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Review Article

Diagnostic Performance and Radiation Dose Estimates in Follow-up Imaging of Endovascular Aneurysm Repair using Dual-Energy Computed Tomography Protocol: A Narrative Review

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Abstract

Purpose: This review aims to evaluate diagnostic performance of dual-energy computed tomography (DECT) in follow-up examinations after endovascular aneurysm repair (EVAR) and its radiation dose estimates compared to the standard triphasic protocol.

Materials and methods: A systematic search was conducted. Articles were screened against the inclusion and exclusion criteria. A narrative review of the literature was performed. A summary statistic table of the calculated mean effective dose, percentages in dose reduction and diagnostic performance of DECT were pooled.

Results: Data from the DECT acquisitions suggested a 98-100% overall accuracy for detecting type I and II endoleaks. The effective dose delivered in the DECT protocol was approximately 61% lower than that delivered to patients by the standard triphasic protocol.

Conclusion: A DECT protocol can replace the standard triphasic protocol in follow-up imaging after EVAR for detecting type I and II endoleaks. This acquisition protocol also significantly reduces the effective dose to the patients.

Keywords: Diagnostic Performance; Radiation Dose; EVAR; Endovascular Aneurysm

Introduction

Since the introduction of endovascular aneurysm repair (EVAR) by Parodi and his colleagues in 1991, this treatment has become widely accepted for thoracic and abdominal aortic aneurysms. It is also a more viable alternative to open surgical repair with significant reductions in complications and mortality [1,2]. Nevertheless, after this procedure, continuous imaging surveillance is required to evaluate for potential complications such as occlusion, stent migration, arteriovenous fistula formation and endoleaks [3,4]. It is important to note that endoleaks are the most common acute and delayed complication after EVAR which occurs in up to 45% of all patients [5,6]. As this complication might cause an enlargement of the aneurysm and hence exacerbate the rupture risk, early detection and treatment are essential [7]. Multiple imaging techniques have been proposed and utilized for the detection and classification of endoleaks for the surveillance of patients who have undergone EVAR. These include computed tomography (CT), magnetic resonance imaging and ultrasonography [8].. Contrast-enhanced CT is the modality of choice [9]. (Endoleak detection using CT is simply assessing a peri-graft flow that reflects the flow of contrast out of the stent-graft and into the aneurysmal sec [10]. The optimal contrast-enhanced CT imaging protocol, however, is still in discussion. The literature has suggested that triphasic protocol is most commonly used, including a non-contrast phase, an arterial phase during contrast administration and a delayed phase to optimize the detection of endoleaks [11,12]. Although this protocol is efficient, after EVAR, patients are required to attend indefinite follow-ups and are exposed to substantial accumulative radiation dose and hence, increased lifelong risk of developing cancers [13]. Therefore, considerable effort and research have been made to examine the possibility of decreasing CT acquisition phases without compromising diagnostic performance of the scan [9]. As such, a study by [14], has reported a comparable diagnostic accuracy for endoleak detection by merely using the non-contrast and delayed phases and ultimately suggested an elimination of the arterial phase.

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In the past decade, the use of dual-energy CT (DECT) has been profoundly investigated and represents a promising advantage in this field. With DECT, it is possible to simultaneously acquire CT data with two different photon energy levels (typically at 80 and 140 kVp), resulting in different degrees of x-ray attenuation, measured in House field units (HU) [15]. As a result, the difference in energy spectra allows the software to characterize iodine, calcium and other materials at low and high photon energies

[16,17]. DECT has therefore been proposed as a preferable CT technique because it has potential clinical implications in follow-up imaging of patients after EVAR. The acquisition of dual-energy data enables the generation of virtual non-contrast data which might remove the need for a routine acquisition of true non-contrast phase [18,16]. In effect, the use of this approach could reduce the radiation burden to patients. To date, there has been no literature review on the use of DECT protocol in patients undergoing follow-up examinations after EVAR, especially with the radiation dose associated with this protocol and the diagnostic accuracy of this protocol compared to the standard triphasic protocol.

Objectives

The purpose of this literature review is to evaluate the following hypothesis and research questions:

DECT protocol can replace the standard triphasic protocol in patients undergoing follow-up examinations after EVAR.

Research question 1

Does DECT protocol provide a significant dose reduction relative to the standard triphasic protocol for these patients?

Research question 2

What is the diagnostic accuracy of DECT protocol in follow-up examinations after EVAR, and how does its diagnostic accuracy compare the standard triphasic protocol?

Methods and Materials

Selection criteria

A systematic search was conducted on 20th May 2018 on the following databases: MEDLINE, PubMed, and Scopus. Terms within each group were combined using "OR" and each group of search terms were combined using "AND" (Table 1). The number of hits for each database is outlined in Table 2. At the completion of the database searches, results were pooled, and all duplicates were removed.

Search strategy

The inclusion criteria were:

- The study:Was published between 2006 and 2018. This is because DECT technology was introduced in 2006.
- Was original and peer-reviewed.
- Reported quantitative measurements of the diagnostic accuracy of DECT in imaging follow-up of TEVAR.

The exclusion criteria were:

The study:

- Was published in languages other than English.
- Was conducted on non-human participants.
- Was a narrative review.

The rationale of excluding articles published prior to 2006 is because DECT technology was introduced in 2006 [16]. The titles and abstracts of the original articles were initially screened. Abstracts that were found to match the inclusion criteria were obtained in full text to confirm their suitability for inclusion. Articles not matching the eligibility were then excluded. All articles meeting the above eligibility criteria were then included in the literature review.

Results of the Literature Search

The literature search yielded 25 potential relevant articles which were exported to EndNote X6 reference management tool (Thomson Reuters, New York City, USA). After the removal of duplicates, eight articles remained. Screening of abstracts and titles resulted in the exclusion of one article. Screening of the full texts of the remaining articles led to the exclusion of a further two articles. A summary of the search and screening process is provided in Figure 1.

Results

This literature review identified five original studies assessing the potential radiation dose reduction in using a DECT protocol and reporting the diagnostic accuracy of this protocol in follow-up imaging after EVAR compared to standard triphasic protocol [19,18,20-22,20]. However, only compare diagnostic performance and radiation dose between the DECT protocol and the biphasic protocol (no arterial phase was performed).

Table 1: Search terms for systematic review.

Search string	Search number	Search term	Search type	Search conditions
	1	Dual-energy computed tomography OR DECT	MeSH Major Topic	Focus
	2	Diagnostic performance	Mesh Heading	Focus
	3	Accuracy	Keyword	
	4 5 6	Radiation Dose 2 OR 3 OR 4 OR 5		
	7 8 9	Endovascular aneurysm repair EVAR 8 OR 9	Keyword	

Legend: * = wildcard, searching for all suffixes of the specified term; OR = results must include either of the terms connected by OR; AND = results must include all the terms connected by AND.

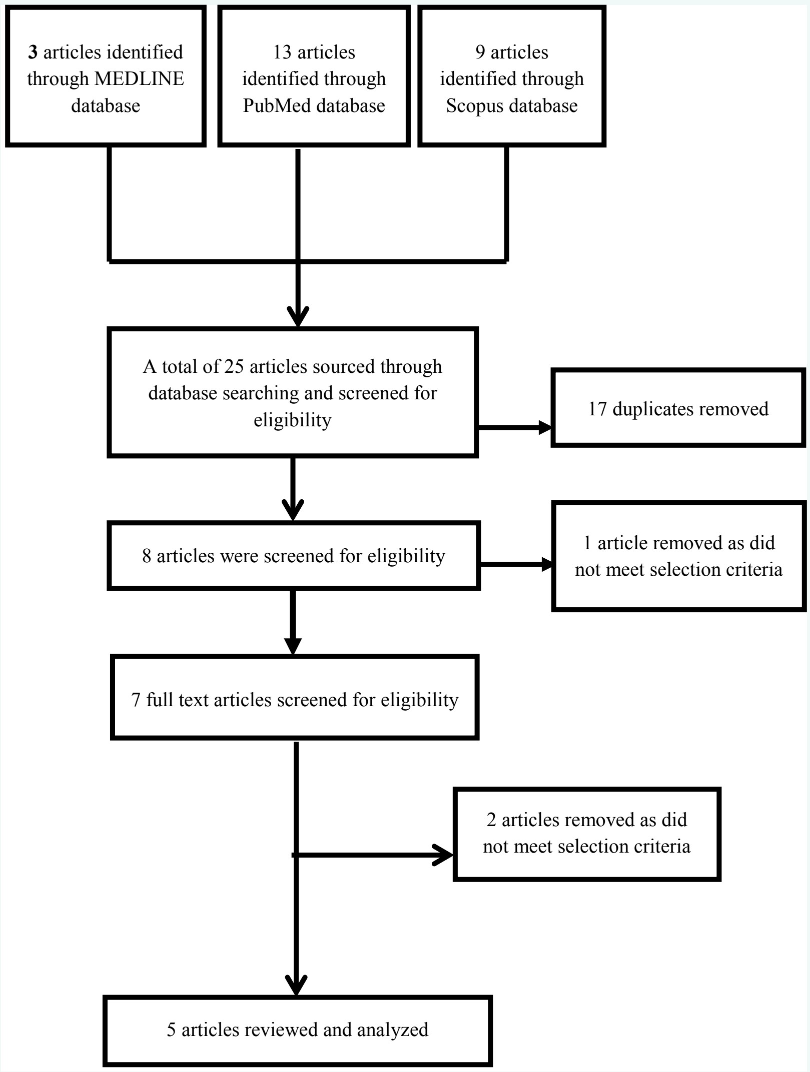

Figure 1 Modified PRISMA Flow diagram (Moher et al. 2015).

CT Acquisition protocol

All examinations in five studies were performed using a dual-source DECT scanner (Somatom Definition, Siemens Medical Solutions) [19,18,20-22]. A triphasic protocol was performed and comprised of a non-contrast, an arterial and a delayed phase. Besides the delayed phase being acquired in the dual-energy mode, other phases were performed using the single-energy mode. The dual-energy delayed phase was acquired 300-seconds post-contrast injection because the timing has been reported to be optimal for the detection and classification of low-flow endoleaks (which is often missed during the arterial phase [15,12]. The area of coverage was the same as the coverage range for the non-contrast acquisition.

Radiation dose estimates

Due to a frequency of complications after EVAR, patients need a lifelong follow-up imaging which is undertaken every 1-3 months after the procedure and every 6-12 months if the aneurysm is stable or decreases in size. As a result, to decrease the radiation dose to patients having surveillance scans, the number of acquisitions can be reduced [14]. For each of the CT acquisitions, patient effective dose (ED) (mSv) was calculated from the dose-length products (mGv x cm) recorded from the CT console. A normalized conversion factor (k) for the chest or abdomen was used to calculate ED (k was 0.014 and 0.017 mSv/mGy x cm, respectively) [15]. The calculated mean ED and percentages in dose reduction was pooled from five studies (see Table 3).

The use of the DECT protocol resulted in a reduction in radiation exposure of 61-64.1% compared with the exposure from standard triphasic acquisition [19,18,21,22]. The study by [20] only examined the dose differences between the DECT protocol and the biphasic protocol (no arterial phase was performed) which resulted in a reduction of 28% in dose. This is particularly important in patients after EVAR as they will undergo lifelong follow-up imaging examinations.

Table 2: Results for each database searched.

Databases	Search field(s)	Number of publications (Hits)
MEDLINE	All fields	6
PubMed	Keyword	13
Scopus	All fields	9

Table 3: Mean radiation dose for the DECT protocol versus the triphasic protocol.

	DECT protocol (mSv)	Triphasic protocol (mSv)	Dose reduction (%)
Chandarana et al., 2008	11.1	27.8	61
Flors et al., 2013	9.8±3.2	22.4±6.5	64.1
Ascenti et al., 2011	7.27	10.08*	28
Stolzmann et al., 2008	10.9	27.4	61
Buffa et al., 2014	10.5±1.8	27.4±2.6	61.7

*This study compared the DECT with a biphasic protocol.

As stated previously, imaging during arterial phase is not essential in diagnosing endoleaks [12]. However, if imaging is performed immediately after EVAR, arterial phase is required to evaluate arterial injuries such as arteriovenous fistulas and pseudoaneurysms [19]. True non-contrast CT images may also be beneficial after stent deployment for assessing type IV endoleaks. This is because the isolated contrast material in type IV endoleaks could be eliminated on virtual non-contrast CT images [12]. Therefore, the use of a triphasic protocol is still critical for immediate imaging after EVAR, but DECT protocol should be then utilized in follow-up examinations to reduce the patient's radiation burden [12].

studies have confirmed that DECT protocol has a potential to replace the standard protocol in follow-up imaging after EVAR with 98-100% overall accuracy for the detection of type I and II endoleaks (see Table 4).

In-line with the literature [19,21] also reported results comparing between DECT protocol and biphasic protocol (non-contrast and delayed phases) and demonstrated that eliminating the arterial phase does not significantly decrease the diagnostic accuracy [12].

Limitations

There were some limitations found in these studies. First, each study examined a relatively small number of participants/ patients (n=24, 48, 74, 118, 148 respectively) [19,18,20-22]. However, all studies have significantly demonstrated that true non-contrast CT may not be necessary for the surveillance of patients after EVAR. Secondly, only type I and II endoleaks were included in all studies. Therefore, it is not possible to assess the diagnostic performance of DECT in detecting type III, IV or V endoleaks. However, these classifications are rarely observed [21,23]. It is also important to note that due to the inherent limitation in the DECT scanner, authors noticed a minimal over-subtraction of the calcification in the virtual non-contrast images compared to the calcification subtraction in the true non-contrast images [19,24]. This could potentially result in a false-positive diagnosis of endoleaks. A larger population might be able to demonstrate this downside of DECT.

Conclusion

In summary, a virtual non-contrast and delayed phase dataset reconstructed from a single DECT acquisition can replace the standard triphasic protocol in follow-up imaging after EVAR for the detection of type I and II endoleaks. Further technical refinements and studies with larger population are required to accurately validate the diagnostic performance of this application. This protocol also significantly reduces the effective dose to the patients.

Table 4: Diagnostic accuracy for the detection of type I and II endoleaks.

	Sensitivity (%)	Specificity (%)	Negative-predictive value(%)	Positive-predictive value(%)	Accuracy (%)
Chandarana et al., 2008	100	100			100
Flors et al., 2013	100	100	100	100	100
Ascenti et al., 2011	100	100	100	100	100
Stolzmann et al., 2008	100	97	100	96	98
Buffa et al., 2014					100

Diagnostic Performance

Five studies tested the feasibility of a single-phase DECT protocol for endoleak detection using a dual-energy mode during a delayed phase, without reducing diagnostic accuracy [19,18,20-22]. The inter-rater agreement in the detection of endoleaks was approximately 100% between the standard and DECT protocols among all studies. Virtual non-contrast images were enough to determine whether the high-attenuating material within the aneurysm was a calcified thrombus or an endoleak. All endoleaks were depicted during the delayed phase [19,18,20-22]. All

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