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Medium and long-term patency results of distal anastomosis connectors: a meta-analysis

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Background: The difficulty of suturing perfect anastomoses in limited-access conditions prevents the transition of traditional coronary artery bypass grafting (CABG) to sternal-sparing approaches, even in the robotic era. Automated coronary anastomotic connector technologies may address these difficulties, but to date, none have achieved broad adoption. Besides versatility, ease-of-use and cost-effectiveness, the key performance parameter of such technology is anastomotic patency. In this meta-analysis, we aim to evaluate published connector devices by examining their patency outcomes in distal anastomoses.

Methods: The literature was systematically searched for studies comparing the angiographic patency of connector constructed coronary anastomoses to handsewn (HS) connections in adult patients undergoing CABG. The primary outcome was anastomosis patency across early (<30 days), mid-term (30 days to 1 year) and long-term (>1 year) follow-up. Random-effects meta-analyses were employed to analyze and compare patency using pooled risk ratios (RR) with 95% confidence intervals (CI).

Results: The search yielded 14 studies concerning eight connector devices. In 4,311 patients, a total of 4,328 anastomoses were constructed, 674 with connector devices and 3,654 with a HS technique. The pooled device patency over all timeframes was non-inferior to the HS technique (RR 0.90, 95% CI: 0.56–1.44). Technologies having a relatively large blood-exposed non-intimal surface area (BENIS, >15 mm^2) performed acceptably when applied to large target vessels [>2.0–2.5 mm inner diameter (ID)]. A tiny anastomotic orifice area (AOA, < ca. 4 mm^2) appeared to adversely affect results. Technologies realizing a generous AOA in combination with a limited BENIS showed superior results and applicability by performing well across the entire range of target coronary artery diameters (>1.0–1.5 mm ID).

Conclusions: The overall results suggest that connectors yield at least non-inferior anastomosis patency outcomes compared to HS techniques in all observed timeframes. Optimizing device characteristics like BENIS and AOA appear fundamental for broad applicability.

Keywords: Meta-analysis; coronary connector; minimal invasive; coronary bypass grafting; anastomosis patency

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Introduction

Coronary artery bypass grafting (CABG) remains the most effective and durable treatment for severe coronary disease, but its invasiveness causes significant surgical trauma (1). In past decades, multiple endeavors to realize less invasive versions of the standard CABG, like completely endoscopic or robotic-assisted procedures, have been made (2). However, contrary to most other surgical areas like urology, gynecology and general surgery, such strategies have shown limited reproducibility, even in experienced hands, and have proven unsuitable for mainstream adoption.

Nowadays, the vast majority of CABG procedures is still performed through a full sternotomy, burdening patients with major surgical trauma and a prolonged recovery period. A transition to less traumatic endoscopic procedures

is very attractive for all stakeholders, especially for the patients, but also for the healthcare system and for the community as a whole as a result of a speedier recovery and an earlier return to active society (3). However, even with specialized master-slave robots, the difficulty of suturing perfect anastomoses prevents a minimal invasive transition. Automated technology for anastomosis construction is broadly considered the 'missing link' to offer reproducibility to endoscopic procedures and to enable mainstream adoption of this strategy (4). Nevertheless, connector technology has proved difficult to realize. To date none has been applied on a large scale in clinical practice (5,6). In this meta-analysis, we aim to analyze the results of connectors for distal anastomoses, i.e., for the vascular connections between the bypass graft and the coronary artery on the heart, by examining their patency outcomes. As a second step, we will attempt to identify key device characteristics for optimal performance. This information could help shaping future connector technologies.

Methods

Search, eligibility & data extraction

A systematic literature search was performed, by two independent researchers, in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Appendix 1). Data extraction and analyses were performed in accordance with the Cochrane Handbook (7,8). PubMed, Cochrane, and EMBASE were comprehensively searched until August 2023, for publications comparing connector devices to handsewn (HS) coronary anastomoses. Various search terms for 'coronary artery bypass grafting' were combined with terms for 'connector devices coronary anastomoses' and 'handsewn coronary anastomoses.' Search strings are provided in the supplementary materials (Appendix 2).

The studies had to be written in English, reporting original data presenting anastomosis patency as the outcome of interest. Included were cohort studies and randomized controlled trials (RCT), comparing connector devices to HS coronary anastomoses in adult patients undergoing CABG. *In-vitro* experiments and animal studies were excluded. In cases of multiple studies by an author or group, we extracted patients' characteristics from the first study and outcomes of interest at subsequent follow-ups from later studies. When two studies by the same institution reported the same outcomes at similar follow-up periods, we only included the most informative publication. In case of discrepancies, we excluded the double report. The assessment of bias risk was conducted using Cochrane's Risk of Bias 2.0 tool for RCTs. The categorizations made were: 'low risk', 'some concern', and 'high risk' based on this evaluation (9). Additionally, non-RCT studies underwent quality evaluation by the Newcastle-Ottawa scale, with quality ratings spanning from low [0–3] to moderate [4–6] and high [7–9] accordingly (10). Data extracted from the included studies included study year, type of connector device employed, study design, number of patients enrolled, and the number of patients treated with the connector device versus those managed using the conventional suture technique. The data also included details regarding the surgical procedure [on-pump, off-pump, hybrid or total endoscopic coronary artery bypass surgery (TECAB)], the graft types, the coronary area targeted with the device, and, if mentioned, the dimensions of the graft and the coronary artery grafted with the device. Furthermore, details were collected on the control group, the methodology employed for assessing patency and the duration of follow-up. In addition, two specific device characteristics were evaluated: the blood exposed non-intimal surface (BENIS), i.e., the area of non-endothelialized surface/foreign body exposed to the blood, and the effective anastomotic orifice area (AOA). These characteristics were chosen based on their potential correlation with an increased risk of device patency failure, as reported in previous studies (6,11).

Considering the compact size and typically gentle application of the investigated anastomotic devices, it is reasonable to anticipate that the healing response of blood vessel tissue would be largely concluded within the initial year of follow-up. One could argue that data collected beyond the first year of follow-up may serve as a predictor for long-term outcomes. Due to the scarcity of data pertaining to various technologies, we have opted to categorize follow-up intervals as short-term (<30 days), mid-term (30 days to 1 year), and long-term (>1 year).

Outcomes

The primary outcome under investigation was the overall anastomosis patency across all devices during the longest observed follow-up timeframe, compared to the HS technique. Additionally, the anastomotic patency was studied in the three consecutive timeframes. Patency was determined through coronary angiography (CAG),

Table 1 Device characteristics

Device	Vessel wall connection method	Arteriotomy	BENIS mm^2/source	AOA mm^2/source	Target vessel ID range (mm)
St. Jude DAD					
1st generation	Clamped with stainless steel hooks	Knife & balloon expansion	5/*	4.9/Wiklund	≥2.5
2nd generation 'Easyload'			3–4/Soylu 2016	3.1/Carrel 2004	<2.0
MVP					
1st generation (4,000 series)	Clamped between gold-coated magnets	Knife	33/Klima 2003	8.1/Klima 2003	≥2.0
2nd generation (6,000 series)			16/Vicol 2006	5/*	2.0–4.0 (6,150 series)
					1.5–2.0 (6,200 series)
U-clip	Clamped with self-tying nitinol sutures	Knife	2–3/*	7–8/*	≥1.0
AADD	Clamped with nitinol hooks	knife	3/Kim 2004	4.5/Kim 2004	–
CAC	Clamped with nitinol frames	Knife	22/Boening 2005	12 (external frame)/ Boening 2005	≥2.0
C-port	Clamped with stainless steel staples	Built-in knife, 4.5 mm incision	8/*	6.2–6.9/Cai 2007	≥1.0

*, estimated value based on available indirect data; –, no vessel size limitations specified. St. Jude DAD (St. Jude Inc., St. Paul, MN, USA); MVP (Ventrica Inc., Fremont, CA, USA); U-clip (Medtronic Inc., Minneapolis, MN, USA); AADD (Bypass Inc., Herzlia, Israel); CAC (Converge Inc., Sunnyvale, CA, USA); C-port (Aesculap Inc., Central Valley, PA, USA). BENIS, blood-exposed non-intimal surface; ID, inner diameter; DAD, distal anastomotic device; MVP, magnetic vascular positioner; AADD, automated anastomotic distal device; CAC, coronary anastomosis coupler.

coronary computer tomography (cCT), or cardiac myocardial resonance imaging (cMRI) as stated in each of the included studies. Secondary outcomes included the anastomotic patency across subgroups defined by the chosen characteristics, BENIS and AOA (2). In addition, patency variations among graft types like arterial, venous, or a combination were investigated. Lastly, the effect of application in TECAB was examined.

Statistical analyses

Statistical analyses were performed using Review Manager (Version 5.4.1; Copenhagen: The Nordic Cochrane Centre, The Cochrane Collaboration). We used random-effects models (Mantel-Haenszel method) instead of fixed-effects for a more robust and conservative risk ratio (RR). The RR was calculated for categorical variables as the effect estimate for all outcomes. The results were presented as a forest plot, depicting the individual RR from each study as well as the overall composite effect estimate. An RR with its 95% confidence interval (95% CI) <1 would favor connector technology. The I^2 statistic and its corresponding P value were computed to assess heterogeneity. Additionally, the data were re-analyzed using fixed-effect models. To examine the potential presence of publication bias, we visually examined the contour-enhanced funnel plot for symmetry. A P value of 0.05 or less was considered statistically significant.

Results

In fourteen studies, seven automated anastomotic devices and one non-automated technology (U-clip) were investigated by comparing their patency to the HS technique. *Figure 1* displays the PRISMA flow diagram. Quality assessments of the included studies are presented in the supplementary materials (Appendix 3). Encompassing 4,311 patients, our analysis investigated the patency of 4,328 anastomoses, 674 performed with connector devices and 3,654 performed with the HS technique (12-25). The

Table 2 Study characteristics

Study	Device	Study design	# pat. device/HS	Surgery	Surgical approach	Graft type	Target	Graft/ coronary diameter (mm)	Control type	Imaging	FU time
Eckstein 2002	St. Jude DAD 1st gen.	NRCT	14	CPB	–	SVG	Non-LAD	SVG: ID <3.5/OD <3 + ID 2.5	In patient control	CAG, CAG + MRI	1 day
Carrel 2004	St. Jude DAD 1st + 2nd gen.	NRCT	14 1st gen (Eckstein) + 18 2nd gen	CPB	–	SVG	Non-LAD	–/ID 2,5 or 2,0	In patient control	CAG + MRI CAG	3–6 months
Wiklund 2005	St. Jude DAD 2nd gen.	RCT	30/30	CPB	–	SVG	Non-LAD	SVG: ID <3.5/OD <2.5 + ID <2.0	Control group	CAG + MRI CAG	6 months
Klima 2003	MVP 1st gen.	NRCT	32	CPB	–	IMA, SVG	All	–/ID >2	In patient control	CAG	6 days
Vicol 2006	MVP 2nd gen.	NRCT	11	–	Sternotomy	IMA, SVG, RA	All	–/ID >1.5	In patient control	CAG	19 months
Wolf 2003	U-clip	NRCT	82	Off-pump > CPB	Sternotomy > MIDCAB	IMA	LAD	–/–*	Historical group	CAG	6 months
Cheng 2021	U-clip	NRCT	126/154	Off–pump	TECAB/ MIDCAB	IMA	LAD/all	–/–*	Control group	64CTA or CAG (hybrid group)	7 years
Kim 2004	AADD	NRCT	14	Off-pump	Sternotomy	IMA, RGEA SVG	All	–/–*	In patient control	CAG	1.5 days
Boening 2005	CAC	NRCT	46	CPB	Sternotomy	SVG	Non-LAD	SVG: ID 3.0–4.0/ID >2.0	In patient control	CAG	2 months
Klima 2005	CAC	NRCT	15	CPB	–	SVG	Non-LAD	–/ID >2.0	In patient control	CAG	2 years
Cai 2007	C-port	NRCT	50	Off-pump > CPB	Sternotomy	SVG	Non-LAD	–/ID >1.0	In patient control	64CTA	3 months
Verberkmoes 2013	C-port	RCT	35/36	CPB > off-pump	Sternotomy	SVG	Non-LAD	–/ID >1.25	Control group	64CTA	1 year
Balkhy 2018	C-port	NRCT	117/3,014	Off-pump	TECAB/–	IMA, SVG	All	–/–*	Historical control	64CTA	1 year
Balkhy 2022	C-port	NRCT	315/170	Off-pump	TECAB	IMA	LAD/all	–/–*	Control group	CAG (hybrid group)	2 months

*, no vessel size limitations specified; –, not described. Data are presented for the device (D) and handsewn (HS) patients. Single values indicate in-patient controls and belong to the device group. FU, follow-up; St. Jude DAD, St. Jude distal anastomotic device; NRCT, non-randomized controlled trial; CPB, cardiopulmonary bypass; SVG, saphenous vein graft; LAD, left anterior descending coronary artery; ID, inner diameter; OD, outer diameter; CAG, coronary angiography; MRI, magnetic resonance imaging; RCT, randomized controlled trial; MVP, magnetic vascular positioner; IMA, internal mammary artery; MIDCAB, minimal invasive direct coronary artery bypass; AADD, automated anastomotic distal device; CAC, coronary anastomotic coupler; RGEA, gastro-epiploic artery graft; 64CTA, 64-slice computed tomography angiography; TECAB, total endoscopic coronary artery bypass.

Table 3 Study results

Study	Device	Patency device	Patency HS	Graft routing/geometry D	Graft routing/geometry control HS
Eckstein 2002	St. Jude DAD 1st gen.	14/14	40/40	Single/–	–
		10/11	–		
Carrel 2004	St. Jude DAD 1st + 2nd gen.	11/12*	41/43*	Single/end to side	– (Lima-lad included)
		7/10	24/25		
Wiklund 2005	St. Jude DAD 2nd gen.	20/27	23/23	Single/end to side	Single/end to side
Klima 2003	MVP 1st gen.	29/31	66/72	–	–
Vicol 2006	MVP 2nd gen.	15/18	18/18	–	–
Wolf 2003	U-clip	63/63	67/70 (POEM trial)	Single/end to side	Single/end to side
Cheng 2021	U-clip	104/107	126/131	Single/single, jump	Single/single, jump
Kim 2004	AADD	13/14	32/34	Single, jump, composite/end & side to side	Single, jump/–
Boening 2005	CAC	29/30	30/37	Single/end to side	–
Klima 2005	CAC	14/15	34/38	–	–
Cai 2007	C-port	42/45	16/18	Single, jump/end to side	Single, jump/end to side
Verberkmoes 2013	C-port	25/29	28/32	Single, jump/end to side	Single, jump/end to side
Balkhy 2018	C-port	121/143	2,369/3,026 (prevent IV)	Single, composite/end & side to side	–
Balkhy 2022	C-port	126/130	85/87	–	–

Data are presented for the device (D) and handsewn (HS) patients. *, data excluded by double report discrepancy; –, not described. St. Jude DAD, St. Jude distal anastomotic device; MVP, magnetic vascular positioner; AADD, automated anastomotic distal device; CAC, coronary anastomotic coupler.

anastomotic technologies are listed in *Table 1*, including several important device parameters. Owing to their physical connector dimensions, so called 1st generation devices (DAD, MVP and also the CAC) were only suitable for larger target coronary arteries [≥2.0–2.5 mm inner diameter (ID)]. The original MVP-4000 was redesigned in a 2nd generation, the 6000 series, which included a version for smaller vessels (>1.5 mm ID or even smaller). The St. Jude DAD was redesigned and slightly downsized in a 2nd generation, the Easyload, aimed at increasing ease-of-use. Only the U-clip and the C-port devices covered the entire target vessel diameter range for coronary artery surgery (ID ≥1.0–1.25 mm). No target vessel ID for the AADD could be found. Out of the fourteen studies, twelve were observational cohort studies: eight compared the patency of device constructed anastomoses to same patient HS anastomoses, two studies used a control group treated in the same institution, and two used historic control groups (12-18,20,21,23-25). The remaining two studies were RCTs comparing the DAD and C-port patency with HS control groups, respectively (19,22). Of all, three studies comprising 205 anastomoses, reported a short-term follow-up of less than a week (1 to 6 days) (12,14,16). Additionally, six studies, comprising 608 anastomoses reported a mid-term follow-up ranging from two to nine months (13,15,18,19,21,25). Five studies (including 3,561 anastomoses) evaluated a long-term follow-up, varying from 1 to 7 years (17,20,22-24). Study characteristics are presented in *Table 2*. *Table 3* lists the patency numbers and provides anatomic details.

Primary outcome

The pooled connector device patency across all timeframes

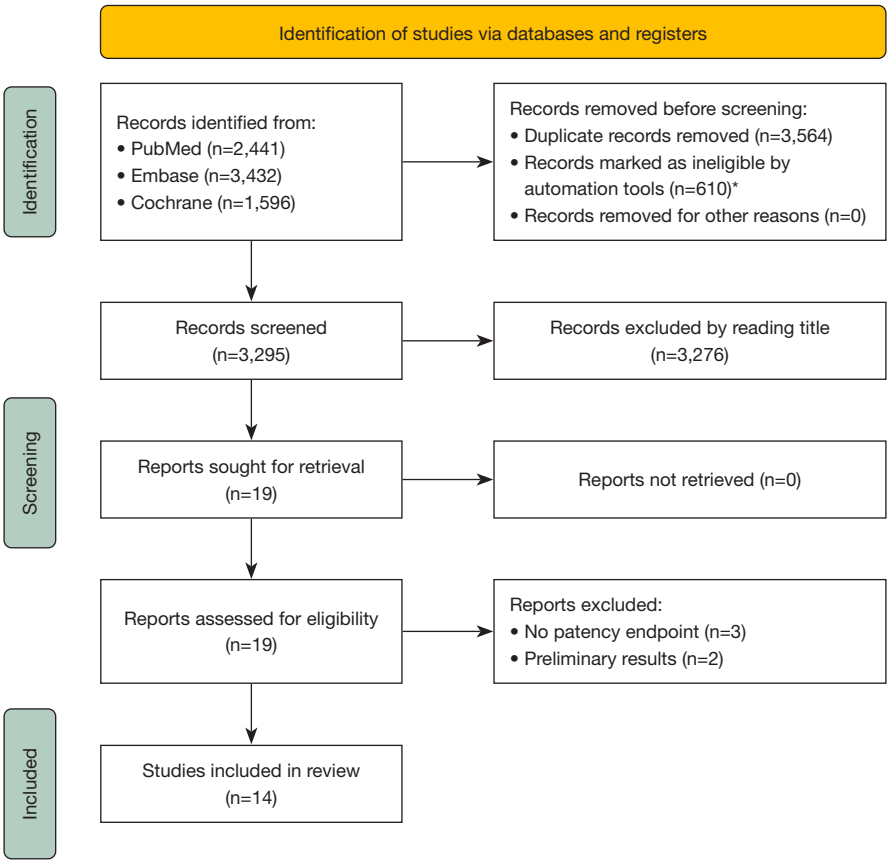

Figure 1 PRISMA 2020 flow diagram for new systematic reviews which included searches of databases and registers only. *, Filters applied: Human study type, Clinical Study, Clinical Trial, Comparative Study, Controlled Clinical Trial, Evaluation Study, Meta-Analysis, Multicenter Study, Randomized Controlled Trial, Technical Report, Validation Study.

did not show a significant difference compared to HS techniques (*Figure 2*). Short-term follow-up was reported by three cohort studies (12,14-16), mid-term by five cohort studies and one RCT (13,15,18,19,21), and long-term by four cohort studies and one RCT (17,20,22,23,24). No significant difference in patency between connectors and HS anastomoses was identified in any of these timeframes (RR: 0.89, 95% CI: 0.25–3.21, I^2=0%) for short-term, (RR: 1.10, 95% CI: 0.30–4.08, I^2=56%) for mid-term and (RR: 0.72, 95% CI: 0.52–1.05, I^2=0%) for long-term follow-up respectively (*Figure 3*). Two devices were notable for their significantly poorer performance compared to others: the MVP-6150 model for smaller target vessels (ID ≥1.5 mm) and the Easyload. The characteristics of these devices were at the extremes of the ranges presented in *Table 1*: the highest BENIS used for smaller target vessel ranges (MVP-6150) and the smallest AOA overall (Easyload). The pooled device patency was inferior to HS anastomoses (RR 8.54, 95% CI: 1.97–37.04, I^2=0%) (*Figure 4*) (15,19,20). Upon excluding these devices, eleven studies comprising 607 connector constructed anastomoses conducted with connectors were compared to 3,545 HS anastomoses (12-14, 16-18,21-25). The connector devices demonstrated superior patency compared to HS anastomosis (RR: 0.71, 95% CI: 0.52–0.99, I^2=0%) (*Figure 5*). When analyzing outcomes using the fixed-effects model, there was no significant difference in the pooled effect estimates compared to the random-effects model (RR 0.69, 95% CI: 0.50–0.95, I^2=0%).

Secondary outcomes

Devices with a large BENIS >15 mm²

Three devices exhibiting a BENIS >15 mm² (CAC, MVP-4000 series and MVP-6000 series) were investigated in four studies that examined 94 anastomoses (14,17,18,20). Three

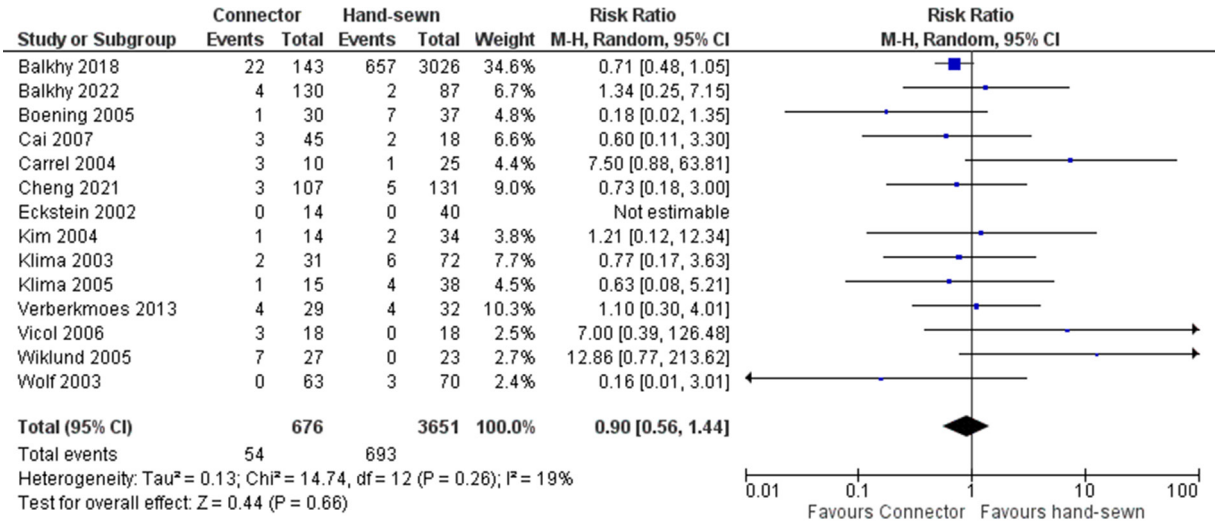

Figure 2 Pooled connector device patency across all timeframes compared to hand-sewn techniques. M-H, Mantel-Haenszel; CI, confidence interval.

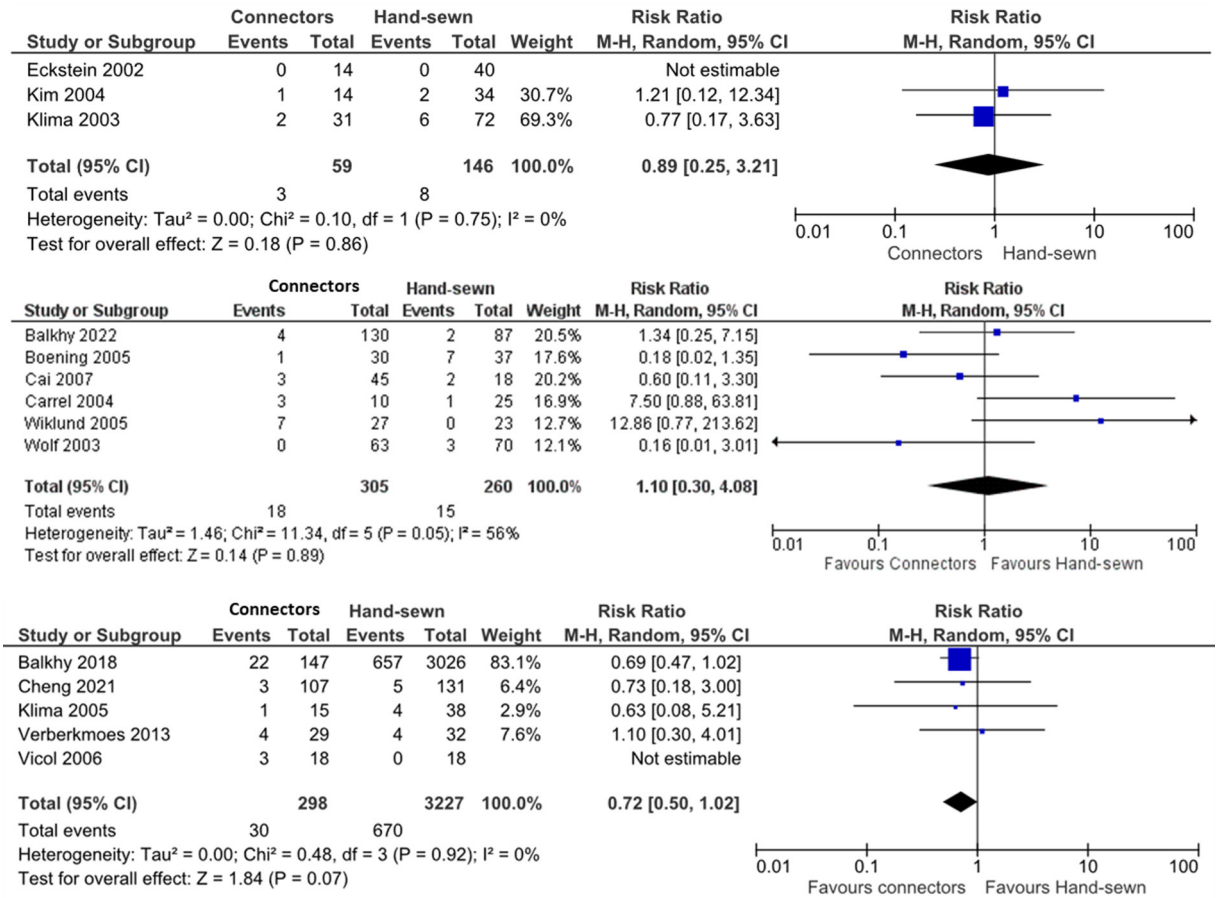

Figure 3 Connectors devices patency compared to hand-sewn technique at three different follow-ups: short-term follow-up (<30 days), mid-term (30 days to 1 year) and long-term (>1 year). M-H, Mantel-Haenszel; CI, confidence interval.

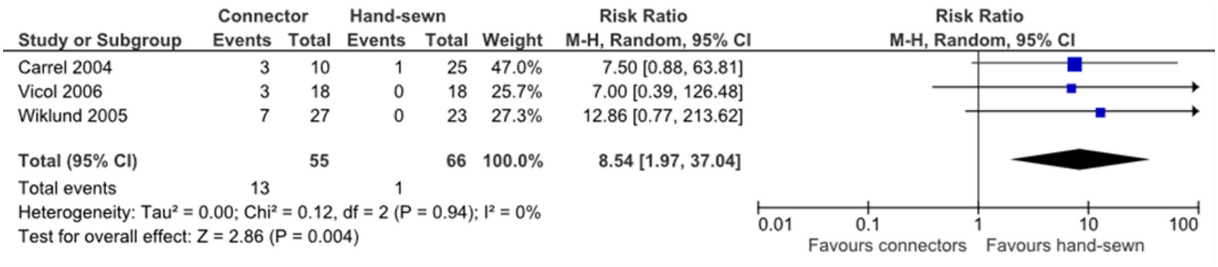

Figure 4 Selected connector devices patency compared to handsewn technique. Devices for smaller vessel range with the largest BENIS (MVP-6150), or with the smallest AOA (<4 mm^2, 2nd generation DAD). M-H, Mantel-Haenszel; CI, confidence interval; AOA, anastomotic orifice area; DAD, distal anastomotic device.

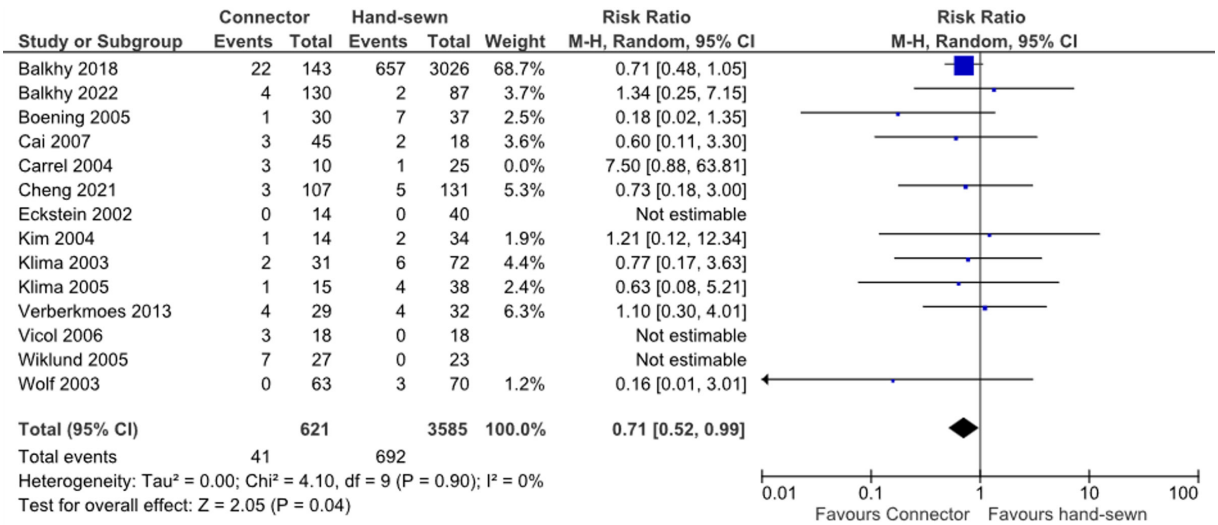

Figure 5 Selected connector devices patency compared to hand-sewn technique, all timeframes, excluded MVP-6150 and Easyload. M-H, Mantel-Haenszel; CI, confidence interval.

studies (76 anastomoses) specified target vessel exclusion criteria, requiring a coronary artery ID ≥2.0 mm (14,17,18). In a small study detailing the experience with the 2nd generation MVP-6150, the exclusion criteria for coronary vessels were revised to a downsized threshold of 1.5 mm ID (18 patients) (20). Overall, these devices demonstrated no statistically significant difference in patency when compared to HS anastomoses (RR: 0.70, 95% CI: 0.21–2.37, I^2=29%) with the remark that 80% of the grafts selectively targeted large diameter coronary artery targets (Figure S1A). When considered separately, MVP-6150 disappointed in smaller vessel ranges (*Figure 4*, Vicol) (20).

Devices with a tiny AOA

The Easyload device realized round anastomoses with an estimated cross-sectional area slightly above 3 mm^2. One RCT and one cohort studies collectively assessed 37 connector anastomoses and compared them to 48 anastomoses performed using the HS technique (15,19). The results showed that the device's patency was significantly lower than that achieved with the HS technique (RR: 9.14, 95% CI: 1.66–50.20, I^2=0%) (Figure S1B, also *Figure 4*, Carrel, Wiklund).

Patency across different graft types

In eight studies, saphenous vein grafts were used exclusively. Excluding the two aforementioned underperforming devices (MVP-6150 and Easyload), the remaining six studies consistently demonstrated significantly higher patency rates for anastomoses constructed with connectors (RR: 0.39, 95% CI: 0.22–0.70, I^2=0%) (12,17,18,21-23). No statistical difference in patency was found in the studies considering

arterial grafts only or in combination with venous grafts (RR: 0.80, 95% CI: 0.42–1.55, I^2=0% and RR: 0.72, 95% CI: 0.50–1.05, I^2=0% respectively) (Figure S1C; C.1: venous grafts, C.2: arterial grafts, C.3: combined).

C-port

Four studies investigated a total of 347 performed anastomoses utilizing the C-port. This CE-marked and Food and Drug Administration (FDA)-approved device represented the sole commercially available automated product. Despite yielding satisfactory results in numerous studies, the technology failed to achieve widespread adoption and was discontinued in 2018 (21-23,25). Its overall patency demonstrated no significant difference compared to HS anastomoses (RR: 0.75, 95% CI: 0.52–1.07, I^2=0%). The C-port device had undergone incremental technical improvements over the years and was available in models optimized for both open chest and closed chest applications. These variations did not appear to exert an influence on patency (see Figure S1D).

Devices used in TECAB

Two connector technologies, the C-port and the U-clips, were applied in TECAB settings. Two studies reported patency data of 237 anastomoses with connectors versus 218 HS anastomoses. No statistically significant patency difference was found (24,25) (RR 0.94 95% CI: 0.32–2.77, I^2=0%) (Figure S1E).

Heterogeneity and bias

No significant heterogeneity was observed across the analyses of the included studies. However, at mid-term follow-up analysis a moderate level of heterogeneity was identified (I^2=56%). No apparent significant funnel plot asymmetry was detected for any of the analyzed outcomes (Appendix 4).

Discussion

This meta-analysis encompassing fourteen studies on the patency outcomes of distal coronary connector devices yielded key insights. (I) All technologies demonstrated commendable performance when applied to large caliber target coronary arteries (≥2.0–2.5 mm ID); (II) devices exhibiting a generous AOA combined with a low BENIS performed effectively even in small vessels; and (III) a small AOA (circa 3 mm²) was associated with unfavorable patency outcomes, even combined with a small BENIS. Notably, upon excluding unfavorably designed devices regarding BENIS and AOA, the patency of connector-constructed anastomosis surpassed that of HS techniques (see *Figure 5*). This observation underscores the potential for enhanced consistency achievable through well-designed automated connector devices, aligning with findings from a previous study by Balkhy, which highlighted the advantages of the C-port connector for establishing reliable anastomoses (23).

Analogous to intracoronary stents, the patency of anastomotic connectors is predominantly influenced by thrombotic risks in the initial phase, followed by a tissue healing response in subsequent stages. Contrary to intracoronary stents, the delivery procedures of anastomotic technology are generally atraumatic, diminishing the likelihood of later hyperplastic, stenosing tissue reactions for most technologies. To comprehend thrombotic risks, an analysis of device properties along Virchow's triad becomes imperative. This triad incorporates the three factors governing intravascular thrombus formation: blood coagulability, endothelial integrity, and blood flow (26). Given that all connector technologies necessitate a dual anti-platelet regimen to reduce coagulability, attention shifts to BENIS and reduced graft flow conditions, as when targeting small caliber vessels or as a result of a tiny AOA. As elucidated by Virchow's triad, enhancing one factor has the potential to alleviate other, less favorable factors. Consequently, alongside the positive impact of dual antiplatelet therapy, the mitigating influence of large-caliber target vessels, characterized by inherently higher graft flows, aids in counteracting the drawbacks associated with sizable BENIS devices such as the MVP-4000 and the CAC. Nevertheless, the downsizing of the MVP into the 2nd generation 6,150 series still presented a significant BENIS area, yielding diminished outcomes when not counterbalanced by high flow.

The Easyload also proved to be disappointing. This device featured the smallest AOA among all devices. This observation suggests that a tiny AOA alone may disrupt the thrombotic equilibrium outlined in Virchow's triad, even in the presence of a relatively small BENIS and when targeting larger coronary arteries. A recent study conducted a mathematical analysis of the impact of AOA limitations for connectors using a finite elements computational flow model (27). They found that the AOA should at least slightly surpass the coronary cross-sectional area. Thus, the Easyload's AOA (3.1 mm^2) would appear to marginally suffice for its intended target vessel range (ID <2.0 mm, coronary cross-sectional area ca. 3.1 mm^2). However, this

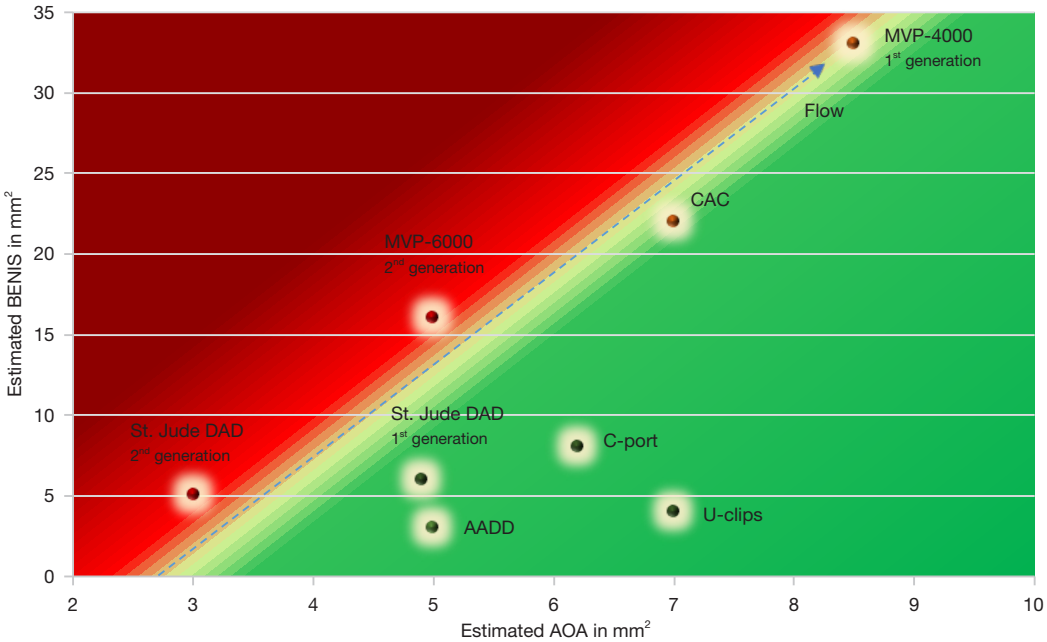

Figure 6 Device characteristics and anastomosis patency. The X-axis represents the estimated AOA and the y-axis represents the connector's estimated BENIS. The quadrant is divided into two sides by a crossing line: a green area below the line, where the observed device patency is satisfactory, and a red area, where device patency is less favorable. This line can be seen to represents the influence of blood flow on device patency, crossing the X-axis at the calculated 2.69 mm^2 (27). AOA, anastomotic orifice area; BENIS, blood exposed non-intimal surface; AADD, automated anastomotic distal device; MVP, magnetic vascular positioner; DAD, distal anastomotic device; CAC, converge anastomotic coupler.

study was confined to considerations of flow alone, leaving the thrombotic risks unexplored. Provided all connectors were correctly placed, our data suggest that the practical lower AOA threshold for reliable anastomotic devices is likely higher.

An explanation might be found in the increased coagulability of blood in the turbulence induced by a small anastomotic hole or the further diminishment of the anastomotic orifice due to the formation of a neointimal layer. Alternatively, a practical consideration for maintaining minimum AOA dimensions would be to ensure a wide enough AOA to enable future percutaneous, catheter-based measurements and interventions (PCI) through the anastomosis. This consideration takes into account the potential progression of coronary atherosclerosis over time. A visual representation elucidating the interplay of device characteristics is presented in *Figure 6*. The X-axis delineates the calculated AOA, while the Y-axis depicts the calculated BENIS. The red area can be regarded as indicative of condition combinations that are not easily alleviated by antiplatelet therapy, forecasting an elevated thrombotic risk, associated with anastomotic thrombosis. The dotted line references the impact of blood flow through the device-coronary anastomoses on device patency.

Incorporating connector devices into TECAB procedures proved advantageous in two studies. The minimal access environment did not adversely affect patency and significantly reduced operation time. After years of robotic skill enhancement and successful navigation of learning curves, the teams regarded connector devices as the missing link to advance closed chest CABG when compared to HS techniques. Noteworthy limitations of the C-port device, however, included limited visibility during deployment, solely indirect assessment of the build-in knife's performance in creating the intended arteriotomy and the necessity for manual stitching of the hole left after removing the device's anvil post-anastomosis construction. Even when the C-port was still available and despite evident benefits for patients and healthcare systems, TECAB programs faced very limited adoption, possibly attributed

to the intricacies of C-port deployment and the high cost of this disposable, single-shot anastomotic device. Future device design should prioritize ease-of-use and cost-effectiveness to enhance accessibility.

Despite relative wide adoption, U-clips, a non-automatic system necessitating the placement by hand of multiple self-closing clips, were discontinued in 2011. Their advantages included the surgeon's freedom to choose anastomosis dimensions, the similarity to the gold standard of hand suturing, and the self-tying nature of the clips. Their disadvantage was the time consuming and precise nature of the clip placement, still very similar to hand suturing. The C-port and the U-clip-based technique were the most widely adopted devices, possibly due to their versatility, as evidenced by being suitable to accommodate both arterial and saphenous vein grafts and their compatibility with coronary arteries as small as 1.00 mm.

Conclusions

We acknowledge several limitations in this study. Primarily, the aggregation of patency results from various technologies presents a challenge, as does the limited number of studies comparing device-assisted anastomosis with HS techniques. Additionally, the existing data are scarce and non-uniform, spanning a period of twenty years and relating to devices that are no longer in commerce. Furthermore, the detection of patency varied across studies due to different diagnostic methods, and the results often reflect outcomes after relatively short follow-up periods. In conclusion, the overall findings suggest that connector technologies may result in no significant difference, and in some cases, potentially achieve superior patency outcomes when essential device design characteristics adequately address patency requirements. However, insights gleaned from past experiences underscore additional prerequisites. These include the necessity for versatility across all practical target vessel types and sizes, encompassing a broad range of vessel wall qualities—parameters not all addressed in this meta-analysis. Moreover, the technology must be user-friendly and easily teachable to facilitate a seamless transition to minimally invasive and closed chest environments. Finally, affordability is crucial for enabling swift and widespread adoption, ushering in an endoscopic era for CABG surgery.

Acknowledgments

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Footnote

Conflicts of Interest: M.G. is a member of the EACTS-endorsed Robotic Cardiothoracic Surgery Taskforce. M.G. and W.J.L.S. are co-inventors of a new anastomotic technology being developed by OctoVascular BV and have a financial interest in this technology. The other author has no conflicts of interest to declare.

References

1. Neumann FJ, Sousa-Uva M, Ahlsson A, et al. 2018 ESC/EACTS Guidelines on myocardial revascularization. EuroIntervention 2019;14:1435-534.
2. Head SJ, Milojevic M, Taggart DP, et al. Current Practice of State-of-the-Art Surgical Coronary Revascularization. Circulation 2017;136:1331-45.
3. European Heart Network (EHN). European Cardiovascular Disease Statistics 2017. Available online: https://ehnheart.org/cvd-statistics/cvd-statistics-2017.html.
4. Balkhy HH, Wann LS, Krienbring D, et al. Integrating coronary anastomotic connectors and robotics toward a totally endoscopic beating heart approach: review of 120 cases. Ann Thorac Surg 2011;92:821-7.
5. Soylu E, Harling L, Ashrafian H, et al. A systematic review of the safety and efficacy of distal coronary artery anastomotic devices. Eur J Cardiothorac Surg 2016;49:732-45.
6. Suyker WJ, Borst C. Coronary connector devices: analysis of 1,469 anastomoses in 1,216 patients. Ann Thorac Surg 2008;85:1828-36.
7. Page MJ, McKenzie JE, Bossuyt PM, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71.
8. Cumpston M, Li T, Page MJ, et al. Updated guidance for trusted systematic reviews: a new edition of the Cochrane Handbook for Systematic Reviews of Interventions. Cochrane Database Syst Rev 2019;10:ED000142.
9. Higgins JP, Altman DG, Gøtzsche PC, et al. The

Cochrane Collaboration's tool for assessing risk of bias in randomised trials. BMJ 2011;343:d5928.
10. Stang A. Critical evaluation of the Newcastle-Ottawa scale for the assessment of the quality of nonrandomized studies in meta-analyses. Eur J Epidemiol 2010;25:603-5.
11. Scheltes JS, van Andel CJ, Pistecky PV, et al. Coronary anastomotic devices: blood-exposed non-intimal surface and coronary wall stress. J Thorac Cardiovasc Surg 2003;126:191-9.
12. Eckstein FS, Bonilla LF, Englberger L, et al. First clinical results with a new mechanical connector for distal coronary artery anastomoses in CABG. Circulation 2002;106:I1-4.
13. Wolf RK, Alderman EL, Caskey MP, et al. Clinical and six-month angiographic evaluation of coronary arterial graft interrupted anastomoses by use of a self-closing clip device: a multicenter prospective clinical trial. J Thorac Cardiovasc Surg 2003;126:168-77; discussion 177-8.
14. Klima U, Falk V, Maringka M, et al. Magnetic vascular coupling for distal anastomosis in coronary artery bypass grafting: a multicenter trial. J Thorac Cardiovasc Surg 2003;126:1568-74.
15. Carrel T, Englberger L, Keller D, et al. Clinical and angiographic results after mechanical connection for distal anastomosis in coronary surgery. J Thorac Cardiovasc Surg 2004;127:1632-40.
16. Kim KB, Cho KR, Choi JS, et al. Initial experience of an automated anastomotic distal device in off-pump CABG. Heart Surg Forum 2004;7:E360-3.
17. Klima U, Kofidis T, Boening A, et al. Long term angiographic monitoring reveals safety and efficacy of the Converge end-to-side anastomotic coupler. Interact Cardiovasc Thorac Surg 2005;4:505-8.
18. Boening A, Schoeneich F, Lichtenberg A, et al. First clinical results with a 30 degrees end-to-side coronary anastomosis coupler. Eur J Cardiothorac Surg 2005;27:876-81.
19. Wiklund L, Bonilla LF, Berglin E. A new mechanical connector for distal coronary artery anastomoses in coronary artery bypass grafting: a randomized, controlled study. J Thorac Cardiovasc Surg 2005;129:146-50.
20. Vicol C, Eifert S, Oberhoffer M, et al. Mid-term patency after magnetic coupling for distal bypass anastomosis in coronary surgery. Ann Thorac Surg 2006;82:1452-6.
21. Cai TH, Acuff TE, Randolph Bolton JW, et al. Prospective evaluation of patency and early experience utilizing an automated distal anastomosis device (C-port). Innovations (Phila) 2007;2:245-50.
22. Verberkmoes NJ, Wolters SL, Post JC, et al. Distal anastomotic patency of the Cardica C-PORT(R) xA system versus the hand-sewn technique: a prospective randomized controlled study in patients undergoing coronary artery bypass grafting. Eur J Cardiothorac Surg 2013;44:512-8; discussion 518-9.
23. Balkhy HH, Patel NC, Ramshandani M, et al. Multicenter Assessment of Grafts in Coronaries: Midterm Evaluation of the C-Port Device (the MAGIC Study). Innovations (Phila) 2018;13:273-81.
24. Cheng N, Zhang H, Yang M, et al. Eleven-year outcomes of U-clips in totally robotic coronary artery bypass grafting versus standard hand-sewn running suture in robotic-assisted coronary artery bypass grafting. Interact Cardiovasc Thorac Surg 2021;33:27-33.
25. Balkhy HH, Nisivaco SM, Hashimoto M, et al. Robotic Total Endoscopic Coronary Bypass in 570 Patients: Impact of Anastomotic Technique in Two Eras. Ann Thorac Surg 2022;114:476-82.
26. Poston R, White C, Read K, et al. Virchow triad, but not use of an aortic connector device, predicts early graft failure after off-pump coronary bypass. Heart Surg Forum 2004;7:E428-33.
27. Crielaard H, Hoogewerf M, van Putte BP, et al. Evaluating the Arteriotomy Size of a New Sutureless Coronary Anastomosis Using a Finite Volume Approach. J Cardiovasc Transl Res 2023;16:916-26.

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Appendix 1 PRISMA Checklist

Section and Topic	Item #	Checklist item	Location where item is reported
TITLE			
Title	1	Identify the report as a systematic review.	
ABSTRACT			
Abstract	2	See the PRISMA 2020 for Abstracts checklist.	
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	Page 1
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	Page 1
METHODS			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	Page 2
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	Page 2, *Table 1*
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	Page 2, S2
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	Page 2, 3, *Table 1,* S2
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	Page 2, 3, *Table 1,* S2
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	Page 2, 3, *Table 1,* S3
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	Page 2, 3
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	Page 2, 3, S2, S3
Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.	NA
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	Page 2, 3, S3
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	Page 2, 3
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	Page 3
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	Page 3
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).	Page 3
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	Page 3

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Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	Page 2, 3, S3, S4
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	Page 2, 3
RESULTS			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	Page 4, *Table 1*
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	NA
Study characteristics	17	Cite each included study and present its characteristics.	Page 4-7, *Table 1-4*
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	S3, S4a, S4b
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	*Table 2-4,* Fig 1-4, S5
Results of syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	Page 4-7
	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	Page 4-7, Fig 1-4, S5, S6
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	Page 8
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	S6
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	NA
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	Page 4-7, Fig 1-4, S5, S6
DISCUSSION			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	Page 8-11
	23b	Discuss any limitations of the evidence included in the review.	Page 8-11
	23c	Discuss any limitations of the review processes used.	Page 10-11
	23d	Discuss implications of the results for practice, policy, and future research.	Page 10-11
OTHER INFORMATION			
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	NA
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	NP
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	NA
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	None
Competing interests	26	Declare any competing interests of review authors.	COI Statement
Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	Data Availability Statement

From: 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. doi: 10.1136/bmj.n71

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Appendix 2 Search strings

PubMed incl. MEDLINE

(coronary artery bypass graft*[Title/Abstract] OR CABG[Title/Abstract] OR coronary surgery[Title/Abstract] OR cardiovascular surger*[Title/Abstract] OR coronary vessel*[Title/Abstract] OR coronary arter*[Title/Abstract] OR "Coronary Artery Bypass"[Mesh] OR "Coronary Vessels"[Mesh])
AND
(connector*[Title/Abstract] OR stapler*[Title/Abstract] OR instrument*[Title/Abstract] OR anastomotic device*[Title/Abstract] OR experimental*[Title/Abstract] OR sutureless[Title/Abstract] OR facilitated[Title/Abstract] OR clip*[Title/Abstract] OR bonding[Title/Abstract] OR nonsuture[Title/Abstract] OR nonsuture[Title/Abstract] OR stapl*[Title/Abstract] OR "Surgical Stapling"[Mesh] OR surgical staplers[MeSH])
AND
(hand-sutured[Title/Abstract] OR sutur*[Title/Abstract] OR conventional[Title/Abstract] OR anastom*[Title/Abstract] OR graft*[Title/Abstract] OR "Suture Techniques"[Mesh])

EMBASE

('coronary artery bypass graft*':ti,ab,kw OR 'CABG':ti,ab,kw OR 'coronary surgery':ti,ab,kw OR 'cardiovascular surger*':ti,ab,kw OR 'coronary vessel':ti,ab,kw OR 'coronary arter*':ti,ab,kw OR 'coronary vessels surgery'/exp OR 'coronary artery surgery'/exp)
AND
('connector*':ti,ab,kw OR 'stapler*':ti,ab,kw OR 'instrument*':ti,ab,kw OR 'anasomotic device*':ti,ab,kw OR 'experimental*':ti,ab,kw OR 'sutureless':ti,ab,kw OR 'facilitated':ti,ab,kw OR 'clip*':ti,ab,kw OR 'non-suture':ti,ab,kw OR 'nonsuture':ti,ab,kw OR 'stapl*':ti,ab,kw OR 'surgical stapling'/exp OR 'connector'/exp OR 'anastomotic device'/exp)
AND
('hand-sutured':ti,ab,kw OR 'sutur*':ti,ab,kw OR 'conventional':ti,ab,kw OR 'anastom*':ti,ab,kw OR 'graft*':ti,ab,kw OR 'suture technique'/exp OR 'vascular suture'/exp)

Cochrane

(coronary artery bypass graft* OR CABG OR coronary surgery OR cardiovascular surger* OR coronary vessel OR coronary arter* OR coronary vessels surgery OR coronary artery surgery)
AND
(connector* OR stapler* OR instrument* OR anasomotic device* OR experimental* OR sutureless OR facilitated OR clip* OR non-suture OR nonsuture OR stapl* OR surgical stapling OR connector OR anastomotic device)
AND
(hand-sutured OR sutur* OR conventional OR anastom* OR graft* OR suture technique OR vascular suture)

https://dx.doi.org/10.21037/acs-2023-rcabg-0190

Appendix 3 Risk of bias assessment in individual studies

The risk of bias was evaluated with Cochrane's risk of bias tool for RCTs (RoB 2.0) tool for randomized controlled trials (RCTs) on five domains (randomization process, deviations from intended interventions, missing outcome data, measurement of the outcome, and selection of the reported result) as 'low risk', 'some concern', and 'high risk' (9). The Newcastle-Ottawa quality assessment scale was used for non-RCT studies. Study quality can range from low (0–3), moderate (4–6), and high (7–9), respectively (10).

Traffic light plot of risk of bias assessment of included studies using RoB 2.0 criteria, and overall risk of bias

RCT Studies: author, reference, publication year	Risks of Bias Domains					
	D1	D2	D3	D4	D5	Overall
Wiklund *et al.* (19) 2005	🟢	🟢	🟡	🟢	🟢	🟡
Verberkmoes *et al.* (22) 2013	🟢	🟢	🟢	🟢	🟢	🟢

D1. bias arising from the randomization process;
D2. bias due to deviations from intended interventions;
D3. bias due to missing outcome data;
D4. bias in measurement of the outcome;
D5. bias in selection of the reported result.

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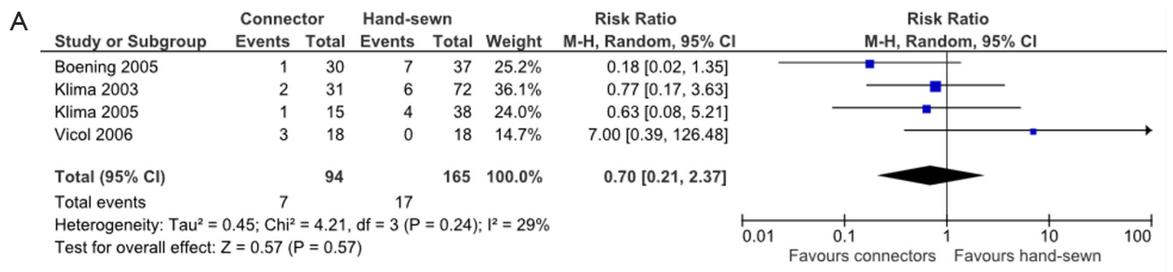
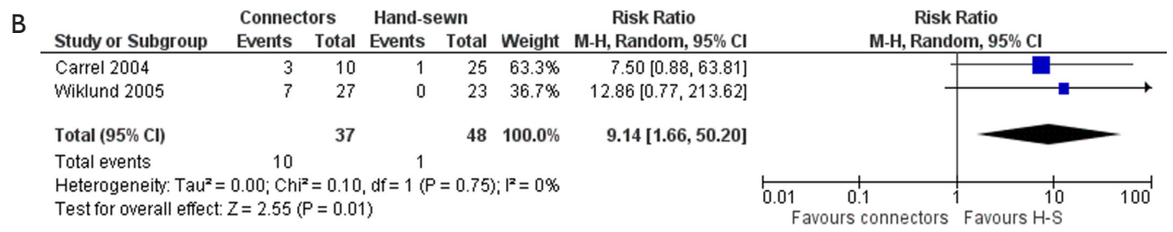
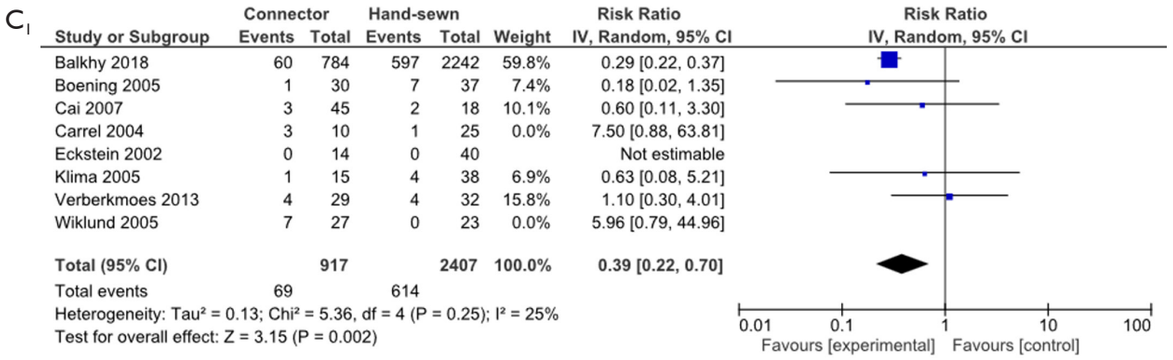
The Newcastle-Ottawa quality assessment for cohort studies. Study quality ranging is divided in low (0–3), moderate (4–6), and high (7–9), respectively

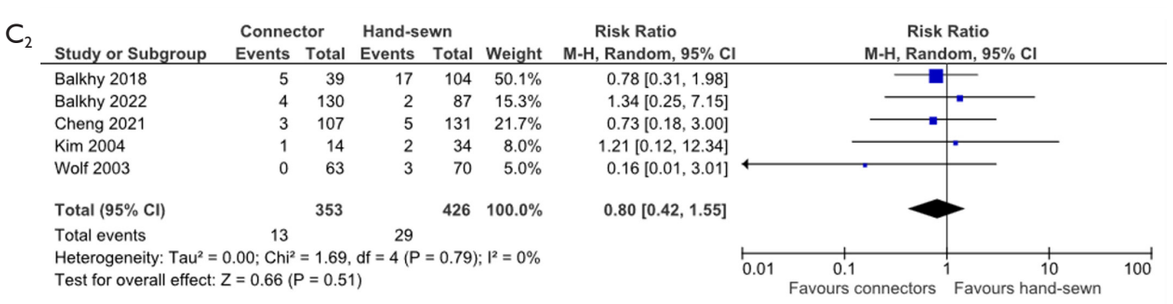
NRCT Studies: first author, reference, publication year.	Selections			Comparability			Outcomes		
	Representative of the intervention group	Selection of the control group	Ascertainment of exposure	Outcome of interest not present at the start of the study	Comparability of cohorts on the basis of design, or analysis controlled for confounders	Assessment of outcomes	Sufficient follow-up time	Adequacy of follow-up	Total (8/8)
Eckstein *et al.* (12) 2002	*	*	*	*	*	*	*	*	8/8
Wolf *et al.* (13) 2003	*	0	*	*	*	*	*	*	7/8
Klima *et al.* (14) 2003	*	*	*	*	*	*	0	*	7/8
Carrel *et al.* (15) 2004	*	*	*	*	*	*	*	0	7/8
Kim *et al.* (16) 2004	*	*	*	*	*	*	0	*	7/8
Klima *et al.* (17) 2005	*	*	*	*	*	*	*	0	7/8
Boening *et al.* (18) 2005	*	*	*	*	*	*	*	*	8/8
Vicol *et al.* (20) 2006	*	*	*	*	*	*	*	0	7/8
Cai *et al.* (21) 2007	*	0	*	*	*	*	*	0	6/8
Balkhy *et al.* (23) 2018	*	0	*	*	*	*	*	*	7/8
Cheng *et al.* (24) 2021	*	*	*	*	*	*	*	*	8/8
Balkhy *et al.* (25) 2022	*	*	*	*	*	*	*	*	8/8

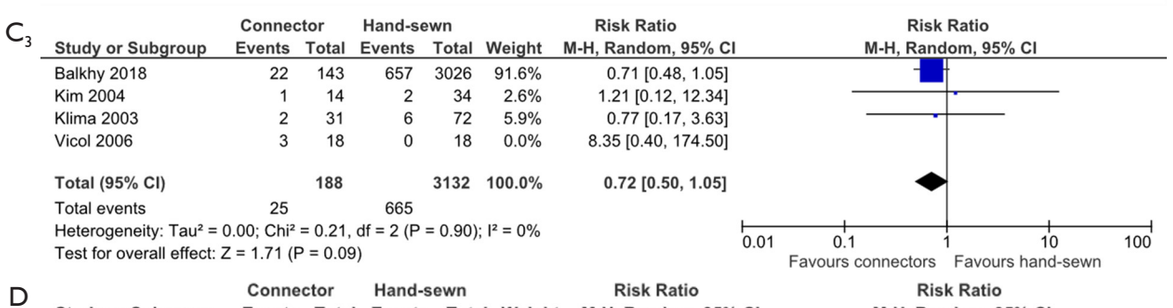
https://dx.doi.org/10.21037/acs-2023-rcabg-0190

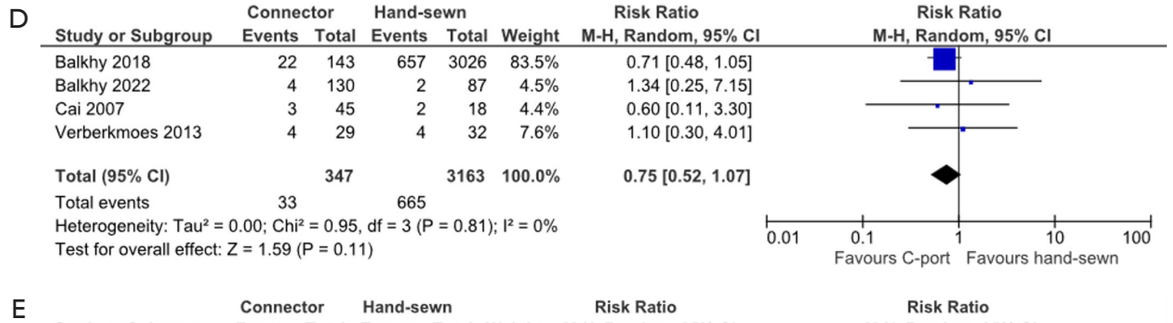












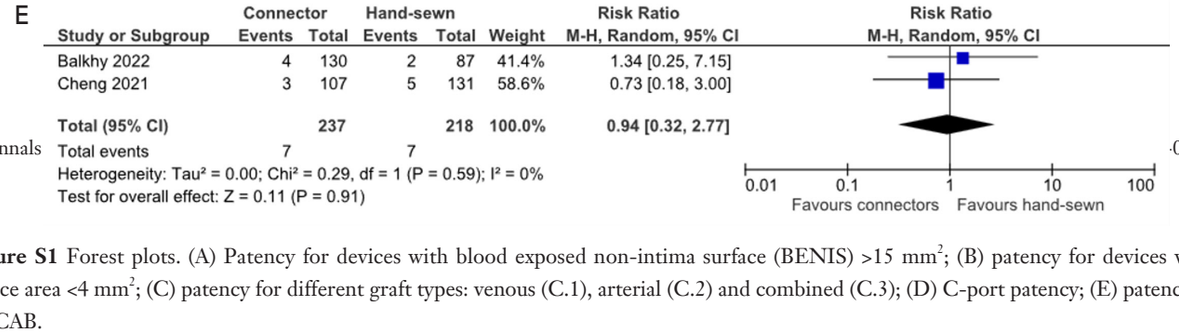
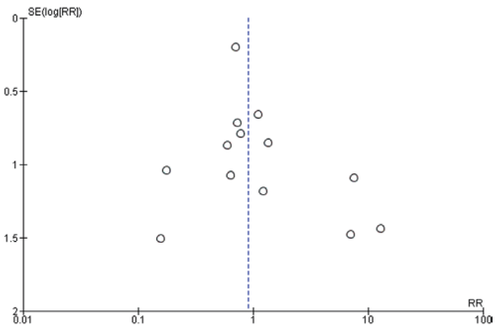


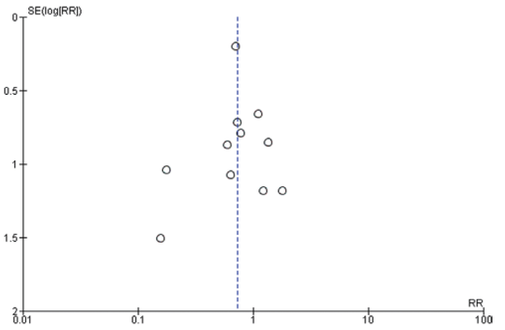
Figure S1 Forest plots. (A) Patency for devices with blood exposed non-intima surface (BENIS) >15 mm^2; (B) patency for devices with orifice area <4 mm^2; (C) patency for different graft types: venous (C.1), arterial (C.2) and combined (C.3); (D) C-port patency; (E) patency in TECAB.

Appendix 4 Funnel plots

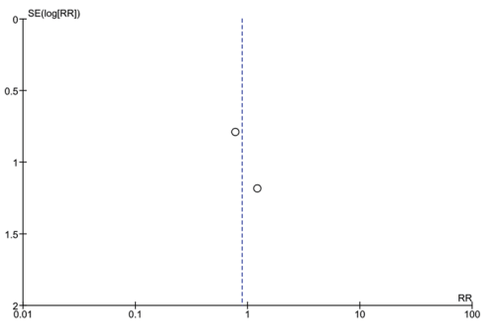
A: Overall studies over patency:

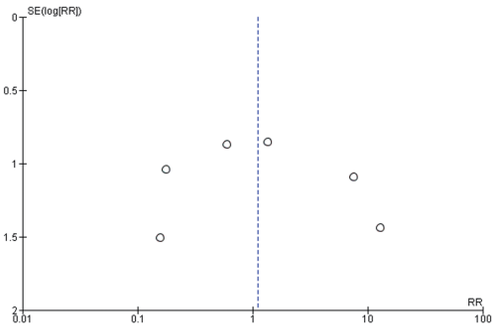


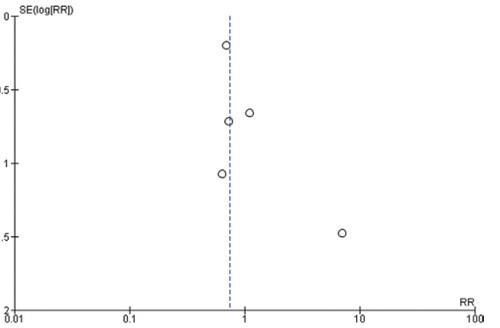
B: Selected studies over patency (without MVP-6150 and Easyload devices):



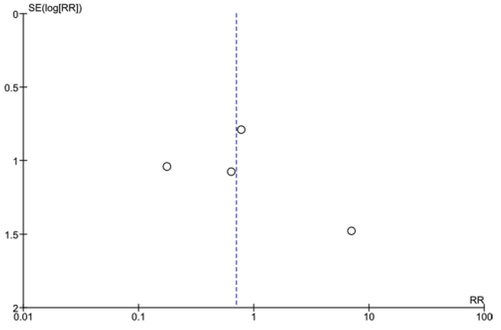
Short, Mid and Long-term follow-up studies:



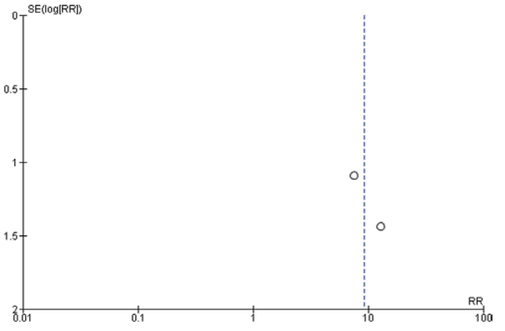




Studies over device with BENIS >15 mm^2:

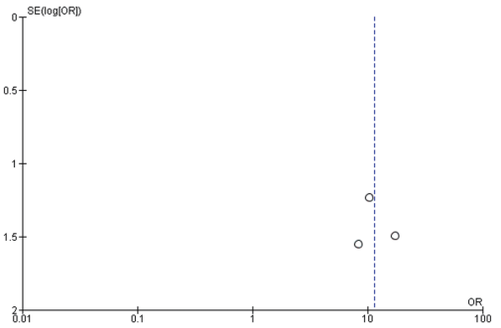


Studies over device with AOA <4 mm^2:

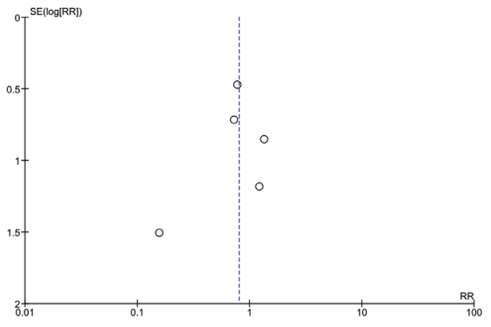


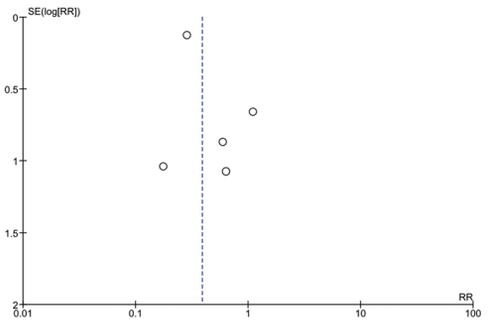
https://dx.doi.org/10.21037/acs-2023-rcabg-0190

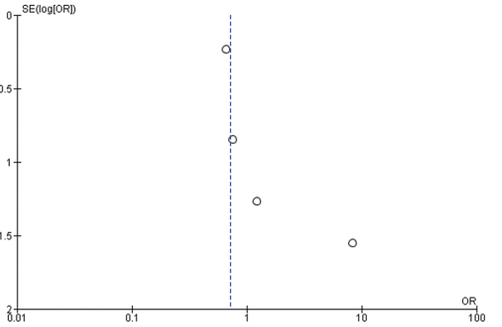
Studies with 2nd generation devices (MVP-6150 and Easyload devices):



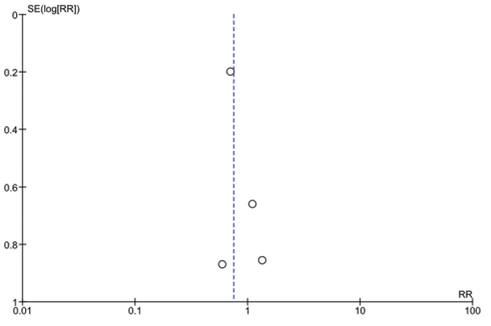
Studies investigating patency in different graft types: arterial, venous and combined (excluded MVP 6150 and Easyload):



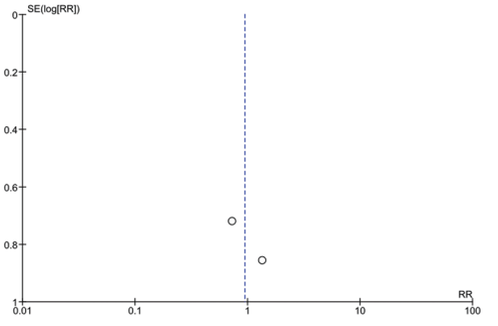




Studies investigating C-port device:



Studies in TECAB



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