Trends in Cardiovascular Medicine xxx (xxxx) xxx

Contents lists available at ScienceDirect

Trends in Cardiovascular Medicine

journal homepage: www.elsevier.com/locate/tcm

Impact of coronary-subclavian steal after surgical myocardial revascularization with internal thoracic artery in chronic hemodialysis patients: A meta-analysis

Massimo Baudo[a,*], Gianluca Torregrossa[b], Aleksander Dokollari[b], Gianluigi Bisleri[c], Lorenzo Di Bacco[a], Stefano Benussi[a], Claudio Muneretto[a], Fabrizio Rosati[a]

[a] Division of Cardiac Surgery, Spedali Civili di Brescia, University of Brescia, Piazza Spedali Civili, 1, Brescia 25123, Italy
[b] Division of Cardiac Surgery, Main Line Health - Lankenau Heart Institute, Wynnewood, PA, United States
[c] Division of Cardiac Surgery, St Michael's Hospital, University of Toronto, ON, Canada

ARTICLE INFO

Keywords:
Coronary subclavian steal
CABG
Arteriovenous fistula
Internal thoracic artery
Meta-analysis

ABSTRACT

Patients in hemodialysis with an arm arteriovenous fistula undergoing coronary artery bypass grafting (CABG) with an internal thoracic artery have been reported to suffer from coronary-subclavian steal (CSS) during dialysis session. However, its occurrence is still debated. A systematic literature review was performed to identify all studies investigating the occurrence of a CSS event in this subset of patients. The primary endpoint was the analysis of CSS and the following early and late survival outcomes. Independent determinants of CSS and the impact of the distance between the arteriovenous fistula (upper arm vs forearm) and the ipsilateral internal thoracic artery graft on CSS events and mortality were studied. Early and late survival outcomes were analyzed by comparing ipsilateral versus contralateral arteriovenous fistula. Of the 1,383 retrieved articles, 10 were included ($n = 643$ patients). The pooled event rate of CSS was 6.46% [95%CI=2.10–18.15], while of symptomatic CSS incidence was 3.99% [95%CI=0.95–15.25]. No survival differences were noted when comparing ipsilateral to contralateral arteriovenous fistula-internal thoracic artery combinations. On meta-regression, the upper arm was associated with more CSS events, while the forearm to lower late mortality rates. Independently from arteriovenous fistula-internal thoracic artery combination, CSS was not associated to higher mortality rates. Particular attention is warranted when selecting the type of conduits for CABG in patients with an arteriovenous fistula or if highly expected to need one in the near future after surgery. A contralateral arteriovenous fistula-internal thoracic artery combination is preferable. If this is not possible, a forearm arteriovenous fistula position should be preferred.

Introduction

Adult patients undergoing chronic hemodialysis treatment have an elevated cardiovascular risk, including a high prevalence of coronary artery disease (CAD) and the subsequent need of coronary artery bypass graft surgery (CABG), especially in those patients with diabetes mellitus and advanced age [1]. In addition, acute kidney injury after CABG can lead to the onset and progression of chronic kidney disease and the need for lifelong hemodialysis treatment [2].

Improved long-term results have been reported for CABG when compared to percutaneous revascularization in patients undergoing hemodialysis [3–6], while the internal thoracic artery is the most widely chosen surgical conduit in these patients due to the excellent graft patency compared to the venous counterpart [7,8]. Furthermore, the ascending aorta of hemodialysis patients might be involved in advanced atherosclerotic disease, therefore, it is recommended to minimize aortic manipulation during CABG surgery in this specific subset of patients. In this setting, the use of internal thoracic artery grafts seems particularly appropriate, resulting in less traumatic and neurologically safer myocardial revascularization procedure [9].

Patients requiring hemodialysis may have chronic arteriovenous fistula located either in the forearm or in the upper arm, ipsilateral or contralateral to the internal thoracic artery targeting the coronary arteries for surgical revascularization. Considering the non-negligible flow in the arteriovenous fistula during dialysis, significant hemodynamic interference may occur between the arteriovenous fistula and the ipsilateral internal thoracic artery graft [10,11]

* Corresponding author.
E-mail address: massimo.baudo@icloud.com (M. Baudo).

https://doi.org/10.1016/j.tcm.2022.12.008
1050-1738/

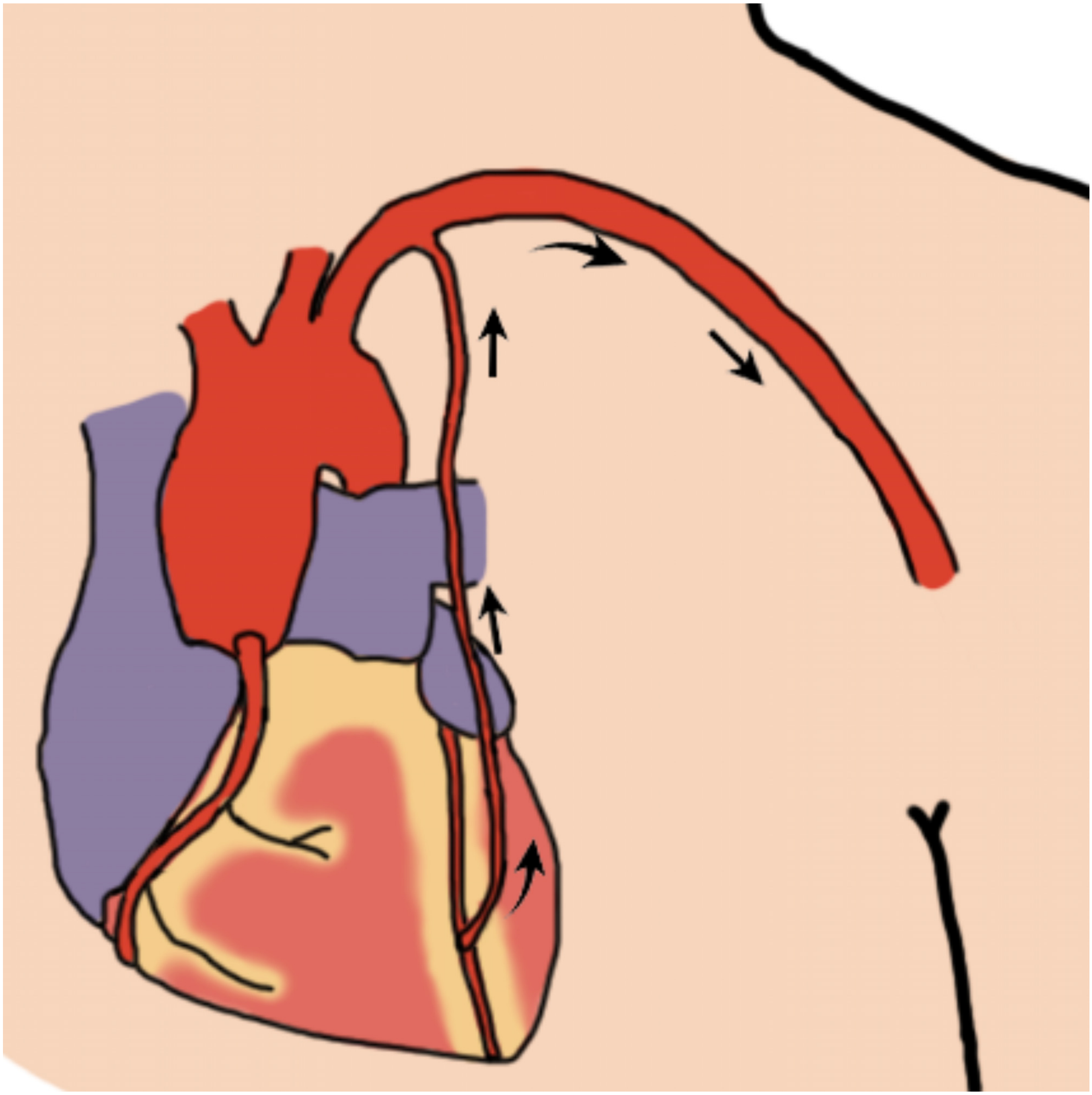

Fig. 1. Mechanism of coronary subclavian steal.

(Fig. 1). This phenomenon, also called coronary-subclavian steal (CSS), is considered a risk factor for the development of postoperative myocardial ischemia in patients with end-stage renal failure requiring hemodialysis [12]. There is a disagreement in medical literature regarding the symptomatic presentation of CSS during hemodialysis treatment with some clinical reports describing such an event during dialysis sessions [13,14], while others do not [15,16]. This disagreement may be explained by variable and unrecognized predisposing risk factors such as stenosis of the feeding subclavian artery, morphologic variability of the internal thoracic artery, location of the arteriovenous fistula, diffuse CAD with poor runoff, or increased blood flow through the arteriovenous fistula [12].

The aim of the current systematic review and meta-analysis is to analyze the incidence of the CSS phenomenon in patients with arteriovenous fistula and ipsilateral internal thoracic artery-coronary anastomosis undergoing hemodialysis. Furthermore, this study aimed to derive independent determinants of this hemodynamic event and to analyze the impact of the distance between the arteriovenous fistula (upper arm vs forearm) and the ipsilateral internal thoracic artery graft on CSS events and mortality. Finally, early and late survival outcomes were analyzed by comparing ipsilateral versus contralateral arteriovenous fistula.

Methods

Literature search strategy

This systematic review was conducted according to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) [17] and AMSTAR (Assessing the Methodological Quality of Systematic Reviews) [18] guidelines (Supplemental Material). The PRISMA flow diagram is presented in Fig. 2. The Ovid MEDLINE, Ovid Embase, PubMed, ScienceDirect, SciELO, LILACS,

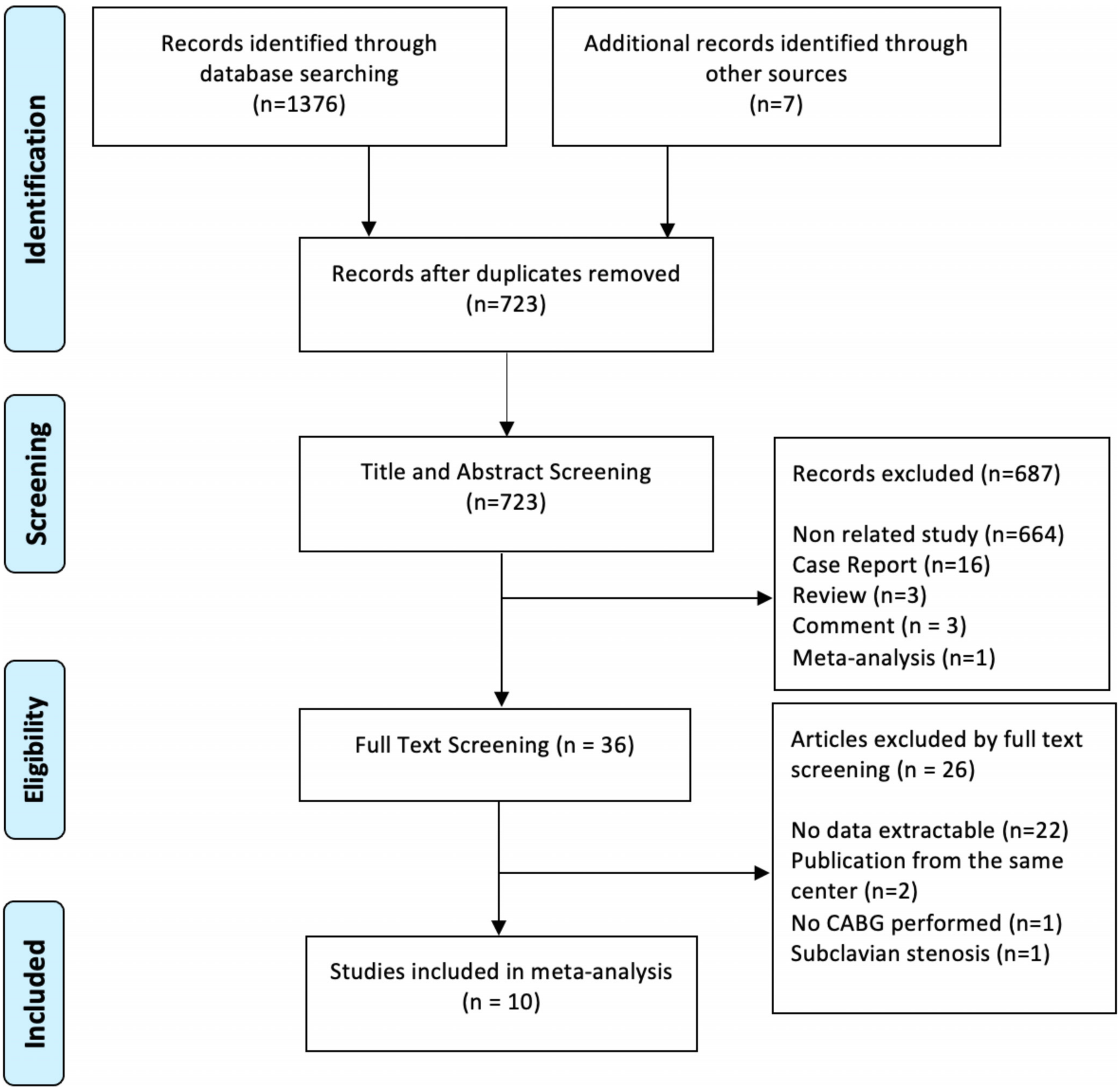

Fig. 2. PRISMA flowchart diagram of included studies.

Google Scholar, gray literature and Cochrane Library databases were searched until May 2022 for publications reporting the clinical outcome of patients in hemodialysis with an upper extremity arteriovenous fistula and have previously undergone CABG with one or both internal thoracic arteries.

The full search strategy is shown in Supplemental Table 1. Furthermore, the references of all studies and reviews were examined to identify additional articles (i.e., “backward snowballing”). The following steps were taken for study selection: 1) identification of titles of records through database search; 2) removal of duplicates; 3) screening and selection of abstracts; 4) assessment for eligibility through full-text articles; and 5) final inclusion in study. Studies were independently screened for inclusion by two authors (M.B. and L.D.B). Discrepancies were arbitrated by a third author (F.R.) to achieve consensus. A librarian was involved in the screening of publications.

This review was registered with the PROSPERO register of systematic reviews (ID: CRD42022344479). There was no individual patient involvement in this study; as such, research ethics board approval or patient’s consent was not required.

Inclusion criteria

Using the PICOS strategy (*P*opulation, *I*nterventions, *C*omparison, *O*utcome, and *S*tudy design), studies were included if the following criteria were fulfilled: 1) reported cohorts of patients undergoing hemodialysis through an upper extremity arteriovenous fistula and have had a CABG surgery with an internal thoracic artery; 2) reported ipsilateral and/or contralateral relation analysis between internal thoracic artery and arteriovenous fistula; 3) only articles written in English language were included.

Exclusion criteria

Studies where: (1) the CSS event could be attributable to a subclavian artery stenosis; (2) case reports; (3) literature reviews; (4) conference abstracts; (5) letters to the editor; (6) commentaries were excluded. Patients with subclavian artery stenosis were excluded based on previous reports where subclavian artery stenosis itself was responsible of angina/symptoms with or without hemodialysis [10]. Therefore, we only considered patients with no other vascular factors having a potential impact on hemodynamics during hemodialysis.

In case of multiple publication from the same Center, the study period was assessed and in case of a study period overlap the publication with the largest sample size was included.

Data extraction and critical appraisal

Microsoft Office 365 Excel software (Microsoft, Redmond, Washington, USA) was used for data extraction. Categorical variables were reported as numbers, while continuous variables were expressed as mean ± standard deviation. Data on study period, study center, country, sample size, and type of cohort grouping were retrieved. The following patient characteristics were abstracted: mean age, sex, mean body mass index (BMI), diabetes mellitus, hypertension, dyslipidemia, smoking history, chronic obstructive pulmonary disease, coronary artery disease (CAD), peripheral artery disease. Of note, smoking history data were not consistent across studies. Some Authors reported this variable as "smoking" or "history of smoking", whereas other Authors added more details, such as "former" or "current" smoker. Comorbidities (e.g. pre-existing pulmonary disease, dyslipidemia), smoking history, BMI, and sex were examined as separate variables, although the possible collinearity could not be assessed or ignored.

Data regarding use of left, right, or bilateral internal thoracic artery during CABG and the position of the arteriovenous fistula in the upper extremity (upper-arm or forearm) were recorded.

Late cardiac-related mortality was defined as death attributable to myocardial ischemia and infarction, heart failure, cardiac arrest because of other or unknown cause, or cerebrovascular accident during follow-up. Late mortality was defined as all causes of death during follow-up.

The Newcastle-Ottawa Quality Assessment Scale for Cohort Studies [19] was used for critical appraisal of the quality of included non-randomized studies. The certainty of the conclusions drawn from comparison meta-analyses were assessed using the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) tool [20].

Statistical analysis

The primary endpoint was the analysis of CSS as an acute event and the following early and late survival outcomes. A Poisson regression modeling was used for late outcomes to account for the studies' differences in follow-up times, assuming a constant event rate. The total number of events and mean follow-up time was used to calculate the total person-time of follow-up in years. The pooled event rate and odds ratio were used for the early outcomes, while a log transformation to model the overall incidence rate and incidence rate ratio were used for late outcomes. All results were calculated with a 95% Confidence Interval.

In all analyses, studies were weighted by the inverse of the variance of the estimate for that study, and between-study variance was estimated with DerSimonian-Laird method with random effects model. Studies with double zeros were included in the meta-analysis and treatment arm continuity correction was applied in studies with zero cell frequencies.

Table 1
Characteristics of the eligible studies and demographics of the patients in the included studies.

Author	Year	Study period	Study type	Country of origin	Patients	Age yrs ± SD	Male	Diabetes	Dyslipidemia	Smoke	COPD	HTN	PAD	STS/ Euroscore	FUP years
Ahn[21]	2017	2000–2013	retrospective	South Korea	25	68 ± 9.1	16	19	NR	NR	NR	21	NR	NR/NR	7.11
Coskun[22]	2013	NR	prospective	Turkey	22	57.8 ± 9	15	12	5	NR	3	12	4	NR/NR	NR
Feldman[23]	2014	2000–2012	retrospective	Israel	57	67.2 ± 7.7	49	44	NR	22	NR	57	32	NR/NR	3.25
Gaudino[13]	2003	NR	retrospective	Italy	5	NR	NR	NR	NR	NR	NR	NR	NR	NR/NR	NR
Hachiro[24]	2021	2002–2019	IPTW	Japan	132	66.3 ± 9.9	99	106	57	57	NR	105	15	3.4/2.6	3.50
Han[25]	2017	2001–2014	retrospective	South Korea	111	65.1 ± 9.2	76	93	16	40	NR	97	10	NR/NR	3.14
Shim[26]	2018	1991–2016	retrospective	South Korea	48	60.9 ± 8.3	40	36	9	9	1	42	32	NR/NR	2.67
Sohn[27]	2022	2004–2018	IPTW	South Korea	43	63.1 ± 8.6	32	35	11	3	5	36	14	NR/NR	4.58
Takami[28]	2014	1993–2011	retrospective	Japan	155	63 ± 8	132	84	60	98	NR	114	48	NR/NR	2.87
Wu[29]	2019	2007–2017	retrospective	Taiwan	45	58.5 ± 9.3	32	30	NR	NR	NR	27	NR	NR/7.5	3.90

COPD = chronic obstructive pulmonary disease; FUP = follow-up; HTN = hypertension; IPTW = inverse probability treatment weighting; NR = not reported; PAD = peripheral artery disease.

Table 2
Baseline demographics of included patients*.

Variable	Value
Age, mean (years ± SD)	63.3 ± 3.7
Male sex, n (%)	592/807 (73.4%)
Smoking history, n (%)	289/715 (40.4%)
Hypertension, n (%)	623/807 (77.2%)
Diabetes, n (%)	568/807 (70.4%)
Dyslipidemia, n (%)	216/680 (31.8%)
COPD, n (%)	9/150 (6.0%)
PAD, n (%)	165/737 (22.4%)
ITA used for CABG, n (%)	
Left ITA	581/812 (71.5%)
Right ITA	280/812 (34.5%)
Bilateral ITA	250/812 (30.8%)
Fistula location	
Forearm	498/634 (78.6%)
Upper arm	136/634 (21.4%)

AVF = arteriovenous fistula; CABG = coronary artery bypass graft; COPD = chronic obstructive pulmonary disease; ITA = internal thoracic artery; PAD = peripheral artery disease; SD = standard deviation.
* The dominator is based on the data availability among the included studies. Inverse probability treatment weighting was considered when present.

Univariate meta-regression was performed to explore the relation between CSS when ipsilateral internal thoracic artery- arteriovenous fistula was used and patient's characteristics. The results were reported as regression coefficient (i.e., β), standard error and p-value.

Heterogeneity was based on the Cochran Q test, with I^2 values. In case of heterogeneity $I^2>50\%$, individual study inference analysis was performed through a "leave-one-out" sensitivity analysis.

Funnel plots by graphical inspection and Egger's test, when feasible, was used for assessment of publication bias.

Hypothesis testing for equivalence was set at the two-tailed 0.05 level. All statistical analyses were performed using R, version 4.2.0 (R Project for Statistical Computing, Wien, Austria) and RStudio version 2022.02.3. Build 492, using the "meta" and "metafor" packages.

Results

Study selection and characteristics

The medical literature search identified 1376 potentially eligible studies. Seven additional articles were identified through backward snowballing. After removal of duplicates, 723 studies were screened. Thirty-six full text articles were assessed for eligibility. Ten studies [13,21–29] met the inclusion criteria (Fig. 2) with a total of 643 patients, 433 with an ipsilateral internal thoracic artery and arteriovenous fistula use, and 210 with a contralateral internal thoracic artery and arteriovenous fistula use. Publication year ranged from 2003 to 2022, and sample size ranged from 5 to 132 patients. Two studies were inverse probability treatment weighting, one was a prospective study, while all the other studies were retrospective. Details of the individual studies are shown in Table 1. The demographics of the included studies are summarized in Table 2. The pooled mean follow-up was 3.67 ± 2.11 years. The critical appraisal of the included studies is shown in Supplemental Tables 2 and 3. Of note, only two of the included studies described the operative risk score of the included patients.

Meta-analysis outcomes

Evaluating patients with ipsilateral internal thoracic artery and upper extremity arteriovenous fistula the pooled event rate of CSS was 6.46% (95%Confidence Interval: 2.10–18.15) (Supplemental Fig. 1). The pooled event rate of symptomatic CSS was 3.99% (95%Confidence Interval: 0.95–15.25) (Supplemental Fig. 2), and PER of 30-day mortality was 8.05% (95%Confidence Interval: 5.46–11.71) (Supplemental Fig. 3). The incidence rate of late death and late cardiac-related death were 8.17%/year (95%Confidence Interval: 5.75–11.62) (Supplemental Fig. 4), and 2.69%/year (95%Confidence Interval: 0.94–7.76) (Supplemental Fig. 5), respectively.

Comparing ipsilateral and contralateral internal thoracic artery to upper extremity arteriovenous fistula the OR of 30-day mortality was 1.03 (95%Confidence Interval: 0.47–2.26) (Supplemental Fig. 6). The incidence rate ratio of late mortality and late cardiac mortality were 0.93 (95%Confidence Interval: 0.71–1.22) (Supplemental Fig. 7) and 1.36 (95%Confidence Interval: 0.78–2.37) (Supplemental Fig. 8), respectively.

The outcomes are summarized in Table 4. Leave-one-out analysis of outcomes to test for heterogeneity did not show significant change of the results and can be visualized in Supplemental Figs. 9–12.

Meta-regression

At univariate meta-regression a higher use of an arteriovenous fistula located in the upper arm with an ipsilateral internal thoracic artery during CABG was significantly associated with more CSS episodes ($p = 0.0443$), when compared to the forearm position of the arteriovenous fistula. Moreover, higher use of a forearm arteriovenous fistula was significantly associated with lower late mortality rates ($p = 0.0052$).

The other patients' analyzed characteristics did not show any significant relation with CSS. Univariate meta-regression outcomes are described in Table 4.

Table 3
Outcome summary.

Outcome	No. of studies	Estimate	95% CI	Heterogeneity: I^2, p-value
CSS phenomenon with ipsilateral ITA and upper extremity AVF				
Coronary subclavian steal	6	PER: 6.46%	2.10 - 18.15	81.1%, $p<0.0001$
Symptomatic CSS	6	PER: 3.99%	0.95 - 15.25	82.9%, $p<0.0001$
30-day mortality	5	PER: 8.05%	5.46 - 11.71	0%, $p = 0.4124$
Late death	8	IR: 8.17%/year	5.75 - 11.62	71.8%, $p = 0.0008$
Late cardiac death	5	IR: 2.69%/year	0.94 - 7.76	70.9%, $p = 0.0082$
Ipsilateral vs. contralateral ITA comparison				
30-day mortality	4	OR: 1.03	0.47 - 2.26	0%, $p = 0.3344$
Late mortality	6	IRR: 0.93	0.71 - 1.22	0%, $p = 0.7085$
Late cardiac death	3	IRR: 1.36	0.78 - 2.37	10.2%, $p = 0.3283$

AVF = arteriovenous fistula; CI = confidence interval; CSS = coronary-subclavian steal; IR = incidence rate; IRR = incidence rate ratio; ITA = internal thoracic artery; OR = odds ratio; PER = pooled event rate.

Table 4
Meta-regression.

Variable	CSS Beta ± SE	p-value	30-day mortality Beta ± SE	p-value	Late death Beta ± SE	p-value	Late cardiac death Beta ± SE	p-value
Mean age	−0.1504 ± 0.1792	0.4013	0.1123 ± 0.1416	0.4279	−0.0300 ± 0.0693	0.6649	−0.0666 ± 0.1994	0.7384
Male sex	0.0104 ± 0.1069	0.9227	−0.0132 ± 0.0198	0.5031	0.0217 ± 0.0214	0.3116	0.0824 ± 0.0518	0.1119
Diabetes	−0.0745 ± 0.0729	0.3068	−0.0139 ± 0.0115	0.2291	0.0017 ± 0.0179	0.9243	0.1167 ± 0.0817	0.1533
Hypertension	−0.0178 ± 0.0590	0.7621	−0.0152 ± 0.0149	0.3054	−0.0011 ± 0.0147	0.9413	0.0522 ± 0.0598	0.3821
Peripheral artery disease	0.0521 ± 0.0474	0.2718	−0.0192 ± 0.0164	0.2407	−0.0088 ± 0.0048	*0.0660*	0.0010 ± 0.0092	0.9130
CABG with Left ITA	0.0472 ± 0.0415	0.2558	−0.0129 ± 0.0267	0.6293	0.0008 ± 0.0124	0.9516	0.0333 ± 0.0457	0.4657
CABG with Right ITA	0.0150 ± 0.0163	0.3571	−0.0229 ± 0.0142	0.1064	−0.0005 ± 0.0072	0.9430	0.0018 ± 0.0165	0.9142
CABG with Bilateral ITA	0.0188 ± 0.0152	0.2157	−0.0091 ± 0.0146	0.5326	−0.0020 ± 0.0062	0.7397	−0.0064 ± 0.0066	0.3295
Fistula in the forearm	−0.0623 ± 0.0310	**0.0443**	NA	NA	−0.0185 ± 0.0066	**0.0052**	0.0079 ± 0.0361	0.8273
Fistula in the upper-arm	0.0623 ± 0.0310	**0.0443**	NA	NA	0.0119 ± 0.0126	0.3452	−0.0275 ± 0.0373	0.4605
Coronary-subclavian steal	–	**–**	−0.0545 ± 0.0423	0.1974	−0.0306 ± 0.0351	0.3841	−0.0114 ± 0.0864	0.8946

Results are expressed as β ± Standard Error, p-value. Positive beta reflects an increase in the event when the frequency of the variable increases, while negative beta reflects a decrease in the event with the increase in the frequency of the variable.
CABG = coronary artery bypass graft; COPD = chronic obstructive pulmonary disease; ITA = internal thoracic artery; SE = standard error.

Discussion

The outcomes of this meta-analysis evidenced that (1) in literature the reported CSS rate is 6.46% overall, and 3.99% if considering only symptomatic events; (2) There are no significant differences in terms of mortality when comparing ipsilateral to contralateral combination of internal thoracic artery-arteriovenous fistula; (3) When ipsilateral internal thoracic artery-arteriovenous fistula are present, the upper arm is associated to more CSS events, despite CSS events are not associated with higher early and late mortality rates (independently from internal thoracic artery-arteriovenous fistula combination). (5) The forearm is associated to lower mortality rates ($p = 0.052$).

Patients with end-stage renal failure undergoing hemodialysis suffer from a high prevalence of significant CAD requiring surgical myocardial revascularization [1,3]. In this specific subset of patients, concerns have been reported for CSS during hemodialysis when performed through an arteriovenous fistula ipsilateral to the internal thoracic artery. In details, the arteriovenous fistula is characterized by a low vascular resistance, while the internal thoracic artery-coronary anastomosis represents a high-resistance vascular bed. The hydrodynamic Venturi effect describes a drop in hydrostatic pressure along areas of high flow speed [30], thus determining a "suction effect" from the subclavian artery towards the arteriovenous fistula, especially during hemodialysis sessions, resulting in CSS (Fig. 1). The suction effect that results in the subclavian artery affects all the branches of this vessel, and may reverse the flow also in the internal thoracic artery ipsilateral to the arteriovenous fistula, stealing blood away from the coronary circulation [13]. Finally, the impact of LAD outflow (or coronary in general) and the internal thoracic artery conduit size on CSS goes along with the resistance of the internal thoracic artery-LAD anastomosis. The coronary and mammary artery should be considered as the two components affecting resistance in this area. If just one of the two worsens, the whole area is negatively affected, while both components must improve to see an overall reduction in arteriovenous fistula steal.

Furthermore, in case of subclavian artery stenosis, the occlusion would be located proximal to both LIMA and arteriovenous fistula thus increasing and worsening the CSS. In this scenario, the "suction effect" driven by the low-resistance bed in the arteriovenous fistula concomitantly with a subclavian stenosis would be even further magnified. These patients could also experience neurological symptoms during hemodialysis (dizziness, vertigo, imbalance, drop attacks) due the ipsilateral vertebral reversal flow. However, there are currently no published studies analyzing a concomitant arteriovenous fistula and subclavian artery stenosis, as the literature is limited to few case reports [31,32].

End-stage renal failure patients requiring hemodialysis often bear the burden of advanced atherosclerosis involving the ascending aorta, while the increased amount of aortic calcification makes any attempts of proximal anastomosis challenging. Moreover, conduit options are more limited in this subset of patients: the radial artery as a graft is not feasible after arteriovenous fistula creation, thus, the use of an in-situ internal thoracic artery is a valuable option in order to minimize aortic manipulation but also to assure higher graft patency rate and excellent mid and long-term survival [7,8].

Coronary-subclavian steal syndrome has been reported when hemodialysis is performed through the arteriovenous fistula ipsilaterally to the in-situ internal thoracic artery-coronary anastomosis with an incidence ranging from 0% [24,27] to 25% [26]. This large heterogeneity might be explained by different methods used to record the CSS phenomenon: Gaudino et al. [13]. and Coskun et al. [22]. evaluated CSS by means of Doppler ultrasound while other authors [21,23–29] only considered symptoms occurring during hemodialysis treatment sessions. The current meta-analysis, among the included patients, found a lower incidence of symptomatic CSS compared to the total number of CSS diagnoses (3.99% vs 6.46%, respectively). As a result, the incidence of CSS defined by clinical symptoms may lead to a possible underestimation. Nevertheless, the present meta-regression showed that an upper arm arteriovenous fistula is significantly associated to more CSS events compared to an arteriovenous fistula positioned in the forearm ($p = 0.0443$), thus suggesting how the Venturi effect could be more significant when a shorter distance is placed between the arteriovenous fistula and the ipsilateral internal thoracic artery-coronary anastomosis. In fact, in the study by Hachiro and colleagues [24] no CSS episodes were reported postoperatively and one of the possible explanation is that all patients had the arteriovenous fistula in the forearm, differently to the other included studies. Despite this association between the arteriovenous fistula location and CSS episodes, the presence of CSS per se was not found to be significantly associated with increased 30-day ($p = 0.1974$), late ($p = 0.3841$) and cardiac-related mortality ($p = 0.8946$) (Table 4).

Other studies evaluated the impact of different internal thoracic artery-arteriovenous fistula combinations on the incidence of CSS during hemodialysis sessions and on early and late outcomes, reporting conflicting data [23–25,27–29]: Feldman et al. [23]. showed that an ipsilateral internal thoracic artery-arteriovenous fistula was associated with an increased risk of major adverse cardiac and cerebrovascular events on long-term follow-up while, Takami et al. [28]. showed that the ipsilateral arteriovenous fistula - internal thoracic artery combination did not increase the operative mortality or the risk of late death and major adverse cardiac and cerebrovascular events. As far as mortality in patients with an ipsilateral internal thoracic artery-arteriovenous fistula remain a concern, in the present meta-analysis the 30-day mortality reached 8.05%, late death 8.17%/year and late-cardiac death 2.69%/year (Table 3). Furthermore, similar early and late survival outcomes were found when ipsilateral internal thoracic artery-arteriovenous fistula was compared to contralateral internal thoracic artery-arteriovenous fistula (OR 1.03, 95%Confidence Interval: 0.47–2.26, and incidence rate ratio 0.93, 95%Confidence Interval:0.71–1.21, respectively) (Table 3). Despite not being statistically significant, a higher incidence of cardiac-related mortality trend was seen among patients with an ipsilateral internal thoracic artery-arteriovenous fistula (incidence rate ratio 1.36, 95%Confidence Interval: 0.78–2.37). However, this higher mortality trend could be a multifactorial phenomenon that might be influenced primarily by the high surgical risk of this frail subset of patients (Table 2) rather than being influenced only by the arteriovenous fistula location or the CSS phenomenon. The present study could not further evaluate the operative risk of the included patients, as only two of the included studies described the patients' surgical risk. Of note, meta-regression showed a significant and more favorable late survival with reduced late death ($p = 0.0052$) in patients having arteriovenous fistula in the forearm ipsilaterally to the internal thoracic artery-coronary anastomosis (Table 4).

Alternative surgical solutions for hemodialysis patients have been considered; however, it has been established that arteriovenous fistulas are the preferred vascular access for chronic hemodialysis due to improved outcomes, a lower complication rate once matured, and reduced costs compared with arteriovenous grafts [33]. An arteriovenous fistula may be more likely to cause a CSS than an arteriovenous graft due to an increased mean volume flow with time [34]. However, in the study by Han et al., [25] arteriovenous grafts were significantly associated with an increased incidence of major adverse cardiac and cerebrovascular events and late mortality.

Limitations

The present meta-analysis could not further analyze outcome differences between arteriovenous fistula and arteriovenous graft due to the lack of sufficient data reported.

It should be noted that none of the included studies is a prospective randomized study, thus maintaining all the associated biases in the final analysis. Our findings should be validated also in randomized trials. Only two studies tried to overcome this drawback by applying statistical models, i.e., Inverse Probability Treatment Weighting. In addition, not all papers reported the outcomes and details of interest, limiting the data availability to perform the analysis.

Conclusions

The current meta-analysis evidence that CSS is a noteworthy phenomenon that clinicians and cardiac surgeons must be aware of. Despite CSS is a "real" clinical issue impacting patients' quality of life, it doesn't seem to have an impact on mortality. The present meta-regression provides interesting findings that must be kept into account when a hemodialysis patient is referred for CABG or conversely, when an arteriovenous fistula is planned in a patient previously submitted to CABG: the contralateral internal thoracic artery to arteriovenous fistula or contralateral arteriovenous fistula to internal thoracic artery-coronary anastomosis should be preferred. Nevertheless, if a contralateral internal thoracic artery-arteriovenous fistula combination cannot be performed, a forearm position of the arteriovenous fistula would be preferrable compared to the upper-arm. Likewise, these considerations should be kept in mind when selecting the type of conduits for CABG to be used in patients with severely compromised preoperative renal function whose progression to dialysis in the years after surgery is highly expected.

Funding statement

None.

Institutional review board approval

This is a meta-analysis of published data, thus no ethical approval was required

Informed consent statement

This is a meta-analysis of published data, thus no informed consent was required

Data availability statement

The data that support the findings of this study are available from the corresponding Author upon reasonable request.

Disclosure statement

The research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Acknowledgements

None.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.tcm.2022.12.008.

References

[1] National Institutes of Health, National Institute of Diabetes and Digestive and Kidney Diseases United states renal data system. 2020 usrds annual data report: epidemiology of kidney disease in the united states. USRDS; 2020. [Internet]Available from https://adr.usrds.org/ .
[2] Helgadottir S, Sigurdsson MI, Palsson R, Helgason D, Sigurdsson GH, Gudbjartsson T. Renal recovery and long-term survival following acute kidney injury after coronary artery surgery: a nationwide study. Acta Anaesthesiol Scand 2016;60(9):1230–40 Oct.
[3] Herzog CA, Ma JZ, Collins AJ. Comparative survival of dialysis patients in the United States after coronary angioplasty, coronary artery stenting, and coronary artery bypass surgery and impact of diabetes. Circulation 2002;106(17):2207–11 Oct 22.
[4] Agirbasli M, Weintraub WS, Chang GL, King SB, Guyton RA, Thompson TD, et al. Outcome of coronary revascularization in patients on renal dialysis. Am J Cardiol 2000;86(4):395–9 Aug 15.
[5] Sunagawa G, Komiya T, Tamura N, Sakaguchi G, Kobayashi T, Murashita T. Coronary artery bypass surgery is superior to percutaneous coronary intervention with drug-eluting stents for patients with chronic renal failure on hemodialysis. Ann Thorac Surg 2010;89(6):1896–900 Jundiscussion 1900.
[6] Terazawa S, Tajima K, Takami Y, Tanaka K, Okada N, Usui A, et al. Early and late outcomes of coronary artery bypass surgery versus percutaneous coronary intervention with drug-eluting stents for dialysis patients. J Card Surg 2012;27(3):281–7 May.
[7] Loop FD, Lytle BW, Cosgrove DM, Stewart RW, Goormastic M, Williams GW, et al. Influence of the internal-mammary-artery graft on 10-year survival and other cardiac events. N Engl J Med 1986;314(1):1–6 Jan 2.
[8] Cameron A, Kemp HG, Green GE. Bypass surgery with the internal mammary artery graft: 15 year follow-up. Circulation 1986;74(5):III30–6 NovPt 2.
[9] Gaudino M, Glieca F, Alessandrini F, Luciani N, Cellini C, Pragliola C, et al. The unclampable ascending aorta in coronary artery bypass patients: a surgical challenge of increasing frequency. Circulation 2000;102(13):1497–502 Sep 26.

[10] Elian D, Gerniak A, Guetta V, Jonas M, Agranat O, Har-Zahav Y, et al. Subclavian coronary steal syndrome: an obligatory common fate between subclavian artery, internal mammary graft and coronary circulation. Cardiology 2002;97(4):175–9.
[11] Rossum AC, Steel SR, Hartshorne MF. Evaluation of coronary subclavian steal syndrome using sestamibi imaging and duplex scanning with observed vertebral subclavian steal. Clin Cardiol 2000;23(3):226–9 Mar.
[12] Cua B, Mamdani N, Halpin D, Jhamnani S, Jayasuriya S, Mena-Hurtado C. Review of coronary subclavian steal syndrome. J Cardiol 2017;70(5):432–7 Nov.
[13] Gaudino M, Serricchio M, Luciani N, Giungi S, Salica A, Pola R, et al. Risks of using internal thoracic artery grafts in patients in chronic hemodialysis via upper extremity arteriovenous fistula. Circulation 2003;107(21):2653–5 Jun 3.
[14] Crowley SD, Butterly DW, Peter RH, Schwab SJ. Coronary steal from a left internal mammary artery coronary bypass graft by a left upper extremity arteriovenous hemodialysis fistula. Am J Kidney Dis Off J Natl Kidney Found 2002;40(4):852–5 Oct.
[15] Rahbar R, McGee WR, Birdas TJ, Muluk S, Magovern J, Maher T. Upper extremity arteriovenous fistulas induce modest hemodynamic effect on the in situ internal thoracic artery. Ann Thorac Surg 2006;81(1):145–7 Jan.
[16] Tokuda Y, Song MH. Internal thoracic artery grafts and upper extremity arteriovenous fistula. Ann Thorac Surg 2007;84(6):2138 Dec.
[17] Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71 Mar 29.
[18] Shea BJ, Reeves BC, Wells G, Thuku M, Hamel C, Moran J, et al. AMSTAR 2: a critical appraisal tool for systematic reviews that include randomised or non-randomised studies of healthcare interventions, or both. BMJ 2017;358:j4008 Sep 21.
[19] Wells G., Shea B., O'Connell D., Peterson J., Welch V., Losos M., et al. The newcastle-ottawa scale (NOS) for assessing the quality of nonrandomized studies in meta-analyses [Internet]. Available from: https://www.ohri.ca/programs/clinical_epidemiology/oxford.asp
[20] Guyatt G, Oxman AD, Akl EA, Kunz R, Vist G, Brozek J, et al. GRADE guidelines: 1. Introduction-GRADE evidence profiles and summary of findings tables. J Clin Epidemiol 2011;64(4):383–94 Apr.
[21] Ahn S, Han A, Kim SY, Choi C, Min SI, Ha J, et al. The incidence and risk factors of coronary steal after ipsilateral AVF in patients with a coronary artery bypass graft. J Vasc Access 2017;18(4):290–4 Jul 14.
[22] Coskun I, Colkesen Y, Altay H, Ozkan U, Demirturk OS, Gulcan O, et al. Hemodynamic effects of left upper extremity arteriovenous fistula on ipsilateral internal mammary coronary artery bypass graft. Thorac Cardiovasc Surg 2013;61(8):663–7 Dec.
[23] Feldman L, Tkacheva I, Efrati S, Rabin I, Beberashvili I, Gorelik O, et al. Effect of arteriovenous hemodialysis shunt location on cardiac events in patients having coronary artery bypass graft using an internal thoracic artery. Ther Apher Dial Off Peer-Rev J Int Soc Apher Jpn Soc Apher Jpn Soc Dial Ther 2014;18(5):450–4 Oct.
[24] Hachiro K, Kinoshita T, Suzuki T, Asai T. Internal thoracic artery graft ipsilateral to the arteriovenous fistula in haemodialysis patients. Interact Cardiovasc Thorac Surg 2021;32(6):864–72 May 27.
[25] Han Y, Choo SJ, Kwon H, Lee JW, Chung CH, Kim H, et al. Effects of upper-extremity vascular access creation on cardiac events in patients undergoing coronary artery bypass grafting. PLoS ONE 2017;12(9):e0184168.
[26] Shim H, Jeong DS, Kim WS, Park PW, Sung K, Jeon CS, et al. Impact of arteriovenous fistula for hemodialysis on clinical outcomes of coronary artery bypass. Ann Thorac Surg 2018;106(6):1820–6 Dec.
[27] Sohn B, Chang HW, Lee JH, Kim D, Kim J, Lim C, et al. Influence of ipsilateral graft inflow to arteriovenous fistula for hemodialysis in coronary bypass surgery. J Clin Med 2022;11(4):1053 Feb 17.
[28] Takami Y, Tajima K, Kato W, Fujii K, Hibino M, Munakata H, et al. Effects of the side of arteriovenous fistula on outcomes after coronary artery bypass surgery in hemodialysis-dependent patients. J Thorac Cardiovasc Surg 2014;147(2):619–24 Feb.
[29] Wu YS, Hsieh SR, Wei HJ, Hsu CY, Tsai CL. Long-term outcomes in coronary artery bypass graft patients using internal thoracic artery with ipsilateral arteriovenous shunt for hemodialysis. Acta Cardiol Sin 2019;35(4):387–93 Jul.
[30] Ritter MA, Ringelstein EB. The venturi effect and cerebrovascular ultrasound. Cerebrovasc Dis Basel Switz 2002;14(2):98–104.
[31] Lee PY, Ng W, Chen WH. Concomitant coronary and subclavian steal caused by ipsilateral subclavian artery stenosis and arteriovenous fistula in a hemodialysis patient. Catheter Cardiovasc Interv Off J Soc Card Angiogr Interv 2004;62(2):244–8 Jun.
[32] Tanaka A, Sakakibara M, Okada K, Jinno Y, Ishii H, Murohara T. Coronary subclavian steal from a left internal thoracic artery coronary bypass graft due to ipsilateral subclavian artery stenosis and an arteriovenous graft in a hemodialysis patient with left vertebral artery occlusion. Intern Med Tokyo Jpn 2013;52(11):1195–8.
[33] Vascular Access 2006 Work GroupClinical practice guidelines for vascular access. Am J Kidney Dis Off J Natl Kidney Found 2006;48(1):S176–247 JulSuppl.
[34] Bavare CS, Bismuth J, El-Sayed HF, Huynh TT, Peden EK, Davies MG, et al. Volume flow measurements in arteriovenous dialysis access in patients with and without steal syndrome. Int J Vasc Med 2013;2013:328601.