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Feasibility of low contrast media volume in CT angiography of the aorta

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Abstract

Objectives: Using smaller volumes of contrast media (CM) in CT angiography (CTA) is desirable in terms of cost reduction and prevention of contrast-induced nephropathy (CIN). The purpose was to evaluate the feasibility of low CM volume in CTA of the aorta.
Methods: 77 patients referred for CTA of the aorta were scanned using a standard MDCT protocol at 100 kV. A bolus of 50 ml CM (Iopromide 300 mg Iodine/ml) at a flow rate of 6 ml/s was applied (Iodine delivery rate IDR = 1.8 g/s; Iodine load 15 g) followed by a saline bolus of 40 ml at the same flow rate. Scan delay was determined by the test bolus method. Subjective image quality was assessed and contrast enhancement was measured at 10 anatomical levels of the aorta.
Results: Diagnostic quality images were obtained for all patients, reaching a mean overall contrast enhancement of 324 ± 28 HU. Mean attenuation was 350 ± 60 HU at the thoracic aorta and 315 ± 83 HU at the abdominal aorta.
Conclusions: A straightforward low volume CM protocol proved to be technically feasible and led to CTA examinations reaching diagnostic image quality of the aorta at 100 kV. Based on these findings, the use of a relatively small CM bolus can be incorporated into routine clinical imaging.

Keywords: Computed tomography; Angiography; Aorta; Contrast media

Key points

- A relatively small contrast media bolus leads to diagnostic quality thoracic-abdominal CTA.
- 100 kV settings are appropriate for CTA of the aorta.

1. Introduction

Computed tomography angiography (CTA) is currently the standard non-invasive imaging method used for the assessment of the aorta. This is mainly due to high image quality, fast acquisition and easy post processing. Indications for CTA are broad, including preoperative evaluation, imaging of aortic aneurysm, aortic dissection or planning for endovascular procedures (EVAR).

Several studies have been conducted concerning sufficient diagnostic luminal attenuation [1–3]. According to the results of those studies, minimal enhancement of vascular structures of diagnostic quality varies between 250 and 350 HU. To achieve optimal enhancement various factors have to be considered [4]: (1) scanner- and scan protocol-related factors, such as kV, tube current, pitch, gantry rotation, and timing of the scan (scan delay); especially in newest scan techniques such as high pitch scanning [5,6]. (2) Patient-related factors, such as weight, body mass index (BMI) and cardiac output, whose influence can be taken into account and compensated for in individualized protocols (e.g. weight-adapted CM protocols) [7–10]; (3) CM and CM administration parameters, which can be modified according to scan technique and patient characteristics.

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According to Bae et al. [4] the key parameters of CM are concentration, volume, physicochemistry (e.g. viscosity or temperature), injection duration and flow rate. Several studies indicate that the Iodine delivery rate (IDR = the amount of Iodine administered to a patient per second in gI/s) is one of the most important parameters for intravascular enhancement [11–13].

In recent years, CM volume reduction has consistently been in the center of research [14–18], with the goal to use CM more efficiently. Apart from faster scanning techniques, new scanner- and especially the latest detector technologies with use of lower kV protocols facilitate lower CM volume. With lower kV settings, contrast to noise ratio (CNR) increases due to decreasing photon energy which approaches the k-edge of Iodine at 33 keV [19] resulting in higher enhancement with lower amount of Iodine. Thus a reduction in CM volume may be achieved without loss of diagnostic image quality, which would be an important improvement in view of potential contrast-induced nephropathy (CIN) [20–22].

Therefore the purpose of this study was to evaluate the feasibility of a low volume CM protocol in 100 kV CTA of the aorta.

2. Materials and methods

2.1. Study population

Seventy-seven consecutive patients referred for CTA of the aorta were evaluated. Indications for CTA were as follows: preoperative evaluation ($n = 7$), EVAR or open aortic surgery follow-up ($n = 35$), aortic aneurysm ($n = 21$), clinical suspicion of bleeding ($n = 3$), aortic dissection ($n = 1$), ischemia ($n = 5$), search for source of pulmonary embolism ($n = 2$), follow-up of lung tumor ($n = 1$) and no specified indication ($n = 2$).

For statistical purposes, patients were divided into 3 groups according to the aorta protocol they were referred for: thoracic aorta (group 1), abdominal aorta (group 2) or combined thoracic-abdominal aorta (group 3).

A waiver of informed consent was given by the local ethical committee (METC 14-4-050).

2.2. CM administration protocol

In order to assess scan start delay, all patients received a test bolus (10 ml Iopromide 300 – Ultravist, Bayer Healthcare, Berlin, Germany – at 6 ml/s, followed by 40 ml saline flush at the same flow rate) through an 18 G i.v. needle (Vasofix®, BBraun, Melsung, Germany) placed in an antecubital vein.

In order to assess time to peak (TTP), a region of interest (ROI) was placed either at the level of the aortic arch for thoracic or combined thoracic-abdominal CTAs, or at the level of L1–L2 abdominal aorta CTAs, using a dedicated software tool (DynEva, Siemens Medical, Forchheim, Germany). Scan start delay was calculated from test bolus delay (10 s) + measured TTP + 4 s. During the latter 4 s breathing instructions were given to the patient and the scan table was moved to its starting position.

The main bolus consisted of 50 ml CM followed by a 40 ml saline chaser, both injected at a flow rate of 6 ml/s (IDR 1.8 g/s, total Iodine load TIL = 15 g). CM was prewarmed to body temperature (37 °C) prior to injection.

All injection parameters were closely monitored by a dedicated software tool (Certegra™ Informatics Platform, Bayer Healthcare, Berlin, Germany).

2.3. Scan protocol

Patients were scanned on a multidetector-row CT (MDCT) (2nd generation dual source scanner, SOMATOM Definition Flash, Siemens, Forchheim, Germany). Scan parameters were as follows: 2 × 128 × 0.6 mm (using z-flying focal spot techniques), pitch value 0.9, 100 kV, quality ref. mAs 120 (+CareDose4D), rot. time 0.33 s, 1.0/0.8 mm slice reconstruction and soft tissue filter (B30f).

2.4. Quantitative and qualitative analysis

Measurements were carried out at 10 different anatomic locations using a dedicated software tool (syngo.via, Siemens, Forchheim, Germany) – 5 thoracic and 5 abdominal: T1 ascending aorta; T2 aortic arch; T3 transition aortic arch – descending aorta; T4 halfway T3–T5; T5 aorta at thoracic spine level Th12; A1 aorta at lumbar spine level L1; A2 halfway A1–A3; A3 aortic bifurcation; A4 right common iliac artery above bifurcation; A5 right common femoral artery (see Fig. 1). At all anatomic locations a circular ROI was manually placed in the lumen of the aorta, carefully avoiding calcifications (Fig. 1). Mean attenuation [HU] and standard deviation (SD) (indicator of image noise) were recorded as well as contrast to noise ratio (CNR).

Overall image quality was assessed by an experienced radiologist (10 years of experience) for every patient on a five-point scale [17]: grade 1 – bad, no diagnosis possible; grade 2 – poor, significantly reduced diagnostic confidence; grade 3 – moderate, sufficient image quality; grade 4 – good; and grade 5 – excellent.

2.5. Statistical analysis

All data were processed via IBM SPSS Statistics ver. 20 (SPSS Inc., Chicago, IL, USA). Body weight, length and age were tested for distribution among groups using a one-way ANOVA. The same test was used in order to compare attenuation and standard deviations between groups. All values are expressed as mean ± SD or as a percentage with the absolute value in brackets. Significance was determined to have been reached at p-value <0.05.

3. Results

Seven patients were excluded in the course of the study: one due to incorrect scan delay timing, six due to non-adherence to the CM injection protocol – the condition of the venous system of five patients meant that flow rates had to be decreased, and one patient had very low cardiac output with poor test bolus attenuation, leading to an increase in volume of the main CM bolus to 90 ml. Thus the final dataset consisted of 70 patients who underwent CTA of the aorta.

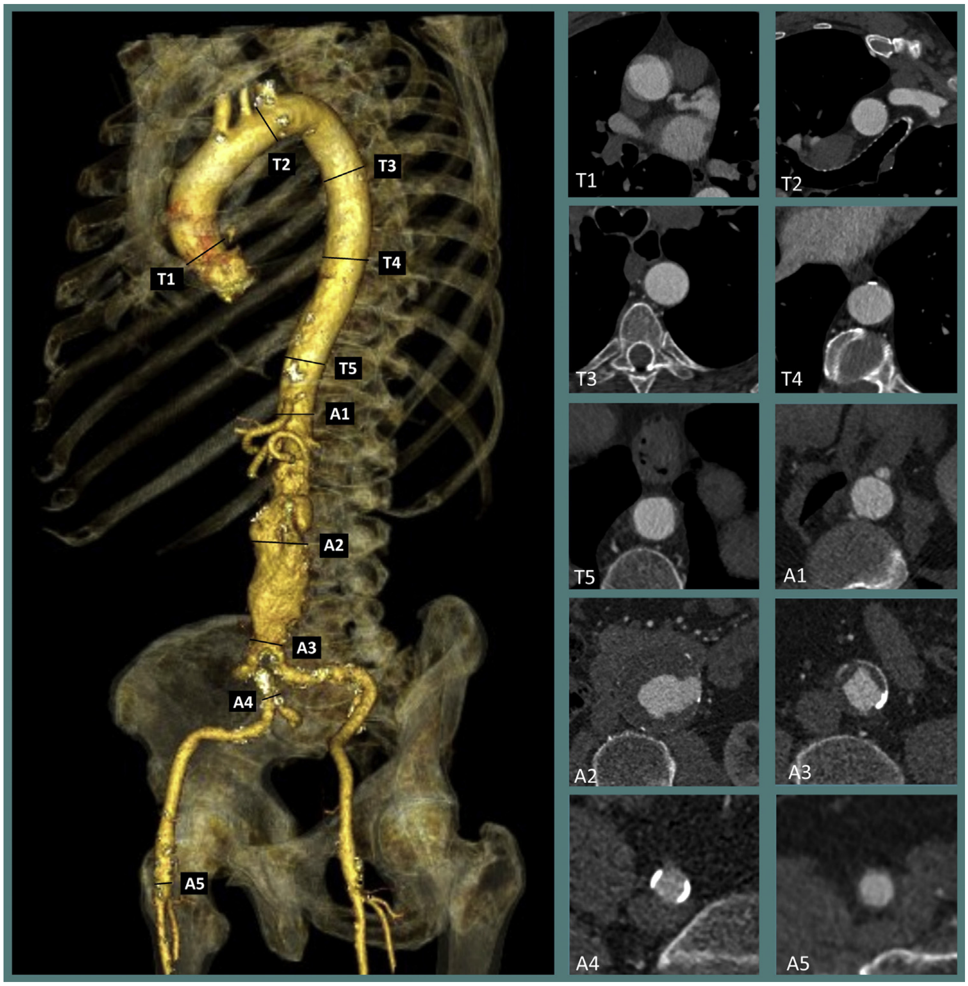

Fig. 1. Anatomic areas of ROIs placement.

No significant difference was found within the age, weight or length distribution between groups. For detailed patient information, see Table 1.

Using one-way ANOVA no significant difference in attenuation was found between groups. The overall mean attenuation was 324 ± 28 HU. The highest attenuation was reached in the region of the aortic arch and the thoracic descending aorta (T3), the lowest intravascular enhancement was obtained in the common femoral artery (A5). For detailed information on attenuation in different anatomic regions and groups, see Table 2.

Table 1
Baseline patients' characteristics, (significant *p*-value <0.05).

	Overall	Group 1 (thoracic)	Group 2 (abdominal)	Group 3 (entire aorta)	*p*-value* (ANOVA)
Number of examinations	70	5	20	45	–
Male	90% (63)	80% (4)	95% (19)	89% (40)	–
Age [years]	67.8 ± 10.9 (range 34–85)	68.6 ± 7.3 (range 60–77)	71.9 ± 10.1 (range 48–84)	66.0 ± 11.2 (range 34–85)	0.130
Weight [kg]	82.4 ± 14.5 (range 60–159)	79.8 ± 6.7 (range 69–86)	87.4 ± 20.7 (range 62–159)	80.5 ± 11.1 (range 60–108)	0.198
Length [cm]	175.2 ± 6.9 (range 160–195)	175.8 ± 3.6 (range 172–180)	174.8 ± 7.4 (range 162–195)	175.3 ± 7.0 (range 160–190)	0.945
Delay [s]	21.8 ± 4.1 (range 7–30)	20.4 ± 1.7 (range 18–22)	24.8 ± 3.5 (range 18–30)	20.7 ± 3.9 (range 7–30)	–
Scan time [s]	5.4 ± 1.1 (range 2.4–8.1)	3.2 ± 0.8 (range 2.4–4.2)	4.3 ± 0.3 (range 3.6–5.0)	6.1 ± 0.5 (range 5.3–8.1)	–

* Significant at <0.05.

Table 2
Measured mean attenuations in HU [mean ± SD (range)], (significant *p*-value <0.05).

Anatomic area	Total number of examinations	Overall mean attenuation	Group 1 (thoracic)	Group 2 (abdominal)	Group 3 (entire aorta)	*p*-value* (ANOVA)
T1 (ascending aorta)	50	327 ± 68 (178–468)	379 ± 35 (326–422)	–	321 ± 69 (178–468)	0.069
T2 (aortic arch)	50	349 ± 60 (232–485)	377 ± 18 (356–399)	–	346 ± 62 (232–485)	0.279
T3 (arch – desc. aorta)	50	367 ± 63 (250–527)	394 ± 16 (365–403)	–	364 ± 66 (250–527)	0.322
T4 (½ T3–T5)	50	346 ± 66 (212–504)	361 ± 16 (339–380)	–	344 ± 70 (212–504)	0.589
T5 (Th12 level)	50	338 ± 70 (218–514)	374 ± 21 (353–408)	–	334 ± 72 (218–514)	0.226
A1 (L1 level)	65	321 ± 74 (155–580)	–	298 ± 84 (155–580)	332 ± 68 (217–471)	0.095
A2 (½ A1–A3)	64	315 ± 83 (98–590)	–	321 ± 94 (150–590)	312 ± 79 (98–489)	0.703
A3 (aortic bifurcation)	64	309 ± 87 (78–610)	–	316 ± 97 (147–610)	306 ± 83 (78–452)	0.685
A4 (RCI artery)	64	283 ± 89 (75–566)	–	297 ± 94 (106–566)	277 ± 86 (75–420)	0.421
A5 (RCF artery)	65	275 ± 102 (43–564)	–	300 ± 102 (99–564)	264 ± 101 (43–437)	0.192
Mean value for group	–	324 ± 28	377 ± 24	306 ± 32	320 ± 28	–

* Significant at <0.05.

The attenuation values for each anatomic region are shown in Fig. 2, and the same results for each scan protocol can be found in Fig. 3.

SD of measurements are presented in Table 3. Mean SD was 28 HU. Overall SD range was 11–75 HU, with lowest SD at aortic arch (T2) and highest SD at half way between L1 and aortic bifurcation (A2). Except for the A4 region (right common iliac artery above bifurcation), there was no significant difference among various protocols. Mean CNR was 15 (SD ± 3). Comparison of CNR and SNR can be found in Fig. 4. Pearson correlation of CNR to BMI did show a decrease of CNR with increasing BMI, both in thoracic and abdominal region (Fig. 5). The median image quality as rated by the radiologist was grade 4.

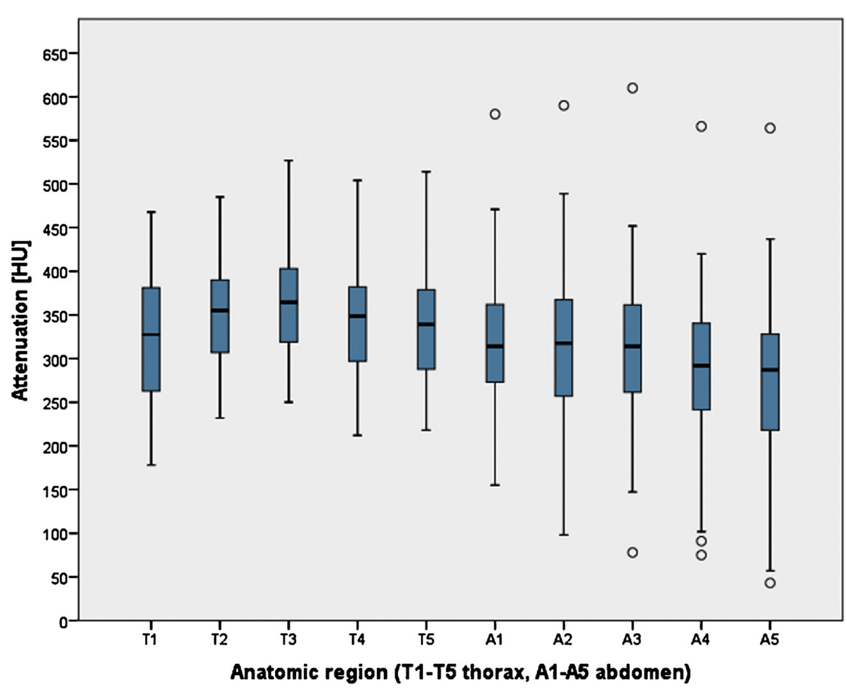

Fig. 2. Attenuation [HU] at different anatomic regions.

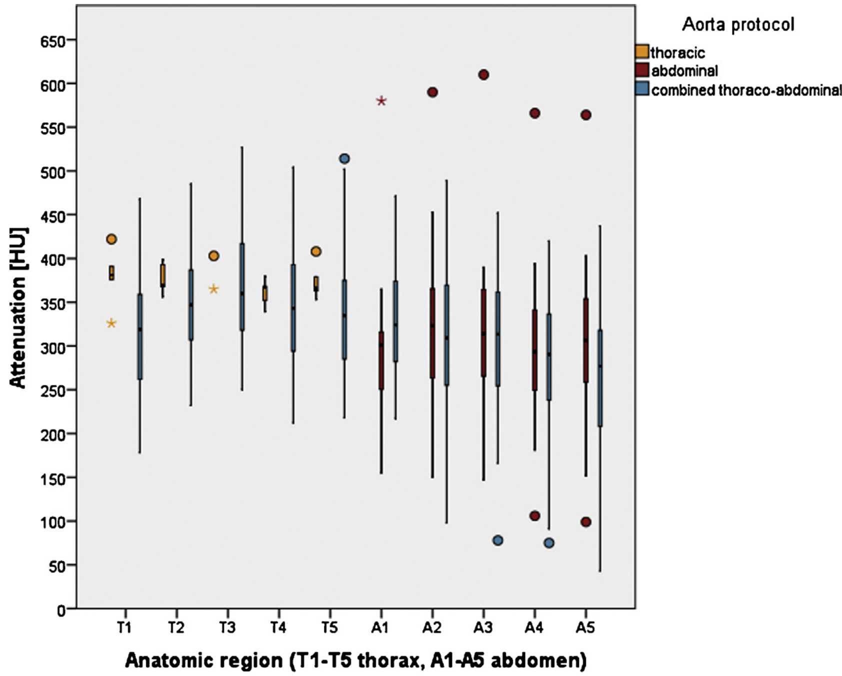

Fig. 3. Attenuation in different anatomic regions and aorta protocols.

Table 3
Measured mean SD in HU [mean ± SD (range)], (significant *p*-value <0.05).

Anatomic area	Total number of examinations	Overall mean SD	Group 1 (thoracic)	Group 2 (abdominal)	Group 3 (entire aorta)	*p*-value* (ANOVA)
T1 (ascending aorta)	50	22 ± 5 (15–35)	24 ± 5 (17–31)	–	22 ± 4 (15–35)	0.440
T2 (aortic arch)	50	20 ± 6 (11–34)	19 ± 4 (15–24)	–	21 ± 6 (11–34)	0.568
T3 (arch – desc. aorta)	50	22 ± 6 (12–36)	18 ± 7 (12–26)	–	22 ± 6 (12–36)	0.317
T4 (½ T3–T5)	50	28 ± 6 (19–48)	31 ± 7 (25–42)	–	28 ± 6 (19–48)	0.316
T5 (Th12 level)	50	31 ± 9 (15–51)	30 ± 12 (18–48)	–	32 ± 8 (15–51)	0.613
A1 (L1 level)	65	36 ± 8 (17–57)	–	37 ± 10 (25–57)	35 ± 7 (17–53)	0.156
A2 (½ A1–A3)	64	35 ± 10 (22–75)	–	38 ± 13 (23–75)	34 ± 8 (22–58)	0.276
A3 (aortic bifurcation)	64	33 ± 9 (18–55)	–	34 ± 9 (21–55)	33 ± 8 (18–54)	0.767
A4 (RCI artery)	64	31 ± 8 (14–54)	–	33 ± 9 (17–54)	29 ± 8 (14–47)	*0.009
A5 (RCF artery)	65	21 ± 4 (13–31)	–	21 ± 4 (13–30)	21 ± 4 (14–31)	0.850

* Significant at <0.05.

4. Discussion

Our results show that the use of low volume CM is feasible for aortic CTA. Compared to our standard CM protocol (volume 96 ml), a reduction of 52% was achieved with the new protocol. However, a combination of 100 kV with optimal scan delay timing is necessary to facilitate this injection protocol.

The reduction of CM volume in CTA is widely asserted in literature. Most of the studies have been performed on pulmonary CTA, usually associated with a reduction of tube voltage to between 110 and 80 kV [15,16,23–25]. However, aortic CTA has also been the center of research: Diehm et al. [14] used 50 ml of CM in the evaluation of aortoiliac aneurysm and compared it to their standard protocol using 100 ml CM (Iodine concentration 320/350 mgI/ml, flow rate 3.5 ml/s). In contrast to our study, CTA was only performed for the abdominal aorta, and bolus tracking technique was used with ROI placed at the suprarenal aorta with a scan delay of 6 s after reaching 200 HU

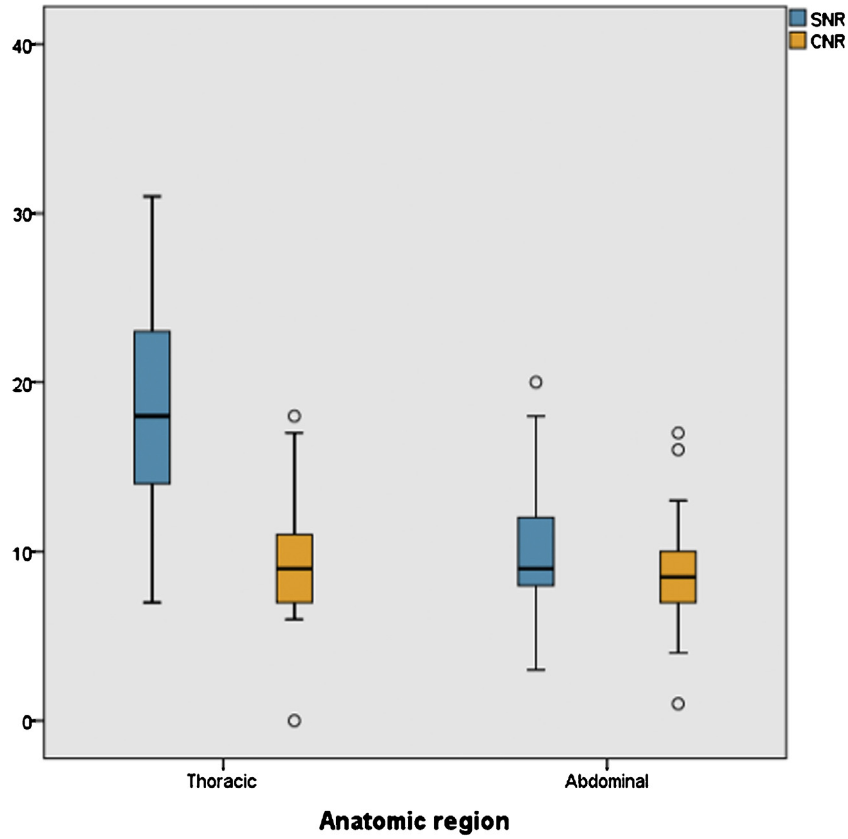

Fig. 4. SNR and CNR at different anatomic regions.

trigger point. The results revealed no significant difference in attenuation levels between groups, despite the use of various CM.

Nijhof et al. [17] compared a standard uniphasic injection protocol of 100 ml CM (Ioversol 350) to a multiphasic injection protocol, resulting in a decrease of CM volume to 89 ml in a 120 kV protocol for scanning the abdominal aorta. The multiphasic protocol was established using an exponentially decelerating rate with a decay of 0.01 ml/s, according to outcomes of previous investigations by Bae et al. [26]. Results were quantitatively and qualitatively comparable but resulted only in 11% reduction in CM volume.

The same authors [18] compared their multiphasic injection protocol mentioned in a previous article [17], to a protocol with a 10 ml test bolus followed by a main bolus of 40 ml (Ioversol 350) in 30 patients (15 patients per group). They did not find any statistically significant difference between attenuations, but it must be noted that only the abdominal aorta was evaluated, and a 120 kV protocol was used.

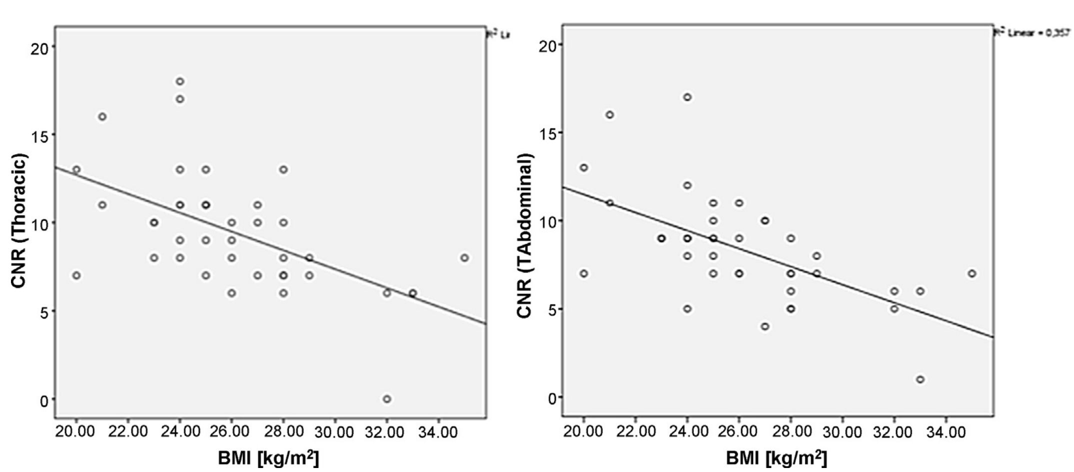

Fig. 5. Correlation of CNR and BMI.

In our study, a 100 kV protocol was used which facilitates higher contrast enhancement due to the contrast to noise ratio (CNR) increase described earlier. Lowering kV thus allows a reduction in CM volume. As was shown in our study, this reduction is functional not only for abdominal or thoracic CTA, but also in combined thoracic-abdominal protocols. It is important to mention, however, that a relatively low volume bolus must be exactly timed. The chosen timing in our study was feasible, but we did experience some decrease of enhancement in peripheral vessels in some patients undergoing combined thoracic-abdominal CTA. This could be due to the fact that a fixed bolus was used, which did not account for individual patient differences (e.g. body weight), and which furthermore did not account for longer scan time necessary in thoracic-abdominal examinations in comparison to just thoracic or just abdominal scanning. Future research should incorporate these findings in individualized protocols.

Future developments in scanner technique – especially in detector technology – might facilitate the use of even lower kV settings in an even broader range of patients, which may lead to further increased contrast enhancement using the same bolus. Although 70 kV and 80 kV were possible at the used scanner the necessary tube current to have sufficient low image noise is not always achievable in all patients, thus lowering kV increases image noise if tube current cannot be adjusted accordingly. Thus the decision was made to use only a 100 kV protocol. This makes the results applicable to a broad range of scanners and not only to the newest high-end machines. Furthermore iterative reconstruction allows reducing image noise also facilitating the use of lower kV settings in future protocols and in scanners which are not capable of higher tube current settings as lower kV settings.

4.1. Limitations

This study has several limitations that should be addressed. It is a single center study performed on a limited number of patients, especially as far as the thoracic aorta protocol is concerned. In addition, only one scan acquisition technique (spiral, standard acquisition pitch) was used. More advanced techniques such as high pitch scanning might not be suitable for reduced CM volume, due to the fast image acquisition outrunning the bolus.

4.2. Possibilities

Using low volume CM is beneficial in terms of CIN prevention, especially in critically ill patients and patients with known impaired renal function. Furthermore, efficient use of CM in combination with lower kV settings could decrease scanning costs.

5. Conclusion

The use of a relatively low volume of CM is feasible and diagnostic image quality in 100 kV CTA of the aorta can be reached. Compared to a standard injection protocol reduction of more than 50% is possible.

Conflict of interest

None declared.

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