Endoleak detection after endovascular aortic aneurysm repair utilizing dynamic, time-resolved computed tomography angiography

Ph.D. Thesis (short version)

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1. Introduction:

The widespread use of endovascular aortic aneurysm repair (EVAR) has become apparent in the past decades. The favorable perioperative mortality rate and the totally percutaneous nature of the procedure were the main driving factors of its success. However, major trials focusing on the long-term outcome of EVAR reported higher re-intervention rate with EVAR few years after the index procedure as compared to open repair. It is evident that as the number of EVARs grew over the years, a subsequent rise in the number of graft-related complications occurred. Thus, it was pertinent to adequately address the sequela of EVAR by utilizing advanced imaging techniques, such as dynamic, time-resolved computed tomography angiography (d-CTA) imaging. This imaging modality overcomes the limitation of having just two acquisition (time) points (early and delayed phase) after contrast injection. D-CTA involves multiple (~10-12) scan acquisitions after contrast injection enabling aneurysm sac imaging during the transit of contrast material across multiple time points Having multiple scans along the contrast enhancement curve opens up a plethora of new aspects in characterizing endoleaks based on objective parameters such as temporal Hounsfield unit change (quantitative analysis).

2. Objectives:

After developing our dynamic CTA protocol for endoleak detection in patients who underwent EVAR, our first objective **(1)** was to explore if d-CTA has better endoleak type diagnosing capability compared to triphasic computed tomography angiography (t-CTA) when using DSA as baseline reference. In addition to determining endoleak type, our second aim **(2)** was to compare the radiation exposure during image acquisition with the two CT modalities. Our third objective **(3)** was to match d-CTA, t-CTA, and DSA in detecting the number of inflow vessels in patients diagnosed with type II endoleak. Time-resolved CTA acquisition opens up a plethora of new aspects to characterize endoleaks based on objective/quantitative parameters. After developing our quantitative image analysis protocol, our fourth objective **(4)** was to demonstrate the feasibility of a quantitative parameter aiding the differential diagnosis of endoleak types. In this study, similar to our third objective, **(5)** we matched d-CTA and DSA in detecting the number of inflow vessels in patients diagnosed with type II endoleak.

3. Methods:

3.1. Study I - Comparison of standard and dynamic computed tomography angiography in endoleak diagnosis

In this retrospective review, a total of 52 patients underwent d-CTA image acquisition after EVAR between 2019 March and 2021 July at the Cardiovascular Surgery Department of Houston Methodist Hospital. Amongst them, we selected patients with available triphasic and dynamic CTA images who had DSA acquisition in order to visualize potential endoleaks after EVAR within a three-month period and no interim interventions.

3.1.1. Qualitative image review

For the expert review of CTA images, two senior vascular imaging specialists and for the DSA image review two senior vascular surgeons were involved in the analysis of the images. Presence of endoleak, type of endoleak, and, if deemed necessary, inflow/target vessels contributing to type II endoleak were also recorded. Discrepancy between reviewers was solved by consensus.

3.2. Study II - Quantitative approach to characterize endoleak types

In this retrospective review patients undergone d-CTA and DSA image acquisition after EVAR between 2019 March and 2021 January at the Cardiovascular Surgery Department of Houston Methodist Hospital were selected (24). Qualitative analysis was the same as in Study I.

3.2.1. Quantitative analysis

Quantitative endoleak analysis being a new concept- to aid endoleak differential diagnosis based on temporal Hounsfield unit change, we selected two different regions of interest (ROI) for analysis: (1, ROI_{aorta}) in the aorta at the level of the proximal graft and (2, $ROI_{endoleak}$) one inside the aneurysm sac where contrast enhancement was detected. Then the software generated the corresponding time attenuation curves (TAC) for each ROI. TAC has multiple quantitative parameters that can be used for analysis, we selected the relative time difference between ROI_{aorta} and $ROI_{endoleak}$ in reaching peak enhancement. Figure 1 demonstrates the quantitative image analysis of a time attenuation curve. Our practice focused on endoleak specific Δtime to peak values (ΔTTP) to highlight the difference in reaching peak enhancement between aorta and endoleak. In type II endoleak cases suspected target vessels can be selected for further analysis which can determine in- and outflow vessels contributing to the endoleak and aid future embolization. Quantitative analysis was performed using the dynamic CTA workflow of syngo.via (Syngo.via, VB30, Siemens Healthineers, Erlangen, Germany).

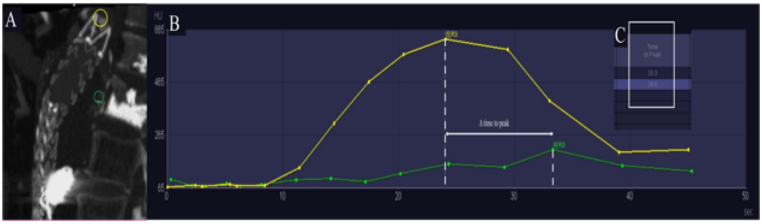


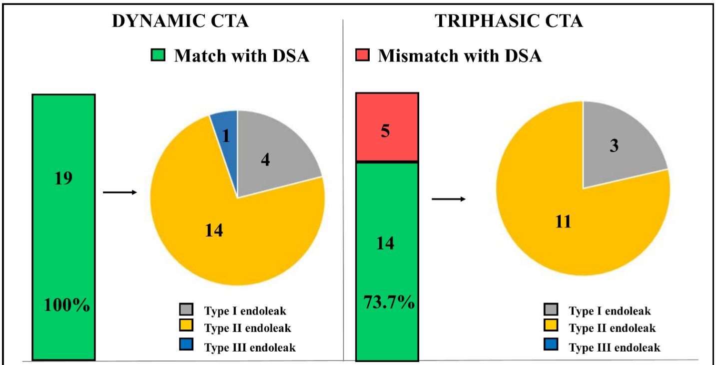
Figure 1. Example of a time attenuation curve analysis in a patient having a type II endoleak from a lumbar artery as inflow. (Fig. 1A) The selected region of interest (yellow above the stent-graft (ROI_{aorta}), green inside the aneurysm sac where endoleak is visualized ($ROI_{endoleak}$)). Fig. 1B demonstrates the generated time-attenuation curves for the selected ROIs in Fig. 1A. Time difference between aortic and endoleak curves in reaching peak Hounsfield unit is recorded (Δ time to peak value - marked with white) (ROI=region of interest).

4. Results:

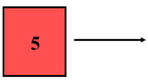
4.1. Study I - Comparison of standard and dynamic computed tomography angiography in endoleak diagnosis

From the 52 patients who underwent d-CTA acquisition in the study period, 19 met the criteria for selection. In this study population 15 out of 19 patients had conventional EVAR, 3 had fenestrated EVAR, and 1 had chimney EVAR. Mean (±Standard Deviation [SD]) age, serum creatinine, and body mass index (BMI) before image acquisition were 78.8 (±6.8) years, 97.3 (±26.5) μmol/L, and 25.8 (±5.8) m^2/kg, respectively.

D-CTA findings matched with DSA findings in 19 out of 19 cases (100%), while t-CTA findings matched 14/19 (73.7%). Figure 2 demonstrates the findings of the qualitative image review. Out of five patients who had a mismatch between t-CTA and DSA, two were discordant, and three were inconclusive for the type of endoleak.



Mismatched cases with DSA:



Case	Triphasic CTA	Dynamic CTA	DSA
1	Type Ia	Type II	Type II
2	No endoleak	Type II	Type II
3	Type Ia or III	Type Ia	Type Ia
4	Type Ia or III	Type IIIc	Type IIIc
5	Type Ib or II	Type II	Type II

Figure 2. Findings of the qualitative image review. Dynamic CTA was compared to triphasic CTA, and DSA was used as reference standard.

In 11 patients, where type II endoleak was confirmed, the number of target arteries identified by d-CTA, t-CTA, and DSA were 23, 17, and 16 respectively ($p=0.009$), and d-CTA identified more target vessels than t-CTA ($p=0.034$).

The mean (±SD) dose-length product (DLP) for d-CTA and t-CTA were 1445 (±550) and 1612 (±530) mGy*cm, respectively ($p=0.255$). Although the DLP values showed no significant difference, it is important to emphasize the differences in acquisition protocols. Dynamic scans were acquired at 80 (interquartile range 70-97.5) kV tube voltage with the scan field of view covering the implanted stent graft only (23-33 cm), while triphasic scans were acquired at 120 kV covering the entire abdomen from diaphragm to pelvis.

4.2. Study II - Quantitative approach to characterize endoleaks

From the 24 patients 3 underwent chimney-EVAR, 3 had FEVAR, and 18 underwent conventional EVAR.

Mean(±SD) age, serum creatinine before d-CTA imaging, and BMI were 78(±7.11) years, 99.9 (±31.0) μmol/L mg/dl, and 26.37 (±5.31) m^2/kg, respectively. The mean (±SD) dose-length product for d-CTA was 1038 (±533) mGy*cm for a total of 12 scans. Total iodinated contrast volume used for d-CTA was 77.1 (± 5.4) ml.

In 23/24 patients (95.8%), d-CTA findings correlated with DSA findings for endoleak type. In one patient, d-CTA demonstrated type III endoleak, whereas no evident endoleak was visible on DSA imaging (Table 1). This patient underwent an Ovation® (Endologix Inc., Irwine, USA) graft implantation and d-CTA imaging demonstrated the defect in one of the polymer sealing rings leading to type III endoleak, which was later relined. In the 16 cases of types II endoleak, d-CTA identified significantly more vessels (lumbar arteries) contributing to the endoleak as compared to DSA (33 vs 21, p=0.010).

Quantitative time-attenuation curve analysis was performed in 23/24 patients, while one patient in our study did not show any contrast enhancement in the aneurysm sac by d-CTA imaging. Amongst 23 patients, Δ TTP values (median, IQR) between ROI_{aorta} and $ROI_{endoleak}$ was 1.64 (0.26-3.17) seconds for type I (n=4), 10.45 (8-12) seconds for type II (n=16), and 5 (4.78-6.05) seconds for type III endoleak (n=3), respectively (p=0.002) (Figure 15). ΔTTP was significantly shorter for type I (p=0.003) and III (p=0.043) endoleaks as compared to type II endoleak.

Table 1 summarizes findings on endoleak types and inflow vessels based on qualitative image review of d-CTA and DSA imaging. In type II endoleak cases, d-CTA identified more feeding vessels than DSA imaging (33 vs 21 vessels, p=0.010).

Endoleak type	Diagnostic Imaging Modality (n=24)		Inflow vessels of endoleak	
	Dynamic CTA	DSA	Dynamic CTA	DSA
I	4	4	Ia seal zone (1), Ia gutter endoleak (3)	Ia (4)
II	16	16	**Lumbar a. (29)** RRA (1) IMA (3)	Lumbar a. (17) RRA (1) IMA (3)
III	**3**	2	Component separation, graft defect, **polymer sealing ring defect**	Component separation, graft defect
No endoleak	1	**2**		

5. Conclusion:

Study I – Comparison of standard and dynamic computed tomography angiography in endoleak diagnosis

Based on our findings we conclude that dynamic computed tomography angiography imaging has better endoleak diagnosing capability as compared to standard triphasic computed tomography angiography when DSA was used as the reference standard.

There was no significant difference reported in radiation exposure between triphasic and dynamic CTA acquisitions.

In type II endoleak cases dynamic CTA identified more inflow vessels contributing to the pathomechanism of the endoleak as compared to triphasic CTA or DSA.

Study II - Quantitative approach to characterize endoleak types

Utilizing multiple CT scans, quantitative parameters such as Δ time to peak value demonstrated feasibility in objective endoleak analysis and can aid the differential diagnosis of endoleak types.

In type II endoleak cases dynamic CTA identified more inflow vessels contributing to the pathomechanism of the endoleak than DSA.

6. Bibliography of the candidate's publications:

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