



Review

Systematic review of the safety and efficacy of contrast injection via venous catheters for contrast-enhanced computed tomography

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ABSTRACT

Objective: To examine the safety and efficacy of contrast injection through a central venous catheter (CVC) for contrast-enhanced computed tomography (CECT).

Methods: A systematic literature search was performed using PubMed. Studies were deemed eligible if they reported on the use of CVCs for contrast administration. Selected articles were assessed for their relevance and risk of bias. Articles with low relevance and high risk of bias or both were excluded. Data from included articles was extracted.

Results: Seven studies reported on the use of CVCs for contrast administration. Catheter rupture did not occur in any study. The incidence of dislocation ranged from 2.2–15.4%. Quality of scans was described in three studies, with less contrast enhancement of pulmonary arteries and the thoracic aorta in two studies, and average or above average quality in one study. Four other studies used higher flowrates, but did not report quality of scans.

Conclusion: Contrast injection via CVCs can be performed safely for CECT when using a strict protocol. Quality of scans depended on multiple factors like flow rate, indication of the scan, and cardiac output of the patient. In each patient, an individual evaluation whether to use the CVC as access for contrast media should be made, while bolus tracking may be mandatory in most cases.

1. Introduction

Central venous catheters (CVCs) are frequently used in critically ill patients requiring continuous intravenous infusions. In many of those patients, CVCs remain the only venous access site, because placement of peripheral intravenous catheters is challenging due to edematous states or recurrent phlebitis. CVCs are also used in patients in need of frequent intravenous access or when toxic drugs need to be administered. Different types of CVCs exist: classic and most frequently used non-tunneled and tunneled CVCs, implantable ports, and peripherally inserted central catheters (PICC) [1]. Each type of catheter has its own maximal flowrate and pressure limit according to the manufacturer [1]. When present, CVCs are the easiest way for the administration of iodine-based contrast for performing enhanced computed tomography (CECT) examinations. Standard CT injection protocols require contrast volumes ranging from 75 to 150 mL with an injection rate between 3 and 5 mL/s [2]. Currently, most manufacturers of CVCs do not recommend high flow rates via CVCs, due to the risk of rupture,

displacement, contrast media extravasation, catheter dysfunction, and thrombosis [3,4]. Several manufacturers produce CVCs specifically designed for so-called power injection [5–8]. This systematic review evaluates whether CVCs can be safely used for the administration of intravenous contrast agents, particularly at higher injection rates for obtaining high-quality images.

2. Methods

2.1. Search strategy and selection

A systematic literature search was performed on September 10th, 2016 using PubMed. A search query was built by linking two content areas: ‘central catheter’ and ‘contrast enhanced’ with relevant synonyms for both areas: ((central line [Title/Abstract] OR central catheter [Title/Abstract] OR CVC [Title/Abstract] OR central venous [Title/Abstract] OR PICC [Title/Abstract] OR port-a-cat* [Title/Abstract] OR PAC [Title/Abstract] OR Port a cath [Title/Abstract]

Abbreviations: CVC, central venous catheter; CECT, contrast-enhanced computed tomography; PICC, peripherally inserted central catheter; TIVAP, totally implantable venous access ports; SVC, superior vena cava; PIPICC, power injectable peripherally inserted central catheter; CT-PICC, CT-injectable peripherally inserted central catheter

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OR jugular line[Title/Abstract] OR jugular catheter[Title/Abstract] OR subclavian line[Title/Abstract] OR subclavian catheter[Title/Abstract]) AND (CT[Title/Abstract] OR CECT[Title/Abstract] OR contrast enhanced[Title/Abstract] OR contrast-enhanced[Title/Abstract] OR power injection[Title/Abstract] OR power injector).

PubMed was searched systematically to identify original publications on the use of CVCs for contrast administration for CT-scans focusing on safety, efficacy, and complications. Exclusion criteria included: no full-text available, publication not written in English or Dutch, review articles, case reports, and studies focusing on the use of CVCs in pediatrics. Duplicate publications were excluded. A cross-check of reference lists from selected articles was performed to identify articles missed by the initial search. Screening of title, abstract, and full text was performed by two authors (SBB, MWB) independently. Disagreements were discussed until consensus was reached. The reference lists of the selected articles were hand searched for relevant cross-References

2.2. Study assessment

The remaining articles were assessed for their relevance and risk of bias by two authors (SBB, MB) independently using predefined criteria (Table 1). Studies were classified as highly relevant if they complied with all criteria and moderately relevant if the reported outcome only included safety or efficacy. Studies were classified as having low risk of bias if they satisfied all criteria and high risk of bias if they satisfied less than three criteria. The remaining studies were classified as having a moderate risk of bias. Studies were only included for further analysis if they scored high or moderate on relevance and carried a low or moderate risk of bias. Discordances were discussed until consensus was reached.

2.3. Data analysis

Incidences of complications were extracted from the selected studies were tabulated and presented as percentages. Data on quality of images was extracted where applicable. Numerators and denominators were provided when reported in the articles.

Table 1
Study assessment.

Study (year)	Relevance			Risk of bias				Included for analysis
	Patients	Outcome: safety	Outcome: efficacy	Standardization of test	Blinding	Selective reporting	Complete data	
Carlson et al (1992)[3]	●	●	○	○	NA	●	●	No
Coyle et al (2004)[31]	●	●	●	●	○	●	●	Yes
Goltz et al (2011)[25]	●	●	●	●	○	●	●	Yes
Herts et al (2001)[30]	●	●	●	●	●	●	●	Yes
Lozano et al (2012)[28]	●	●	○	●	NA	●	●	Yes
Macht et al (2012)[26]	●	●	○	●	NA	●	●	Yes
Morden et al (2014)[29]	●	●	○	●	NA	●	●	Yes
Sanelli et al (2004)[27]	●	●	○	●	NA	●	●	Yes

NA = not applicable

Relevance

Patients: ● = patients with a central catheter

Outcome: safety: ● = data on complications, injection rate and pressure; ○ = data on either complications, injection rate and pressure

Outcome: efficacy: ● = data on quality of images; ○ = no data on quality of images

Risk of bias

Standardization of test: ● = yes; ○ = no

Blinding: ● = reviewer of quality of the images was blinded for route of injection; ○ = reviewer was not blinded

Selective reporting: ● = adequate sample selection; ○ = inadequate sample selection

Completeness of outcome data: ● < 10% missing data; ○ > 10% missing data

3. Results

3.1. Search and selection

The literature search yielded 484 unique hits. Twenty-three articles were considered eligible for answering the research question after selection based on title and abstract. Seventeen articles were excluded during full text screening because of the following reasons: incorrect domain (n = 1) [9], outcome not focusing on safety, efficacy, and complications (n = 1) [10], CVC use in pediatrics (n = 7) [11–17], in vitro studies (n = 4) [18–21], no original article (n = 3) [1,22,23], and not meeting language requirements (n = 1) [24]. During cross referencing, one study was included missed by the initial search [25]. Eventually, eight studies were eligible for critical appraisal (Table 1) [3,25–31].

3.2. Study assessment

Three studies scored high on relevance [25,30,31] and five scored moderate on relevance [3,26–29]. The risk of bias was low in one study [30], moderate in six studies [25–29,31], and high in one study [3] (Table 1). Carlson et al. [3] evaluated the system pressure in thirteen patients with Port-A-Caths. The pressure measurement was not standardized: five patients' injection pressures were measured with a pressure gauge that was placed in-line during injection and eight patients' injection pressures were not. They did not report on the quality of the CT images and only one sentence addressed the absence of complications. The lack of standardization and limited relevance made us decide to exclude this study from data analysis. Finally, seven studies [25–31] were included for further analysis (Table 2).

3.3. Data analysis – safety

The study characteristics and main results are presented in Table 2. Coyle et al. [31] found two (2/110; 1.8%) externally ruptured PICCs while injected at a rate of 2 mL/sec. However, the ruptures were caused by mechanic obstructions; i.e. one of the ruptured PICCs was clamped, the other kinked at the venous entry site. Another PICC ballooned without rupturing and further injected was stopped. Goltz et al. [25] evaluated power injections in 141 patients with totally implantable venous access ports (TIVAPs) in their forearm. One (1/141; 0.7%) TIVAP's tip was dislocated in the brachiocephalic vein and revealed a catheter rupture during an interventional retrieval attempt. Three (3/

Table 2
Results.

Study (year)	n	Type of study	Type of CVC	Injection rate and peak injection pressure	Outcome: complications	Outcome: image quality
Coyle (2004) [31]	110	PS	12 SL, 5F PICC 98 DL, 5F PICC	1–2 mL/s (n = 8), 2 mL/s (n = 89), 2–3 mL/s (n = 9), 4 mL/s (n = 4) SL; 16–79 psi, DL: 40–135 psi.	2 (1.8%) ruptured 1 ballooning (DL, 4 mL/s)	81 average; 23 above average; 6 below average
Goltz (2011) [25]	141 vs 50 peripheral catheter	RS	141 TIVAP forearm	TIVAP: Max 1.5 mL/s; mean pressure 121.9 ± 24.1 psi. Peripheral: 3 mL/s, pressure limit 300 psi	1 (0.7%) dislocation with ruptures (2.1%) suspected systemic infection < 4 weeks	31/44 (70.4%) trigger threshold not reached. Significant higher aortic contrast via peripheral catheter
Herts (2001) [30]	174 vs 51 peripheral	RCT	117 port-type, 41 3L, 10 DL, 6 unknown	CVC: 1.5–2 mL/s, pressure cut-off 100 psi. Peripheral: 2.5–3 mL/s, pressure cut-off 300 psi	1 (0.6%) CVC no longer patent. 1 positive blood culture	Less contrast enhancement in thoracic aorta, pulmonary artery, liver in CVC group
Lozano (2012) [28]	78	PS	Power injectable PICC (4–6F, SL/DL)	Mean injection rate 4.13 ± 0.855 mL/s (range 3–5); pressure limit 300 psi	12/78 (15.4%) dislocation	–
Macht (2012) [26]	104	RS	Distal 16G lumen of Arrow multi-lumen (3L, 5L)	3L: 4.4 ± 0.5 mL/s; 200.7 ± 17.5 psi; 5L: 4.6 ± 0.6 mL/s; 194.5 ± 6.5 psi	No complications	–
Morden (2014) [29]	243 high rate vs. 138 rate increase	RS	CT-PICC (4–6F, SL/DL/3L)	Injection rates 2–5 mL/s. Pressure limit 300 psi	20/243 (8.2%) displaced vs. 3/138 (2.2%)	–
Sanelli (2004) [27]	104	PS	Arrow multi-lumen CVC (n = 89). Percutaneous sheaths IJV (n = 15)	3 mL/s (n = 15); 4 mL/s (n = 8); 4 mL/s (n = 79); 5 mL/s (n = 2). Pressure limit 300 psi; 5/43 pressure-limited (306–316 psi)	13/60 (21.7%) blood cultures positive during ICU course	–

Legend: CVC = central venous catheter, PS = prospective study, SL = single lumen, F = French, PICC = peripherally inserted central catheter, DL = double lumen, RS = retrospective study, TIVAP = totally implantable venous access port, RCT = randomized controlled trial, 3L = triple-lumen, G = gauge, 5L = quintuple-lumen, IJV = inferior jugular vein, ICU = intensive care unit

141; 2.1%) TIVAPs were removed due to suspected systemic infection within four weeks after power injection, which was confirmed with positive cultures in one case. Herts et al. randomized 225 patients, after reassessment because of inability to obtain access, in a central venous access group ($n = 174$) and a peripheral venous access group ($n = 51$). No significant differences in early, delayed, and late complications were found. In the central venous access group, one (1/174; 0.6%) patient reported that her device was no longer patent, while being successfully used for chemotherapy after contrast injection. In one (1/174; 0.6%) patient an infection was reported. Two studies implemented a strict safety protocol, in which they verified the correct position of the CVC in the superior vena cava (SVC) on scout view before contrast injection, checked for adequate blood return, and checked the patency of the catheter afterwards. They did not report complications relating to the injection using the CVC [26,27]. Although one of these studies reported 13/60 (21.7%) patients with positive blood cultures during admittance on the intensive care unit, they reported that this may not necessarily be due to the contrast injection using the CVC [27]. These thirteen patients received multiple drug therapies through the same CVC and the positive blood culture rate is consistent with previously published reports in literature [32,33]. Lozano et al. [28] evaluated the frequency of displacement of power injectable PICC (PIPICC) after contrast injection. Correct catheter position was defined as cephalic to or caudal to the right tracheobronchial angle. A total of 12/78 (15.4%) PIPICC tips changed in position after injection of contrast medium. Seven displaced toward the brachiocephalic veins. They found that PIPICCs positioned in the proximal SVC (cephalic to tracheobronchial angle) before contrast administration had a higher risk of displacement compared to catheters positioned in the distal SVC (caudal to tracheobronchial angle) before contrast administration (5/8 (62.5%) vs. 7/69 (10.1%)). Distal location in the SVC decreased this risk by 89% (RR 0.11 [CI 0.026-0.487], $p = 0.006$). Displacement of central catheters in non-central positions like the brachiocephalic vein is associated with an increased risk of thrombosis and the authors recommend checking the position of the CVC after power injection [34]. Morden et al. [29] evaluated a rate increase technique of the saline flush after contrast injection via CT-injectable PICCs (CT-PICC), in which they started with a saline flush at 2 mL/s and progressively increased to the rate of contrast injection. With this technique, they found a lower incidence of CT-PICC tip displacement (20/243 (8.2%) without rate increase technique vs. 3/138 (2.2%) with rate increase technique).

3.4. Data analysis – efficacy

Goltz et al. [25] found a significantly lower arterial contrast density in patients with TIVAPs compared with classic peripheral cannula, resulting in limited image quality. In 31/44 (70.4%) examinations, manual initialization was necessary, while initial arterial bolus tracking was performed, because the trigger threshold had not been reached in time. This might be the result of the lower flow rate of 1.5 mL/s through TIVAPs. Triggering with automatic scan initiation resulted in significantly higher contrast in the aorta compared to manual scan initiation (163 HU vs 144 HU, $p = 0.039$), concluding automatic scan initiation should be aimed at. In Herts et al., two reviewers who were blinded for route of injection measured the enhancement of the large vessels. The level of enhancement of the thoracic aorta, pulmonary artery, and liver vasculature was significantly less dense in the central venous access group compared to the peripheral venous access group [30]. No significant difference was seen in the enhancement of the abdominal aorta. In Coyle et al. CT images were assessed subjectively by the radiologist supervising the CT examination, which resulted in categorizing the quality of CT images as average in 81/110 (74%) of cases and above average in 23/110 (21%) of cases.

4. Discussion

The most reported complication of contrast injection through a CVC was rupture of the CVC, with incidences ranging from 0% to 1.8% due to mechanical obstructions. Late complications as suspected infection of CVCs were observed in 0.6% to 2.1% of cases. These suspected infections may very well not be the result of using the CVC for contrast injection, as the CVCs are frequently used for administration of other agents. The incidence of suspected infections did not differ from other previously reported incidences of catheter infections [32,33]. When assessing CVC displacement, the incidence ranged from 2.2% to 15.4%. Catheter displacement carries a higher risk for thrombosis of CVC [34]. None of the studies reported thrombosis, which may have been the result of following a strict protocol, including checking the localization of CVC before and after scanning. Catheter displacement can be reduced when saline is flushed with the rate increase technique [29].

Data on efficacy was inconsistent. Power injection via TIVAPs at a flow rate of 1.5 mL/s leads to inadequate arterial contrast density, which is mandatory if pulmonary embolism or liver metastasis are suspected [25]. Flowrates of 1.5 mL/s may be too slow for adequate aortic contrast density. Additionally, bolus tracking was not successful in 70.4% of the scans, with no good explanation why bolus tracking failed. Vascular enhancement of the pulmonary artery and thoracic aorta were inadequate when injecting through the Bardport and triple-lumen Hickman catheters as well [30]. One study reported satisfactory quality of scans [31]. This discrepancy may be explained by the difference in scoring of quality. The latter study subjectively reported quality of scans, with no mention of Hounsfield units measured [31]. This may indicate that while injection of contrast media via CVCs leads to decreased contrast enhancement, it does not necessarily result in diagnostic accuracy. The need for vascular enhancement (i.e. with pulmonary embolism) should be evaluated for determining whether or not to use CVCs as access for contrast media. On the other hand, all three studies' flowrates barely exceeded 3 mL/sec [25,30,31], in contrast to the other four studies who used median flowrates of 4 mL/sec [26–29]. The quality of scans when using higher flowrates remains underexposed.

The different types of CVC, warming of contrast media, injection rates, and pressure cut-offs limits us in making a generalized advice on the applicability of CVC for contrast injection. Patient-related factors need to be taken into consideration as well. Patient body size and cardiac output affect contrast enhancement [35]. Contrast enhancement will be lower in larger patients. Similarly, in patients with decreased cardiac output, the contrast material bolus arrival and clearance will be delayed, resulting in delayed but stronger peak arterial and parenchymal enhancement [35]. When timing is critical, a bolus-tracking technique should be used.

An important limitation of this review is the differing in types of CVC, contrast and injection rates used in the included studies. Another limitation is the possibility of publication bias in our original literature. However, we tried to reduce other limitations by using strict and pre-defined criteria for the inclusion of studies to be able to draw conclusions from available literature.

5. Conclusion

Contrast injection via CVCs is a safe alternative to peripheral injection if a strict protocol is followed. Implementing a safety protocol before power injecting via CVC is advisable. This safety protocol should include aspirating blood before injecting contrast media, localizing the CVC before and after injection, making sure no kinking of the CVC and attached lines occurs, using sterile syringes, and making sure the CVC is patent after scanning. The quality of scans varies and remains not sufficiently investigated in scans with higher flow rates.

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Conflict of interest

The authors declare no conflict of interest.

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