analysis of technical success comparing PTA and stenting of the included studies



Primary Outcomes

Technical success rate was significantly higher in stent group 92.8 % (95 % CI 90.3–94.7 %) compared to the PTA group (86.9 %, 95 % CI 82.2–90.5 %; $p = 0.007$) (Fig. 2). For primary patency, no significant difference was observed for short-term follow-up as primary patency in the stent group was 88.7 % (95 % CI 84.9–91.8 %) and 89.9 % in the PTA group (95 % CI 81.5–94.7 %) (Fig. 3). No significant difference was observed in primary patency at >2 years as primary patency rates were 76.9 % (95 % CI 68.4–83.6 %) in the stenting group and 79.6 % (95 % CI 63.5–89.8 %) in the PTA group ($p = 0.729$) (Fig. 4). There was no significant difference in symptom resolution rate between the stenting group (82.2 %, 95 % CI 60.6–93.3 %) and the PTA group (73.0 %, 95 % CI 63.6–80.7 %, $p = 0.327$) (Fig. 5). Retreatment rates at follow-up were also similar: 5 % (95 % CI 0.03–0.09 %) in the stenting group and 6 % (95 % CI 0.03–0.08 %) in the PTA group ($p = 0.929$) (Fig. 6). Among patients in the PTA group, 4 % were retreated with PTA and 2 % were retreated with stenting. Among patients in the stenting group, 2 % were retreated with PTA and 2 % were retreated with stenting.

Secondary Outcomes

There was no significant difference in the rates of stroke within 30 days of the procedure (2 % PTA group, 2 % stenting group, $p = 0.742$). TIA and periprocedural mortality rates were 1.8 and 2.4 %, respectively, for the stenting group, but not reported as an outcome for the PTA group. There were no differences in arterial fistula, distal embolization, and dissection between PTA and stenting. There was no difference in long-term outcomes rates such as mortality. Table 3 summarizes rates of perioperative complications.

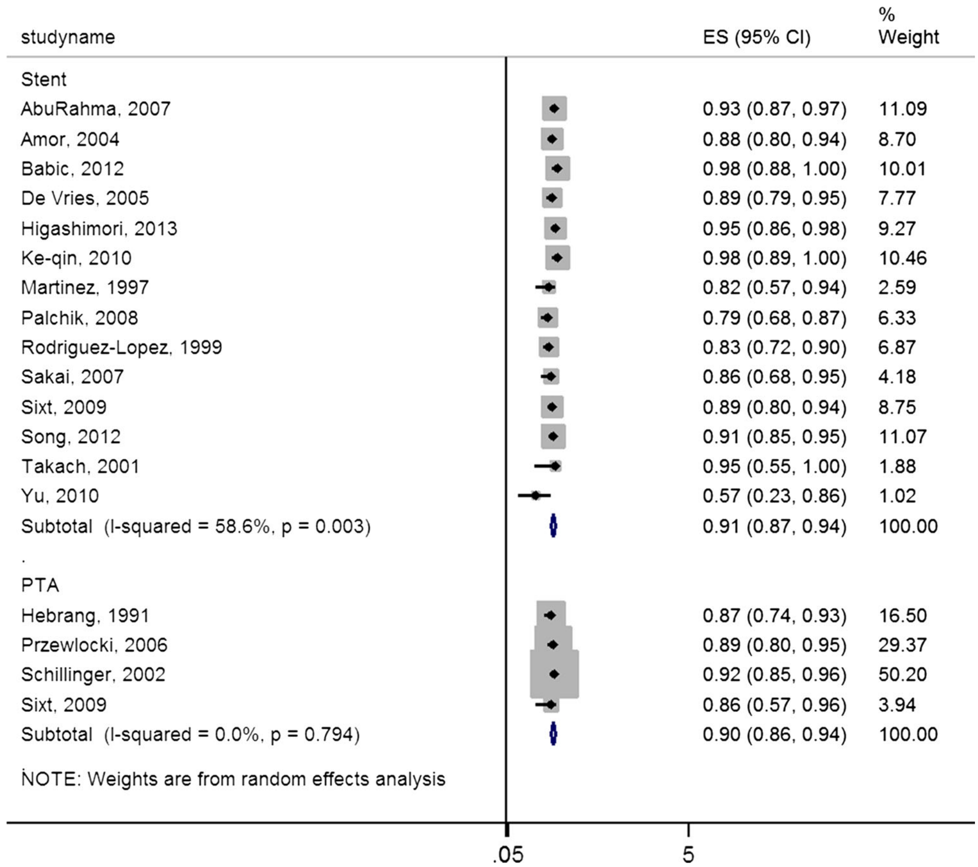


Fig. 3 Meta-analysis of 1ry patency less than 24 months comparing PTA and stenting of the included studies

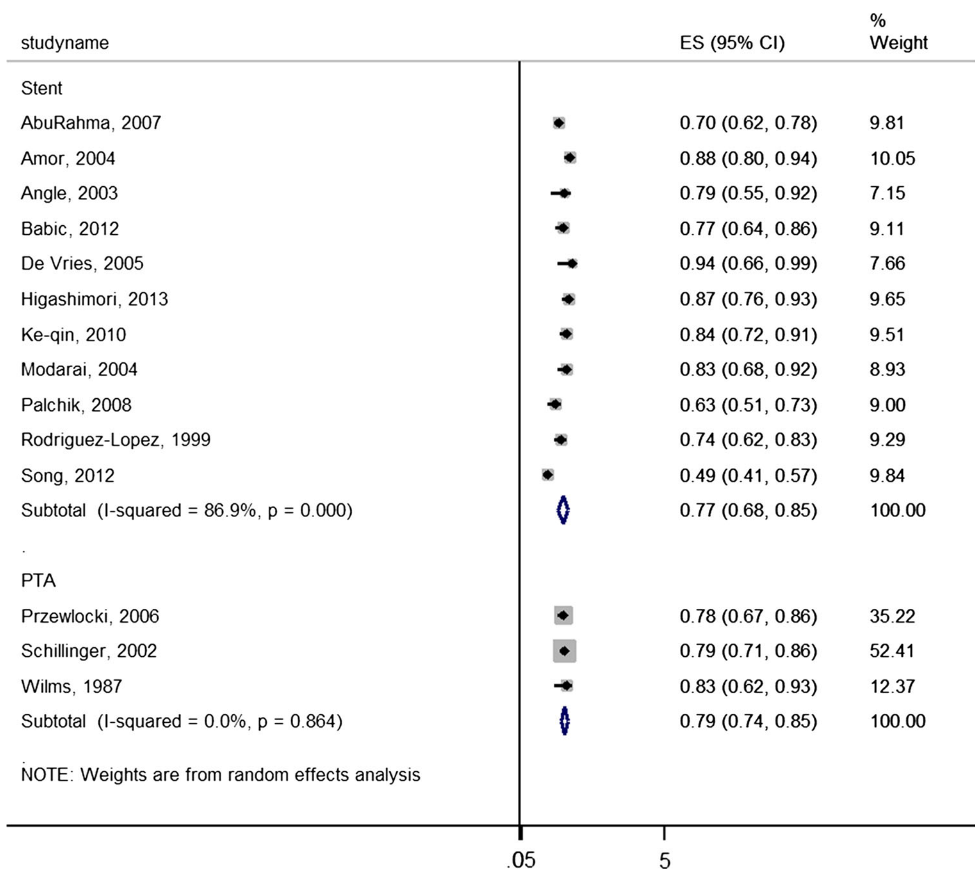


Fig. 4 Meta-analysis of 1ry patency more than 24 months comparing PTA and stenting of the included studies

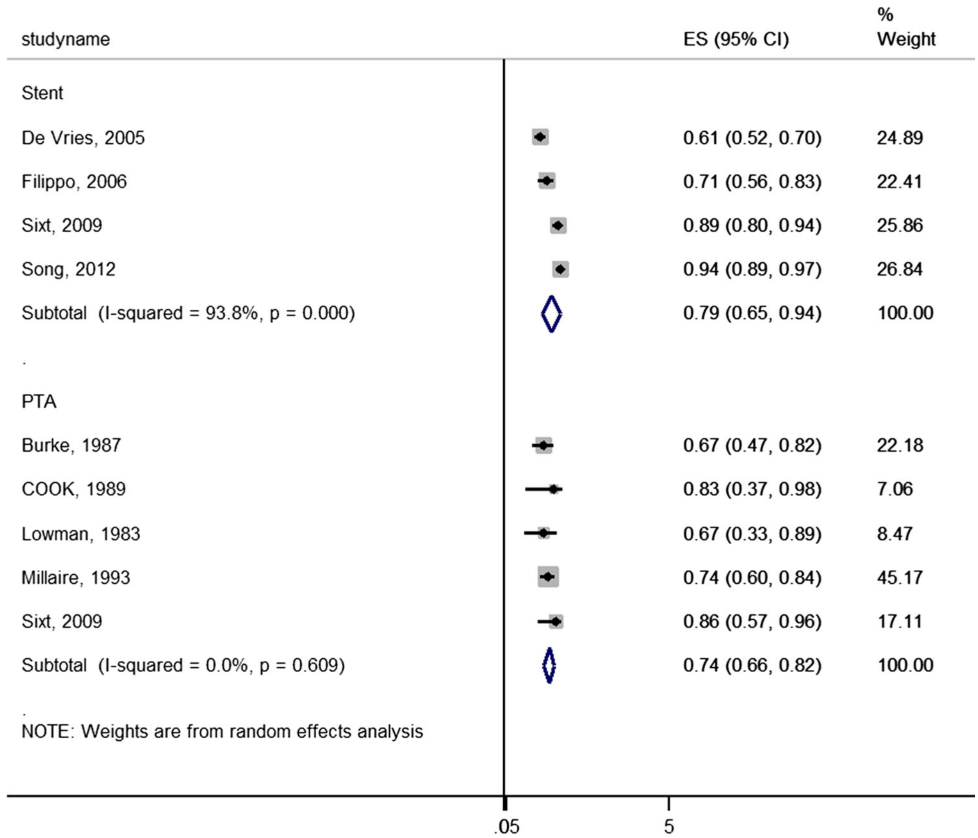


Fig. 5 Meta-analysis of symptoms resolution comparing PTA and stenting of the included studies

Heterogeneity and Publication Bias

Due to the lack of comparative studies, we were unable to evaluate publication bias. Publication bias is quite likely in this body of evidence that consists of small non-registered case series. It is plausible that case series with less favorable outcomes are not published. There was no heterogeneity in technical success outcomes in the PTA and stent placement studies, while there was high heterogeneity in the analyses of stent placement studies for the <2 years primary patency, >2 year primary patency, symptoms improvement, and retreatment outcomes.

Discussion

Endovascular treatment options of subclavian artery occlusive disease (SAOD) aim to increase or establish blood flow across an obstructed arterial segment. This is most commonly accomplished with either mechanical dilation (percutaneous balloon angioplasty) with or without placement of a stent to buttress the vessel wall. Both procedures have demonstrated technical feasibility and safety; however, direct comparison of outcomes between these procedures is limited to observational studies with variable measures of outcome. The results of the current meta-analysis show that stent placement demonstrated significantly higher technical success rate than PTA alone. Otherwise, no significant differences were found for short- or long-term patency rates, symptom resolution, or incidence of retreatment. Furthermore, we found no significant differences in the rates of perioperative complications (TIA, stroke, arterial fistula, distal embolization, or mortality).

To date, the largest systemic review by Chatterjee in 2013 included 544 patients, of which 307 underwent angioplasty and 237 underwent stent placement. Stenting after PTA was significantly superior to angioplasty alone for treatment of subclavian artery stenosis and maintenance of patency at 1 year $p = 0.004$, without significant complication rates for either procedure [24]. The current study adds to the literature by expanding the search criteria to include 1726 patients with longer follow-up time. Non-comparative studies comparing PTA to PTA with stent placement include a study of 108 interventions by Sixt et al. who demonstrated excellent 1 year patency rates with angioplasty (79 %) and PTA with stenting (89 %), although differences were not significantly different $p = 0.2$ [25].

The addition of stents to PTA in the management of SOAD remains in debate [26]. In theory, stents should resist the elastic recoil of a vessel wall after PTA [27].

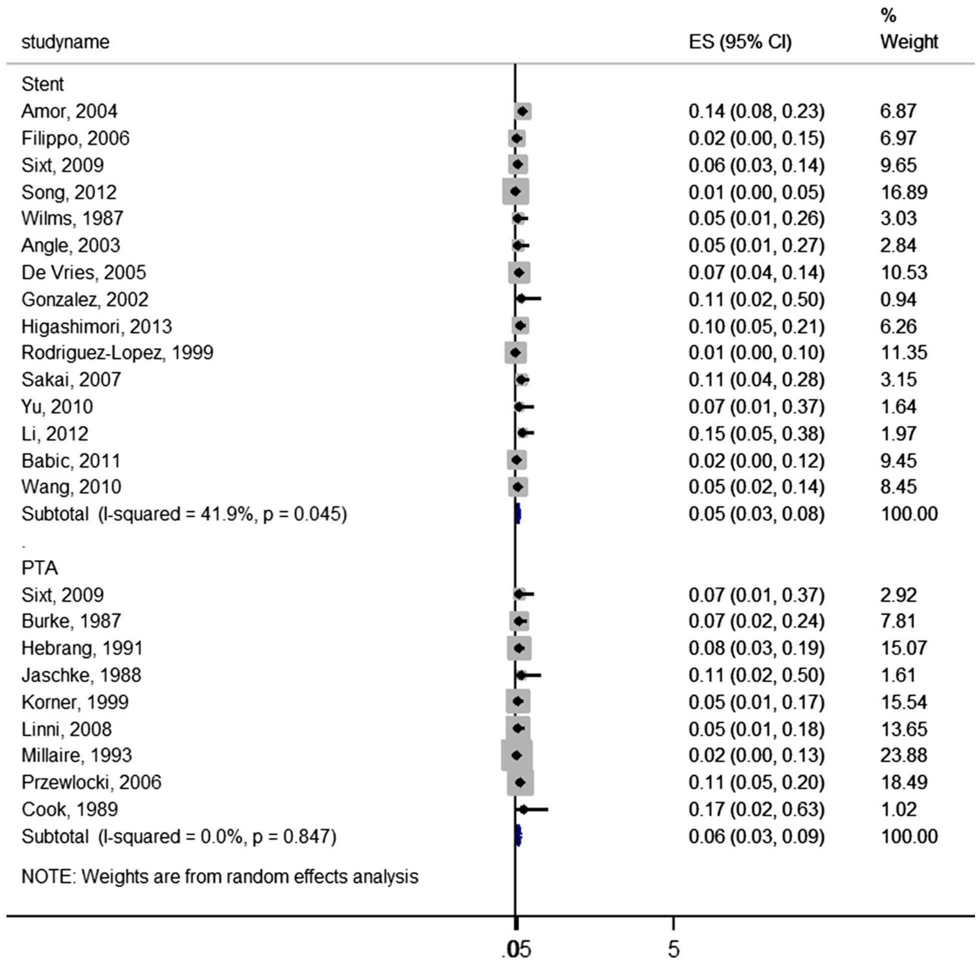


Fig. 6 Meta-analysis of retreatment comparing PTA and stenting of the included studies

Table 3 Meta-analysis of the results

Intervention	Outcome	Effect size	95 % CI LL	UL	*p* value	*I*-square	Number of studies
PTA	Technical success	88 %	0.85	0.92	0.007	10.4	11
Stenting		95 %	0.93	0.97		1.9	18
PTA	Technical failure	15 %	0.09	0.25	0.058	50.4	5
Stenting		7.5 %	0.05	0.12		58.2	10
PTA	1ry patency $\leq$ 24	90 %	0.86	0.94	0.766	0	4
Stenting		91 %	0.87	0.94		58.6	14
PTA	1ry patency > 24	79 %	0.74	0.85	0.729	0	3
Stenting		77 %	0.68	0.85		86.9	11
PTA	Retreatment	6 %	0.03	0.08	0.929	0	9
Stenting		5 %	0.03	0.09		41.9	15
PTA	Symptoms resolution	74 %	0.66	0.82	0.372	0	5
Stenting		79 %	0.65	0.94		93.8	4
PTA	Periprocedural mortality	N/R	N/R	N/R	1	N/R	N/R
Stenting		2.4 %	0.01	0.05		2	7
PTA	Stroke < 30 days	2 %	0.01	0.13	0.742	N/R	N/R
Stenting		2 %	0.02	0.05		0	8
PTA	TIA < 30 days	N/R	N/R	N/R	1	N/R	N/R

Table 3 continued

Intervention	Outcome	Effect size	95 % CI LL	UL	*p* value	*I*-square	Number of studies
Stenting		1.8 %	0.01	0.06		0	3
PTA	Fistula < 30 days	N/R	N/R	N/R	1	N/R	N/R
Stenting		1.5 %	0.01	0.05		0	3
PTA	Distal embolization <30 days	3 %	0.008	0.10	0.629	35.6	3
Stenting		2.1 %	0.01	0.04		0	6
PTA	Dissection < 30 days	N/R	N/R	N/R	1	N/R	N/R
Stenting		3.5 %	0.02	0.07		32	6
PTA	Miscellaneous complications <30 days	10.1 %	0.06	0.16	0.108	31.3	8
Stenting		6 %	0.04	0.1		7.3	11

However, in-stent stenosis due to neointimal hyperplasia may result in subsequent narrowing of the lumen and recurrence of flow-limiting stenosis [28]. Nonetheless, endovascular treatments appear to offer a safe and effective alternative to surgical bypass. Although patency rates after endovascular intervention are reported to be less than surgical bypass [7], the ease of reintervention through a percutaneous approach (transfemoral or transbronchial) makes such an option attractive, especially to patients with significant comorbidities. In the future, other advancements in endovascular treatment such as drug eluting stents, drug eluting balloons, and cutting balloons can be studied to determine if they further improve patency rates and offer sustainable relief of symptoms.

The main limitation of systematic review was inherent to the non-comparative design of the included studies. The heterogeneity observed in some of the analyses reflects the real world variation in disease process and patient presentation. In any case, a true determination of efficacy will require a randomized controlled trial. The quality of evidence is low due to imprecision, methodological limitations, and heterogeneity [29, 30].

In conclusion, endovascular management of subclavian arterial occlusive disease is a viable and effective option and mitigates the need for surgical bypass. The current study summarizes the available data and demonstrates relatively little difference in technical, clinical, and angiographic outcomes between the use of angioplasty alone or with placement of a stent. Until further studies are available, the decision between interventions should be made on a case-by-case basis based on availability of surgical expertise and unique patient characteristics.

Compliance with Ethical Standards

Conflict of Interest All authors declare that they have no conflicts of interest.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

Appendix

See Table 4.

Table 4 Search strategy

N	Searches	Results
1	exp subclavian steal syndrome/	2711
2	(((unilateral or ipsilateral) adj1 "subclavian artery" adj1 (stenos* or occlusion)) or "basilar steal syndrome*" or "brachial-basilar insufficiency syndrome*" or "congenital subclavian steal syndrome*" or "innominate artery steal syndrome*" or "innominate steal syndrome*" or "subclavian artery stenos*" or "subclavian carotid artery steal syndrome*" or "subclavian steal" or "subclavian steal phenomenon" or "subclavian steal steno-occlusive" or "subclavian steal syndrome*" or "subclavian-carotid artery steal syndrome*" or "vertebral artery flow reversal").mp.	3487
3	1 or 2	3487
4	angioplasty/or carotid angioplasty/or laser angioplasty/or patch angioplasty/or percutaneous transluminal angioplasty/or transluminal coronary angioplasty/	67,589
5	(angioplast* or "balloon dilation*").mp.	152,640
6	4 or 5	152,640
7	exp Stents/	162,341
8	exp stent/	162,341
9	stent*.mp.	208,079
10	7 or 8 or 9	208,261
11	3 and (6 or 10)	987
12	exp evidence-based medicine/	728,585
13	exp meta-analysis/	137,212
14	exp Meta-Analysis as Topic/	30,318
15	exp "systematic review"/	80,471
16	exp Guideline/or exp Practice Guideline/	346,428
17	exp controlled study/	4,538,063
18	exp Randomized Controlled Trial/	734,232
19	exp triple-blind procedure/	72
20	exp Double-Blind Method/	345,733
21	exp Single-Blind Method/	51,813
22	exp latin square design/	276
23	exp Placebos/	269,937
24	exp Placebo Effect/	7361
25	exp comparative study/	2,485,033
26	exp Cross-Sectional Studies/	316,010
27	exp Cross-Over Studies/	102,319
28	exp Cohort Studies/	1,710,774
29	exp longitudinal study/	1,083,231
30	exp retrospective study/	876,935
31	exp prospective study/	711,800
32	exp population research/	68,441
33	exp observational study/	67,158
34	exp clinical trial/	1,749,422
35	clinical study/	54,387
36	exp Evaluation Studies/	213,346
37	exp Evaluation Studies as Topic/	1,152,840
38	exp Twin Study/	32,017
39	exp quantitative study/	5920
40	exp validation studies/	116,064
41	exp experimental study/	14,891
42	exp quasi experimental study/	2085
43	exp field study/	1564

Table 4 continued

N	Searches	Results
44	in vivo study/	191,467
45	exp panel study/	379
46	exp Pilot Projects/	173,742
47	exp pilot study/	173,742
48	exp prevention study/	2168
49	exp replication study/	967
50	exp theoretical study/	1,416,575
51	exp Feasibility Studies/	101,266
52	exp Models, Theoretical/	1,436,545
53	exp trend study/	11,509
54	exp correlational study/	11,649
55	exp case–control studies/	800,333
56	exp confidence interval/	123,775
57	exp regression analysis/	584,481
58	exp proportional hazards model/	97,930
59	exp multivariate analysis/	348,950
60	"limit follow up studies to medline only. embase maps to follow up".ti.	0
61	exp follow-up studies/	1,359,601
62	exp case study/	1,752,499
63	"limit case study above to embase only. medline maps to case report".ti.	0
64	odds ratio/	391,729
65	"limit odds ratio above to embase. medline maps to risk".ti.	0
66	((evidence adj based) or (meta adj analys*) or (systematic* adj3 review*) or guideline* or (doubl* adj blind*) or (doubl* adj mask*) or (singl* adj blind*) or (singl* adj mask*) or (tripl* adj blind*) or (tripl* adj mask*) or (trebl* adj blind*) or (trebl* adj mask*) or "latin square" or placebo or random* or control* or multivariate or "comparative study" or "comparative survey" or "comparative analysis" or compar* or (intervention* adj2 study) or (intervention* adj2 trial) or "cross-sectional study" or "cross-sectional analys*" or "cross-sectional survey*" or "cross-sectional design*" or "prevalence study" or "prevalence analys*" or "prevalence survey*" or "disease frequency study" or "disease frequency analys*" or "disease frequency survey*" or crossover or "cross-over" or cohort* or "longitudinal study" or "longitudinal survey" or "longitudinal analysis" or longitudinal* or "retrospective study" or "retrospective survey" or "retrospective analysis" or retrospectiv* or "prospective study" or "prospective survey" or "prospective analysis" or prospectiv* or "population study" or "population survey" or "population analysis" or "concurrent study" or "concurrent survey" or "concurrent analysis" or "incidence study" or "incidence survey" or "incidence analysis" or "follow-up study" or "follow-up survey" or "follow-up analysis" or "observational study" or "observational survey" or "observational analysis" or "case study" or "case series" or "clinical series" or "case studies" or "clinical study" or "clinical trial" or "evaluation study" or "evaluation survey" or "evaluation analysis" or "twin study" or "twin survey" or "twin analysis" or "quantitative study" or "quantitative analys*" or "validation study" or "validation survey" or "validation analysis" or "experimental study" or "experimental analysis " or "quasi experimental study" or "quasi experimental analysis" or "quasiexperimental study" or "quasiexperimental analysis" or "field study" or "field survey" or "field analysis" or "in vivo study" or "in vivo analysis" or "panel study" or "panel survey" or "panel analysis" or "prevention study" or "prevention survey" or "prevention analysis" or "replication study" or "replication analysis " or "theoretical study" or "theoretical analysis " or "feasibility study" or "feasibility analysis " or "trend study" or "trend survey" or "trend analysis" or (correlation* adj2 study) or (correlation* adj2 analys*) or "case control study" or "case base study" or "case referent study" or "case referent study" or "case compeer study" or "case comparison study" or study or trial or pilot or "odds ratio" or "confidence interval" or "regression analysis" or "hazards model" or "change analysis").mp.	22,420,920
67	from 61 keep 802022-1317651	515,630
68	from 62 keep 1-26110	26,110
69	from 64 keep 1-324971	324,971
70	or/12-59	12,775,921

Table 4 continued

N	Searches	Results
71	66 or 67 or 68 or 69 or 70	23,573,157
72	11 and 71	364
73	from 11 keep 517-985	469
74	limit 73 to (clinical trial, all or clinical trial, phase i or clinical trial, phase ii or clinical trial, phase iii or clinical trial, phase iv or clinical trial or comparative study or controlled clinical trial or evaluation studies or guideline or meta-analysis or multicenter study or observational study or practice guideline or pragmatic clinical trial or randomized controlled trial or systematic reviews or twin study or validation studies) [Limit not valid in Embase, CCTR, CDSR; records were retained]	32
75	72 or 74	365
76	limit 75 to (book or book series or editorial or erratum or letter or note or addresses or autobiography or bibliography or biography or comment or dictionary or directory or interactive tutorial or interview or lectures or legal cases or legislation or news or newspaper article or overall or patient education handout or periodical index or portraits or published erratum or video-audio media or webcasts) [Limit not valid in Embase, Ovid MEDLINE(R),Ovid MEDLINE(R) In-Process, CCTR, CDSR; records were retained]	9
77	75 not 76	356
78	from 11 keep 986-987	2
79	77 or 78	357
80	remove duplicates from 79	277

References

1. Fields WS, Lemak NA. Joint study of extracranial arterial occlusion. VII. Subclavian steal—a review of 168 cases. JAMA. 1972;222(9):1139–43.
2. Bryan AJ, Hicks E, Lewis MH. Unilateral digital ischaemia secondary to embolisation from subclavian atheroma. Ann R Coll Surg Engl. 1989;71(2):140–2.
3. Sueoka BL. Percutaneous transluminal stent placement to treat subclavian steal syndrome. J Vasc Interv Radiol. 1996;7(3):351–6.
4. Olsen CO, Dunton RF, Maggs PR, Lahey SJ. Review of coronary-subclavian steal following internal mammary artery-coronary artery bypass surgery. Ann Thorac Surg. 1988;46(6):675–8.
5. Edwards WH, Mulherin JL Jr. The surgical reconstruction of the proximal subclavian and vertebral artery. J Vasc Surg. 1985;2(4):634–42.
6. Wylie EJ, Effeney DJ. Surgery of the aortic arch branches and vertebral arteries. Surg Clin North Am. 1979;59(4):669–80.
7. AbuRahma AF, Bates MC, Stone PA, Dyer B, Armistead L, Scott Dean L, Scott Lavigne P. Angioplasty and stenting versus carotid-subclavian bypass for the treatment of isolated subclavian artery disease. J Endovasc Ther. 2007;14(5):698–704.
8. Bachman DM, Kim RM. Transluminal dilatation for subclavian steal syndrome. AJR Am J Roentgenol. 1980;135(5):995–6.
9. Joseph S, Mandalam KR, Rao VR, Gupta AK, Unni NM, Rao AS, Neelakandhan KS, Unnikrishnan M, Sandhyamani S. Percutaneous transluminal angioplasty of the subclavian artery in nonspecific aortoarteritis: results of long-term follow-up. J Vasc Interv Radiol. 1994;5(4):573–80.
10. Mathias KD, Luth I, Haarmann P. Percutaneous transluminal angioplasty of proximal subclavian artery occlusions. Cardiovasc Intervent Radiol. 1993;16(4):214–8.
11. Millaire A, Trinca M, Marache P, de Groote P, Jabinet JL, Ducloux G. Subclavian angioplasty: immediate and late results in 50 patients. Cathet Cardiovasc Diagn. 1993;29(1):8–17.
12. Tyagi S, Verma PK, Gambhir DS, Kaul UA, Saha R, Arora R. Early and long-term results of subclavian angioplasty in aortoarteritis (Takayasu disease): comparison with atherosclerosis. Cardiovasc Intervent Radiol. 1998;21(3):219–24.
13. Bogey WM, Demasi RJ, Tripp MD, Vithalani R, Johnsrude IS, Powell SC. Percutaneous transluminal angioplasty for subclavian artery stenosis. Am Surg. 1994;60(2):103–6.
14. Rodriguez-Lopez JA, Werner A, Martinez R, Torruella LJ, Ray LI, Diethrich EB. Stenting for atherosclerotic occlusive disease of the subclavian artery. Ann Vasc Surg. 1999;13(3):254–60.
15. Hadjipetrou P, Cox S, Piemonte T, Eisenhauer A. Percutaneous revascularization of atherosclerotic obstruction of aortic arch vessels. J Am Coll Cardiol. 1999;33(5):1238–45.
16. Henry M, Amor M, Henry I, Ethevenot G, Tzvetanov K, Chati Z. Percutaneous transluminal angioplasty of the subclavian arteries. J Endovasc Surg. 1999;6(1):33–41.
17. Korner M, Baumgartner I, Do DD, Mahler F, Schroth G. PTA of the subclavian and innominate arteries: long-term results. Vasa. 1999;28(2):117–22.
18. Motarjeme A. Percutaneous transluminal angioplasty of supra-aortic vessels. J Endovasc Surg. 1996;3(2):171–81.
19. Bali HK, Bhargava M, Jain AK, Sharma BK. De novo stenting of descending thoracic aorta in Takayasu arteritis: intermediate-term follow-up results. J Invasive Cardiol. 2000;12(12):612–7.
20. Schillinger M, Haumer M, Schillinger S, Ahmadi R, Minar E. Risk stratification for subclavian artery angioplasty: is there an increased rate of restenosis after stent implantation? J Endovasc Ther. 2001;8(6):550–7.
21. Moher D, Liberati A, Tetzlaff J, Altman DG. Reprint—preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. Phys Ther. 2009;89(9):873–80.
22. Higgins JP, Thompson SG, Deeks JJ, Altman DG. Measuring inconsistency in meta-analyses. BMJ. 2003;327(7414):557–60.
23. DerSimonian R, Laird N. Meta-analysis in clinical trials. Control Clin Trials. 1986;7(3):177–88.
24. Chatterjee S, Nerella N, Chakravarty S, Shani J. Angioplasty alone versus angioplasty and stenting for subclavian artery stenosis—a systematic review and meta-analysis. Am J Ther. 2013;20(5):520–3.

25. Sixt S, Rastan A, Schwarzwalder U, Burgelin K, Noory E, Schwarz T, Beschorner U, Frank U, Muller C, Hauk M, Leppanen O, Hauswald K, Brantner R, Nazary T, Neumann FJ, Zeller T. Results after balloon angioplasty or stenting of atherosclerotic subclavian artery obstruction. Catheter Cardiovasc Interv. 2009;73(3):395–403.
26. Brountzos ENMK, Kelekis DA, Andreas H, Mahnken, Hülsbeck SM. Cirse Quality Assurance Guidelines For The Endovascular Treatment of Occlusive Lesions of the Subclavian and Innominate Arteries Cardiovascular and Interventional Radiological Society of Europe; 2013.
27. Palmaz JC, Kopp DT, Hayashi H, Schatz RA, Hunter G, Tio FO, Garcia O, Alvarado R, Rees C, Thomas SC. Normal and stenotic renal arteries: experimental balloon-expandable intraluminal stenting. Radiology. 1987;164(3):705–8.
28. Shah PK. Inflammation, neointimal hyperplasia, and restenosis: as the leukocytes roll, the arteries thicken. Circulation. 2003;107(17):2175–7.
29. Balshem H, Helfand M, Schunemann HJ, Oxman AD, Kunz R, Brozek J, Vist GE, Falck-Ytter Y, Meerpohl J, Norris S, Guyatt GH. GRADE guidelines: 3. Rating the quality of evidence. J Clin Epidemiol. 2011;64(4):401–6.
30. Guyatt GH, Oxman AD, Kunz R, Brozek J, Alonso-Coello P, Rind D, Devereaux PJ, Montori VM, Freyschuss B, Vist G, Jaeschke R, Williams JW Jr, Murad MH, Sinclair D, Falck-Ytter Y, Meerpohl J, Whittington C, Thorlund K, Andrews J, Schunemann HJ. GRADE guidelines 6. Rating the quality of evidence–imprecision. J Clin Epidemiol. 2011;64(12):1283–93.
31. Przewlocki T, Kablak-Ziembicka A, Pieniazek P, Musialek P, Kadzielski A, Zalewski J, Kozanecki A, Tracz W. Determinants of immediate and long-term results of subclavian and innominate artery angioplasty. Catheter Cardiovasc Interv. 2006;67(4):519–26.
32. Higashimori A, Morioka N, Shiotani S, Fujihara M, Fukuda K, Yokoi Y. Long-term results of primary stenting for subclavian artery disease. Catheter Cardiovasc Interv. 2013;82(5):696–700.
33. Li Y, Yin Q, Zhu W, Wang Y, Fan X, Liu D, Chen M, Wang Q, Xu G, Yan B, Liu X. Endovascular stenting for atherosclerotic subclavian artery stenosis in patients with other craniocervical artery stenosis. J Thromb Thrombolysis. 2013;35(1):107–14.
34. Babic S, Sagic D, Radak D, Antonic Z, Otasevic P, Kovacevic V, Tanaskovic S, Ruzicic D, Aleksic N, Vucurevic G. Initial and long-term results of endovascular therapy for chronic total occlusion of the subclavian artery. Cardiovasc Intervent Radiol. 2012;35(2):255–62.
35. Song L, Zhang J, Li J, Gu Y, Yu H, Chen B, Guo L, Wang Z. Endovascular stenting vs. extrathoracic surgical bypass for symptomatic subclavian steal syndrome. J Endovasc Ther. 2012;19(1):44–51.
36. Wang KQ, Wang ZG, Yang BZ, Yuan C, Zhang WD, Yuan B, Xing T, Song SH, Li T, Liao CJ, Zhang Y. Long-term results of endovascular therapy for proximal subclavian arterial obstructive lesions. Chin Med J. 2010;123(1):45–50.
37. Linni K, Ugurluoglu A, Mader N, Hitzl W, Magometschnigg H, Holzenbein TJ. Endovascular management versus surgery for proximal subclavian artery lesions. Ann Vasc Surg. 2008;22(6): 769–75.
38. Sixt S, Rastan A, Schwarzwalder U, Schwarz T, Norry E, Frank U, Muller C, Beschorner U, Burgelin K, Nazary T, Hauswald K, Hauk M, Neumann FJ, Zeller T. Long term outcome after balloon angioplasty and stenting of subclavian artery obstruction: a single centre experience. Vasa. 2008;37(2):174–82.
39. Palchik E, Bakken AM, Wolford HY, Saad WE, Davies MG. Subclavian artery revascularization: an outcome analysis based on mode of therapy and presenting symptoms. Ann Vasc Surg. 2008;22(1):70–8.
40. Van Noord BA, Lin AH, Cavendish JJ. Rates of symptom reoccurrence after endovascular therapy in subclavian artery stenosis and prevalence of subclavian artery stenosis prior to coronary artery bypass grafting. Vasc Health Risk Manag. 2007;3(5): 759–62.
41. Filippo F, Francesco M, Francesco R, Corrado A, Chiara M, Valentina C, Giuseppina N, Salvatore N. Percutaneous angioplasty and stenting of left subclavian artery lesions for the treatment of patients with concomitant vertebral and coronary subclavian steal syndrome. Cardiovasc Intervent Radiol. 2006;29(3):348–53.
42. De Vries JP, Jager LC, Van den Berg JC, Overtoom TT, Ackerstaff RG, Van de Pavoordt ED, Moll FL. Durability of percutaneous transluminal angioplasty for obstructive lesions of proximal subclavian artery: long-term results. J Vasc Surg. 2005;41(1):19–23.
43. Modarai B, Ali T, Dourado R, Reidy JF, Taylor PR, Burnand KG. Comparison of extra-anatomic bypass grafting with angioplasty for atherosclerotic disease of the supra-aortic trunks. Br J Surg. 2004;91(11):1453–7.
44. Angle JF, Matsumoto AH, McGraw JK, Spinosa DJ, Hagspiel KD, Leung DA, Tribble CG. Percutaneous angioplasty and stenting of left subclavian artery stenosis in patients with left internal mammary-coronary bypass grafts: clinical experience and long-term follow-up. Vasc Endovascular Surg. 2003;37(2): 89–97.
45. Schillinger M, Haumer M, Schillinger S, Mlekusch W, Ahmadi R, Minar E. Outcome of conservative versus interventional treatment of subclavian artery stenosis. J Endovasc Ther. 2002;9(2):139–46.
46. Takach TJ, Reul GJ, Gregoric I, Krajcer Z, Duncan JM, Livesay JJ, Cooley DA. Concomitant subclavian and coronary artery disease. Ann Thorac Surg. 2001;71(1):187–9.
47. Martinez R, Rodriguez-Lopez J, Torruella L, Ray L, Lopez-Galarza L, Diethrich EB. Stenting for occlusion of the subclavian arteries. Technical aspects and follow-up results. Tex Heart Inst J. 1997;24(1):23–7.
48. Cook AM, Dyet JF. Six cases of subclavian stenosis treated by percutaneous angioplasty. Clin Radiol. 1989;40(4):352–4.
49. Jaschke W, Menges HW, Ockert D, Huck K, Georgi M. PTA of the subclavian and innominate artery: short- and long-term results. Ann Radiol. 1989;32(1):29–33.
50. Burke DR, Gordon RL, Mishkin JD, McLean GK, Meranze SG. Percutaneous transluminal angioplasty of subclavian arteries. Radiology. 1987;164(3):699–704.
51. Wilms G, Baert A, Dewaele D, Vermylen J, Nevelsteen A, Suy R. Percutaneous transluminal angioplasty of the subclavian artery: early and late results. Cardiovasc Intervent Radiol. 1987;10(3): 123–8.
52. Lowman BG, Queral LA, Holbrook WA, Estes JT, Bayly B, Dagher FJ. The correction of cerebrovascular insufficiency by transluminal dilatation: a preliminary report. Am Surg. 1983; 49(11):621–4.
53. Miyakoshi A, Hatano T, Tsukahara T, Murakami M, Arai D, Yamaguchi S. Percutaneous transluminal angioplasty for atherosclerotic stenosis of the subclavian or innominate artery: angiographic and clinical outcomes in 36 patients. Neurosurg Rev. 2012;35(1):121–5.
54. Yu J, Korabathina R, Coppola J, Staniloae C. Transradial approach to subclavian artery stenting. J Invasive Cardiol. 2010;22(5):204–6.
55. Sakai C, Sakai N, Kuroiwa T, Ishihara H, Adachi H, Morizane A, Yano T, Kajikawa R, Yamagami H, Kobayashi J, Kondo K, Kikuchi H. Stenting for chronic total occlusion of the proximal subclavian artery. Interv Neuroradiol. 2007;1:135–40.

56. Amor M, Eid-Lidt G, Chati Z, Wilentz JR. Endovascular treatment of the subclavian artery: stent implantation with or without predilatation. Catheter Cardiovasc Interv. 2004;63(3):364–70.
57. Gonzalez A, Gil-Peralta A, Gonzalez-Marcos JR, Mayol A. Angioplasty and stenting for total symptomatic atherosclerotic occlusion of the subclavian or innominate arteries. Cerebrovasc Dis. 2002;13(2):107–13.
58. Kumar K, Dorros G, Bates MC, Palmer L, Mathiak L, Dufek C. Primary stent deployment in occlusive subclavian artery disease. Cathet Cardiovasc Diagn. 1995;34(4):281–5.
59. Perrault LP, Carrier M, Hudon G, Lemarbre L, Hebert Y, Pelletier LC. Transluminal angioplasty of the subclavian artery in patients with internal mammary grafts. Ann Thorac Surg. 1993;56(4):927–30.
60. Hebrang A, Maskovic J, Tomac B. Percutaneous transluminal angioplasty of the subclavian arteries: long-term results in 52 patients. AJR Am J Roentgenol. 1991;156(5):1091–4.