REVIEW ARTICLE

The use of central venous catheters for intravenous contrast injection for CT examinations

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ABSTRACT. The use of intravenous (iv) contrast media in CT examinations is often of great value in improving diagnostic accuracy. The preferable route of administration is via a peripheral iv cannula, with powered injectors allowing reliable delivery of rapid flow rates. However, many patients with a pre-existing central venous access device may have difficult peripheral access and there is a temptation to use the central device for delivery of contrast media. This review summarises the available evidence for the safe and effective use of these devices to assist the radiologist in balancing the relative risks and benefits of their use for contrast medium injection.

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CT examinations are commonly performed with the intravenous (iv) use of iodinated contrast media (CM), either as a fundamental part of the examination (e.g. CT angiography) or to improve soft-tissue contrast. Generally, peripheral iv access can be secured easily and safely for injection of CM via high-powered automated injectors. However, in certain patient groups, peripheral iv access is difficult and central access may be the only available route for contrast enhancement. Many emergency and critical care patients require CT examinations which would best be conducted after iv contrast. The use of existing central venous catheters (CVC) for CM injection is therefore a tempting alternative to potentially fruitless, or even damaging, attempts at peripheral access (such as with extensive burns, lymphoedema or to preserve potential sites for future arteriovenous fistula formation). The radiologist is best placed to weigh up the relative risks and benefits of using a CVC for power injection of CM, as they will have a clearer knowledge of the relative importance of contrast enhancement for accurate interpretation. They are also more likely to be familiar with the power-injector delivery devices in use in their department. This review summarises the current literature regarding the safety and potential complications of using the central venous route for CM injections. The aim is to help quantify the risks so that a reasoned decision about whether to proceed with the lines can be made by the radiologist in conjunction with the clinicians caring for the patient.

Search strategy and literature review

A search of MEDLINE, Embase, the Cochrane library, Web of Science and Scopus was performed using the exploded medical subject headings (MeSH) terms “central venous catheter” AND “contrast media”. A free text search

for central catheter* AND contrast AND ((computed AND tomography) OR (“tomography, X-ray computed” in MeSH)) was also performed. The abstracts were reviewed for relevance and the references followed up.

Types of central venous catheter

Central catheters can be divided into non-tunnelled, tunnelled, dialysis/apheresis lines (which themselves may be tunnelled or non-tunnelled), implanted ports and peripherally inserted central catheters (PICC). A vast range of different catheters are available in single- and multi-lumen combinations, each with their own flow and resistance characteristics. The most common use, in a general acute hospital setting, is intensive care unit patients with a non-tunnelled CVC for the delivery of drugs and fluids, central venous pressure monitoring and venous sampling. Units with a large haematology or oncology practice are likely to encounter large numbers of patients with tunnelled lines, primarily for chemotherapy. Implanted ports are also used in this situation and are frequently seen in paediatric practice for intermittent use, such as antibiotic administration in cystic fibrosis. Many manufacturers now recognise that CT power injection is an increasingly common requirement for CVCs and power injector-capable catheters and ports from the major manufacturers are appearing on the market [1–4]. However, until these newer, highly resilient catheters become routinely inserted, non-power injector-rated CVCs are likely to be encountered in the majority of cases, and the temptation to use them for CM injection will remain. Most power injectors allow specification of a maximum injection pressure as well as a flow rate, theoretically reducing the risk of catheter damage.

Current practice and recommendations

It is unclear how widespread the practice of CM injection via CVCs is. A survey of 12 randomly selected

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radiology departments in North West England has shown that there is a considerable variability in practice (Table 1). There are no published UK recommendations for the use of CVCs for this indication. The British Committee for Standards in Haematology Guidelines [5] for the management of CVCs in adults does cover this issue. In 2004, the Medicines and Healthcare Products Regulatory Agency (MHRA) issued a device alert suggesting injection at a maximum rate of 2 ml s^{-1} and a pressure limit below the manufacturer's recommended maximum [6]. This alert has subsequently been withdrawn, apparently owing to the availability of power-injector capable CVCs, although the validity of the alert for other types of CVC remains (MHRA, personal communication, July 2009). The Northern Ireland Adverse Incident Centre has also issued a medical device or equipment alert that remains active with regard to this issue (essentially identical to the MHRA alert) [7], but this takes a blanket approach to all lines and all patient groups, and it is unclear on what evidence their suggestions are based. Similarly, the USA Food and Drug Administration (FDA) has issued its own recommendations for CVC use for power injection, but these simply state that the manufacturers' recommendations are to be followed and do not review the available evidence [8]. Therefore, most hospitals are left to devise their own guidelines, which may contribute to variability in use of these devices for contrast injection.

Risks of incorrect use

There are many examples of damage to CVCs from the pressures generated by power injection. The FDA has received reports of catheter rupture, leading to extravasation of contrast and loss of vascular access, or even fragmentation and embolisation, which has led to the need for the subsequent surgical removal [8]. Catheter obstruction and the late non-function are also reported, occasionally leading to the loss of access for drug administration including inotropic support [7]. Furthermore, there are reports of adverse patient outcomes unrelated to failure of the catheter, but with mediastinal contrast extravasation

[9], mediastinal haematoma and cardiac arrhythmia reported as risks [10]. A particular problem with tunnelled lines is that the site of damage may be in the portion of the line that lies in the subcutaneous tunnel and therefore invisible to the naked eye [7]. Furthermore, catheters may weaken without any external signs of damage, shortening their lifespan and potentially leading to late rupture [8]. Older catheters may be at increased risk and the MHRA recommends particular caution should be exercised with catheters over 3 months old [7]. Figure 1 shows an example of the damage that can occur to a CVC after power injection.

Nevertheless, despite these reports, it is important to remember that the majority of these complications are relatively minor and the only intervention needed is catheter replacement owing to non-functioning. In the majority of cases, this should be straightforward; however, in a minority of patients vascular access options may be limited (*e.g.* long-standing haemodialysis) and loss of a functioning CVC may be more problematic.

Manufacturer recommendations

Owing to the vast range of different catheters available exhaustive data on the pressure ratings of different CVCs are not easily collated. Furthermore, devices are frequently altered and the current technical specifications presented here may not correspond to those in use at any particular institution. However, to illustrate the general point, details of several commonly used non-tunnelled devices that may be encountered in a typical intensive care unit or emergency department are presented in Table 2.

Devices specifically designed for power-injection are also available [1–4], which are generally rated for pressures of 300 psi and flow-rates of up to 10 ml s^{-1} . These more pressure-resilient devices are easily identified by their external labelling. In the case of implanted ports, where there may be no external clue to the internal structure of the particular port that has been implanted, these can sometimes be identified by a particular shape, palpation guides or the presence of a radio-opaque label

Table 1. Use of central venous catheters (CVC) for contrast media injections in 12 radiology departments in the North West of England

Department	Use CVC?	How is it used?	Departmental guidelines?
1	Yes	Following Medicines and Healthcare Products Regulatory Agency guidance, with a 50 psi pressure limit on the injector	Yes
2	Yes	Reduced rate to 2.5 ml s^{-1} , doctor connects, no pressure limit, line is flushed first	No
3	Yes	Reduced rate to 2 ml s^{-1} , doctor connects, no guideline for line checking	No
4	Yes	Reduced rate to 2 ml s^{-1} , doctor connects, no guideline for line checking	No
5	Yes	Reduced rate to 2 ml s^{-1} , doctor connects, no guideline for line checking	No
6	Yes	Normal protocol (occasionally reduced injection rate at radiologist preference), ward nurse connects and checks line	No
7	Yes	Hand inject only	Yes
8	Yes	Hand inject only	Yes
9	No	In the process of developing a formal policy	Work in progress
10	No	N/A	N/A
11	No	N/A	N/A
12	No	N/A	N/A

Figure 1. An example of “ballooning” from over-pressurisation of a multilumen central venous catheter. The proximal damaged lumen (white arrow) has substantially dilated when compared with the normal lumina (black arrow). Image courtesy of Dr Ravindra Kumar, Specialist Registrar in anaesthetics and intensive care.

on the port itself [3]. Of note is the use of power injector-capable ports, which necessitate the use of special power-rated infusion sets to access the port and allow connection to the power injector itself.

Interestingly, although the pressure tolerances (10–50 psi) of the catheters would suggest power injection may not be feasible at all (some power injectors have a lowest possible pressure limit of 50 psi), in reality there are several complicating factors. Firstly, the pressure rating given by the manufacturer relates to the pressure within the catheter itself, whereas the pressure limiter on the power injectors measures the pressure at the injector, which may be considerably higher. For example, *in vitro* experiments have shown that the pressure at the junction between the power injector and the connection tubing may be five times higher than the pressure in the CVC itself [13]. Secondly, these pressure ratings are often considerably lower than the actual pressure that the catheter can tolerate, and are tested to tolerate in quality assurance programmes [14]. Recent *in vitro* testing of a sample of 42 catheters rated to only 15 psi by the manufacturer showed the lowest pressure at failure was 213 psi, with one CVC tolerating a pressure of 320 psi before failure [15]. Thirdly, a body of published work has shown that higher pressures can be used with certain catheters with very low complication rates (discussed later).

Evidence for the safe use of CVCs for power injection of CM

Substantial amounts of *in vitro* data are available for various types of CVCs, although the direct relevance to the *in vivo* situation is unclear. Clearly, *in vivo* data are substantially more relevant for the practising clinician. Evidence for the use of CVCs for CT contrast enhancement is available for many types of line, including PICCs, non-tunnelled CVCs and implanted ports, in both adults and children. Table 3 summarises the relevant *in vivo* literature [10, 16–20].

A striking finding is the relative paucity of data available. It is clear, from the fact that substantial numbers of adverse incidents related to power injection via CVCs are recorded, that this practice must be relatively widespread. By July 2004, the USA FDA had received over 250 reports of adverse incidents relating to power injection via CVCs [8]. Nevertheless, this must be balanced against the vast numbers of CT examinations occurring per annum in the USA, estimated at 27 million in 2007 [21], although the percentage in which contrast is injected via a CVC is unknown. The authors of the many of the papers outlined in Table 3 point out that they followed strict protocols during their use of CVCs for power injection, and that their findings may not be generally applicable without the same strict precautions being taken. It is interesting to note that the pressure limits specified were often in excess of the manufacturers' recommended maxima. Use of CVCs in the published *in vivo* work has generally been preceded by either *in vitro* preparatory experiments or research into the manufacturers' specified pressure limits with the resultant modification of the CT injection protocols. This may not be the case in all departments that currently use CVCs for power injection and there is, therefore, some difficulty in generalising these data to the wider clinical population. Nevertheless, the fact that these data do exist demonstrates that, within well-controlled circumstances, it is feasible to power inject and achieve adequate contrast enhancement in a safe manner. A pooled estimate of all the data for power injection available from Table 3 shows there are a total of 6 adverse events from 858 cases, a crude event rate of 0.7%.

Is hand injection a reasonable alternative?

Hand injection of contrast via a CVC has been suggested as an alternative method of administration. This is an attractive option as the intuitive impression is

Table 2. Details of some commonly used non-tunnelled devices

Manufacturer	Power-injector rated CVC available?	Rated maximum pressure for other CVC	Reference
Arrow	Yes	15 psi or hand injections with a larger than 10 ml syringe	Arrow website [11]
Bard	Yes	25–40 psi depending on the catheter	Bard website [12]
Cook	Yes	Varies with the catheter, generally 20–50 psi	Cook product material
VYGON	No	21.7 psi (1 bar) for the commonly used MultiCath	Instructions for use of the device

CVC, central venous catheter.

Table 3. Trials reporting outcomes for the use of central venous catheters (CVC) for contrast media injection *in vivo*

Reference	Study type	Patient population	Devices used	Tip localisation	Flow rate	Pressure limit	Outcome
Herts [16]	Randomised controlled trial	109 adult examinations	Implanted ports and non-tunnelled CVC	Aspiration and flushing	1.5–2.5 ml s ⁻¹	100 psi	1 equivocal episode of temporary catheter blockage
Sanelli [17]	Prospective	104 adult examinations	Arrow-Howes multilumen non-tunnelled CVC	Scout and axial pre-contrast CT followed by aspiration and flushing (usually)	3.0–5.0 ml s ⁻¹	306–316 psi	No complications related to power injection
Coyle [18]	Prospective	110 adult examinations	Single and dual lumen PICC	Flushing (usually)	90% at 2.0 ml s ⁻¹	120 psi	2 ruptures (operator error) 1 ballooning without rupture
Rigsby [19]	Prospective	63 children (250 cases referred to in text)	PICC, implanted ports and tunnelled CVC	Aspiration and flushing	2.0 ml s ⁻¹	25 psi	No ruptures
Kaste [20]	Retrospective	285 children	Implanted ports and tunnelled CVC	Aspiration and flushing	0.3–0.8 ml s ⁻¹	300 psi	1 tunnelled CVC split 1 PICC connector damaged
Donnelly [21]	Retrospective	1440 children	Unclear	Flushing	Hand injection	Hand injection	4 ruptures

PICC, peripherally inserted central catheters.

that the pressures generated will be insufficient to damage the line. Furthermore, outside the radiology department, lines are routinely accessed, flushed and administer drugs using hand injection. Therefore, it is assumed that this could be extended to use within the department for CM. There are several disadvantages to hand injection. It is difficult to reliably deliver a set volume of contrast in a particular time, making it problematic for the radiographer to commence scan acquisition in a particular phase of contrast enhancement. A reliable, consistent column of contrast medium cannot be easily achieved, and examinations that rely on this (*e.g.* CT angiography) are likely to yield inconsistent results. The assumption that line damage is unlikely to occur with hand injection may be erroneous. Hand injection, particularly when using small syringes, can generate high pressures, and in one *in vitro* study the pressures generated for equivalent flow rates were higher for hand injection than for power injection [13]. With power injectors a pressure limit can be specified, and therefore controlled, but the pressures being generated by hand injection are unknown, and cannot be limited. Catheter damage in relation to hand injection has also been documented *in vivo* [20]. These disadvantages, in combination with the question of whether or not hand injection is safer than a pressure-limited power injection, suggest that this practice should be treated with caution.

A possible protocol for CVC use with power injectors

Given the findings of the literature above and the numbers of reports of damage to CVCs from power injection, one possible solution would be to prohibit use of all CVCs for contrast power injection, unless specifically rated as power-injector capable. However, this would seem to be excessively conservative given the fact that safe use with a low event rate has been demonstrated in the work outlined above. One possible protocol is outlined in Figure 2.

Perhaps the most important step is to consult with the clinician and determine how important a contrast-enhanced CT is to their patient management. If contrast enhancement is mandatory, then under most circumstances it should be possible to reduce the injection flow rate (2.0 ml s⁻¹ is a commonly used rate and recommended by the MHRA) with only minor compromise to the diagnostic image quality. If a higher flow rate is required, then either a higher risk of CVC damage must be accepted or a reduction in the quality of the scan should be expected. This may be sufficient for the exclusion of gross pathology (*e.g.* a large central pulmonary embolus (PE) rather than a subsegmental PE). The maximum pressure limit on the power injector should also be reduced; 100–150 psi is used in our department. At all times, it should be realised that the absolute risk of an adverse event is small, and this can be stated to the clinician. In many circumstances, it may appropriate to accept this risk and proceed with a standard rate of injection.

In practical terms, it is important to ensure that the catheter lies within the venous system. Successful low-resistance flushing of the line alone is not sufficient to confirm intravascular placement, as a catheter that has

*Assuming a standard, rather than power-injector capable CVC is in place

**If there is any doubt at this stage, consider unenhanced axial slices through the line tip to confirm intravascular location

Figure 2. A possible protocol for clinical use of central venous catheter (CVC) for contrast injection. CXR, chest radiograph.

perforated the vessel wall and lies extraluminally can still often be easily flushed [22]. Successful aspiration of blood from the line makes intravascular placement substantially more likely, but even this is not infallible. Placement of the tip within a bloody collection, such as a haemothorax, can allow aspiration of blood, which mimics the intravascular location [23]. Furthermore, the line may be intravascular but have been placed or migrated in an inappropriate vessel (e.g. cranial misdirection of a subclavian CVC into the upper jugular vein). These tests should be performed with the patient's arms in the position that they will be located in for the duration of the scan (often above the head for body imaging, if the patient is able to do so), because subclavian lines in particular may move with arm abduction [24]. At all times, the person handling the line should have received appropriate training to minimise the risk of introducing infection.

The vast majority of patients will have had a recent chest radiograph, which can be used to confirm line position. The radiograph can also be used to look for signs of impending erosion through the vessel, particularly the superior vena cava (SVC). A curve at the end of the CVC is highly suggestive of impending perforation and should prompt catheter repositioning [25]. Such a line should, therefore, not be used for contrast injection. If no recent chest radiograph is available, one solution is to obtain a CT topogram that covers the CVC. This image is analogous to a chest radiograph and can be used to help determine line position. If there is any residual doubt after these methods (line aspiration/flushing and chest radiograph/topogram, a very rare situation in practice, unenhanced axial CT slices through the line tip can be used to definitively confirm the position of the distal lumen.

If a multilumen CVC is in place, the distal lumen should be used unless it is so narrow that acceptable flow

rates cannot be achieved. Although this may be somewhat counterintuitive (this is the longest lumen, and therefore by Poiseuille's equation a given flow rate will require a greater pressure), for several reasons. Firstly, this lumen will be located at the tip of the line and therefore it is the only lumen whose position can be demonstrated directly by the chest radiograph. Unless it is known exactly how proximal to the line tip the other luminal openings are located, their positions cannot be determined with certainty. Secondly, this is commonly the largest calibre lumen, with the increase in radius often outweighing the increase in length in terms of maximum flow rates. Thirdly, and most importantly, the risk of catheter damage is felt to be lower when using the distal lumen of a multilumen CVC [24], perhaps because the side-facing lumen may lie directly against the vessel wall and the subsequent jet of turbulent contrast medium may damage the vein.

It is not clear what the medicolegal position is regarding any adverse events that occur if a CVC is used at a pressure rating above the manufacturer rated maximum. We are not aware of any medicolegal claims or complaints specifically regarding this issue. Given that the MHRA advice makes no reference to pressure limits, and that departments would otherwise be likely to use a standard pressure setting (usually 300 psi), adopting the protocol suggested here is likely to reduce the pressure that the CVC is exposed to. Use of a device in a fashion beyond that recommended by the manufacturer (*i.e.* "off-label" use) is generally to be avoided where possible. However, if there is no suitable alternative then the MHRA recommends that an appropriate risk assessment should be undertaken and regularly reviewed, ethical and legal implications should be considered, the risk minimised as far as possible and patient consent obtained [26]. The literature presented in this review should therefore help departments to perform a balanced judgement of whether or not CVC use is clinically and medicolegally justifiable in any particular situation and to minimise patient risk by modifying injector protocols. As long as this is communicated effectively to the clinician and patient involved then we would suggest that this is an appropriate practice.

Conclusion

CVCs are commonly used vascular access devices and have multiple uses. In patients where peripheral access is difficult or impossible, the use of these lines for power injection of CM is feasible and safe as long as certain precautions are taken. There is approximately a 1% risk of adverse events, the majority of which are minor, lead to no patient harm and only require catheter replacement to rectify. In the majority of cases, replacement can be achieved relatively easily, although there is a minority in whom this can be more problematic. Following discussion with the clinical team, the radiologist is best placed to weigh up the risks and benefits between the (modest) risk of CVC damage and the risk of failing to obtain a diagnostic quality scan (with the associated detriment to clinical decision-making regarding patient management). Knowledge of the risks of CVC use for this application is vital to allow an informed decision to be

made such that the best possible patient outcome can be obtained.

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