Původní sdělení | Original research article

Induced apnea for better CT visualization of coronary arteries in children under 1 year. And is heart rate so essential?

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SÚHRN

Úvod: CT koronarografia je u detí pod 1 rok života užitočná zobrazovací technika s vysokou rozlišovacou schopnosťou. CT vyšetrenie u týchto detí zostáva pre radiológov a klinikov výzvou pre radiačnú záťaž a pohybové artefakty.
Ciele: Hodnotenie kvality CT koronarografie detí pod 1 rok života použitím kvalitatívnych a kvantitatívnych parametrov.
Materiál a metódy: Retrospektívna štúdia realizovaná v jednom centre medzi aprílom 2022 a augustom 2024. Kvalita zobrazenia koronárnych tepien bola hodnotená skúseným radiológom prostredníctvom skórovacieho systému.
Výsledky: Bolo realizovaných 10 vyšetrení u 9 pacientov. Neprítomnosť, respektíve minimálne pohybové artefakty boli dosiahnuté u väčšiny vyšetrení (90 %). U väčšiny pacientov bolo skóre hodnotenia 1, len jeden pacient mal skóre 2. Z uvedeného vyplýva, že CT koronarografia v riadenom apnoe zlepšuje kvalitu vyšetrenia. Frekvencia srdca nemá vplyv na kvalitu vyšetrenia koronárnych tepien u danej skupiny pacientov. Najlepšia fáza na vizualizáciu celého priebehu koronárnych tepien bola medzi 30 – 50 % srdcového cyklu. Avšak u jedného pacienta bola ľavá koronárna tepna, ramus interventricular anterior a ramus circumflexus lepšie vizualizované v 70 – 80 % srdcového cyklu.
Záver: CT koronarografia v riadenom apnoe reprezentuje efektívnu zobrazovaciu metódu vizualizácie koronárnych tepien u detí do 1 roka života s lepšou kvalitou vyšetrenia.

Keywords:
Children
Coronary arteries
CT angiography
Induced apnea
Propofol

ABSTRACT

Background: Coronary CT angiography (CCTA) in children under one year of age is a usefull technique in visualization of coronary arteries with high spatial resolution. CT examination of children under 1 year remains a challenge for radiologists and clinicians due to radiation and motion artefacts.
Objectives: To evaluate image quality of CCTA examinations performed in children under 1 year using qualitative and quantitative parameters.
Materials and methods: A single center retrospective study of CCTA with induced apnea, performed between April 2022 and August 2024. We investigated quality of coronary arteries imaging via a visual grading analysis by two experienced radiologists.
Results: 10 CCTA examinations performed in 9 patients were included. Absent or minimal motion artifacts were seen in most of the studies (90%). The image quality was excellent in the majority of the CT examinations. The majority of patients had an image score of 1, with only 1 study receiving a score of 2. It appears that coronary artery imaging is greatly improved with apnea, according to the radiologist's experience. The heart rate does not seem to impact the visibility of coronary arteries in this patient group. The best phase for visualizing the entire course of the coronary arteries was between 30–50%. However, in 1 patient, the visibility of the left main coronary artery, left anterior descending, and circumflex artery was better in the 70–80% phase. CCTA with induced apnea was compared to 11 CCTA examinations performed before April 2022. The image quality in this earlier patient group was inferior to that of the induced apnea group. Moti-

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on artifacts were absent or minimal in 50% of the studies. Only two patients received an image score of 1; the majority of patients (6 patients) received an image score of 2, with the remaining patients receiving an image score of 3 (3 patients).

Conclusion: Coronary computed tomographic angiography with induced apnea presents a practical and efficacious imaging technique for coronary artery visualization in infants under one year of age, yielding superior image quality and detail compared to CCTA performed without induced apnea.

Introduction

Echocardiography represents the most important diagnostic method in patients with CHD.[1] A detailed understanding of variations and coexisting lesions is crucial for future surgical planning. In some cases the whole course of coronary arteries (CA) must be visualized, not only proximal parts, then coronary CT angiography (CCTA) is helpful.[2,3]

CT provides high spatial resolution with excellent visualization of the CA. In recent years, cardiac CT has emerged as a powerful diagnostic tool in the assessment of young children with suspected or known CHD. Advances in CT technology have allowed for dramatic decreases in radiation dose (the effective dose <1 mSv) without loss of quality in visualization.[4]

The high-resolution three-dimensional imaging capabilities of CCTA allows for detailed visualization of the complex cardiac anatomy, providing critical insights into the precise nature and extent of structural abnormalities. This information is invaluable in guiding the development of personalized treatment strategies and surgical planning, ultimately improving the prognosis for these vulnerable patients.[5]

Cardiac CT is sensitive to respiratory motion artifacts which can reduce the quality of imaging especially the CA. It is impossible to avoid these artifacts in children under age of 1 year. General anesthesia with induced apnea can solve these problems. We present the study when we want to prove that induced apnea during CCTA effectively reduce motion artifacts.[6]

Anesthesia protocol

First, the anesthesiologist conducts an anesthesiology consultation and prepares the patient. The parents are fully informed and complete an anesthesiology questionnaire, which includes anamnestic questions. The parents then consent to the procedure under general anesthesia.

Patients are kept fasting for 6 hours, with breast milk restricted for 4 hours and water/tea for 2 hours.

The patient typically receives premedication for 20–30 minutes in the department. Dexmedetomidine is commonly administered intranasally as a premedication, also to slow the heart rate in children, especially newborns. The dexmedetomidine dose is 3 µg/kg administered intranasally. ICU patients are usually continuously sedated and do not require premedication. They will have a peripheral intravenous cannula provided in the department.

After premedication, the patient is transported under monitoring, including pulse oximetry, and is fully monitored in ICU,, with ventilator and oxygen, before arriving at the CT worplace accompanied by a nurse and a parent.

The patient was stabilized; positioned supine in the CT gantry, and continuous monitoring was maintained. General anesthesia was induced in all patients through intravenous administration of propofol, with the dose titrated accordingly. Some ICU patients also received continuous dexmedetomidine. Patients from the department were provided nasal oxygen, and a bolus of propofol was used to induce controlled apnea. First, a CT scan was performed, and then, following the radiologist›s instructions, the anesthesiologist administered a bolus of propofol to induce apnea. All patients were preoxygenated with 100% oxygen. Following the CT study, the child was carefully removed from the CT gantry and mechanically ventilated using a bag and mask until spontaneous ventilation returned or ventilation was induced by the ventilator. The patient was closely monitored and stabilized, ensuring their ventilation and oxygenation parameters returned to their previous, baseline values. Throughout this process, the patient was continuously monitored, with measures such as ECG, pulse oximetry, and ventilation parameters closely tracked (**Fig. 1**).

Anesthesia was performed in all patients without any complications, and the patients were subsequently transported back to their respective departments.

Cardiac CT protocol

Electrocardiogram-gated studies were performed using a volumetric technique with a 320-MDCT scanner (Aquilion ONE; Canon Medical Systems, Ōtawara, Japan).

In the context of CT coronary imaging for infants, temporal resolution is of utmost importance. Mentioned CT scanner achieves a temporal resolution of 175 ms. A z-axis coverage of 80–100 mm is sufficient to visualize the coronary arteries, thus eliminating the need for table movement.

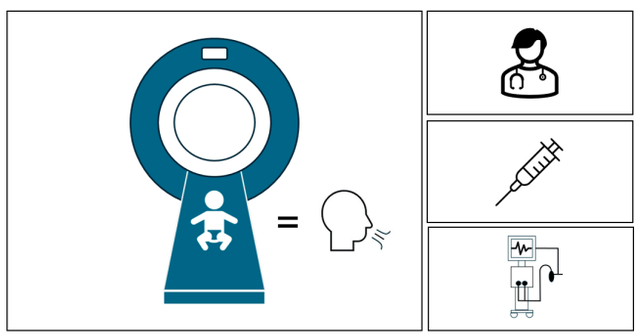

Fig. 1 – Scheme of coronary CT angiography with induced apnea.

The gantry rotation time was 0.35 seconds, and the tube voltage was set at 80 kV. The tube current in mA was based on the patient's age and weight. A non-ionic contrast agent, Visipaque, with a concentration of 320 mg/ml was injected through a 22-gauge cannula using a dual-syringe power injector at a dose of 1.5 ml/kg. The triphasic contrast injection protocol is the preferred technique, involving an initial bolus of full-strength contrast agent, followed by a contrast-saline mixture, and finally a normal saline flush.The injection rate was 0.7–0.8 ml/s, and the contrast medium was injected via a lower or upper extremity.

To optimize image acquisition, the region of interest should be positioned within the chamber, targeting a Hounsfield unit value of up to 200. Scanning should be initiated once this threshold is reached, as determined by monitoring density curves. A short delay, approximately 2 seconds, between the scan initiation command and the commencement of the scanning process, is also crucial. Implementing a bolus tracking methodology with a monitoring time of 1.5 seconds is also recommended.

All images were obtained with prospective ECG gating during two cardiac cycles. Half-scan reconstruction was used to reconstruct phases at every 5–10% across the cardiac cycle. A three-dimensional adaptive iterative dose reduction algorithm was employed to obtain 0.5-mm-thick axial slices. The PhaseXact scanner software automatically determined the cardiac phase with the least motion for CT angiography image reconstruction. The attending radiologist then selected individually the best motion-free cardiac phase adjacent to the predefined target phase using ImageXact software, which allows for half-scan reconstruction of data across the entire spectrum of cardiac phases covered by the rotation time.

Image analysis

The Digital Imaging and Communications in Medicine (DICOM) datasets of pre-selected CCTA studies were transferred to a post-processing workstation (Vitrea; Canon Medical Systems). Image-reformatting techniques, including multiplanar reformation and maximum-intensity projection, were used to assess the CCTA examinations. Qualitative evaluation was performed by a single, well-experienced radiologist in cardiac imaging. The images were subjectively scored for overall image quality and motion artifact, as described by Saleh et al.[7] (**Table 1**).

Radiation dose calculation

The volume CT dose index (CTDIvol) and dose-length product (DLP) displayed on the CT console were recorded for each CTA examination. The CTDIvol and DLP based on the 32-cm phantom were multiplied by a factor of 2.6 to obtain the radiation doses based on a 16-cm phantom. Using scanner manufacturer recommendations, we plugged in the same scanning parameters (tube voltage, tube current, collimation) on the scanner console initially for a body scan (32-cm phantom) and then for a head scan (16-cm phantom), which yielded a conversion factor of 2.6 for our scanner. CT dose index and dose-length product, based on a 32 cm sized phantom, and efective dose of CCTA were (mean dose-length product (DLP) 36.7 mGy·cm, range 26.1–68.55 mGy·cm, mean volumetric CT dose index (CTDIvol) 26.1 mGy, range 18.29–32.58 mGy, and the mean calculated effective dose 0.95 mSv, range 0.57–1.78 mSv) (**Table 2**).

Table 1 – Subjective scale for scoring image quality and/or motion artifacts on CT angiography

Score 1 – Excellent images with absent motion artifacts (high diagnostic confidence)
Score 2 – Good images with mild motion artifacts (diagnostic quality image)
Score 3 – Fair images with moderate motion artifacts (indeterminate diagnosis)
Score 4 – Poor quality images due to severe motion artifacts (nondiagnostic)

Table 2 – Radiation dose parameters

DLP (mGy.cm)	36.7 (26.1–68.55)
CTDIvol (mGy)	26.1 (18.29–32.58)
Effective dose (mSv)	0.948 (0.57–1.78)

Study population

Between April 2022 and August 2024, 9 patients with various diagnoses underwent CCTA using a 320-MDCT scanner at our institution. All patients included in this study were younger than 1 year (5 boys, 4 girls). The CT examinations were performed under general anesthesia with induced apnea. In all patients, the apnea was induced by a bolus injection of propofol. **Table 3** shows the demographic data of the patients. The diagnoses included 5 patients with D-transposition of great arteries (**Fig. 2**), 2 patients with dilated cardiomyopathy, 1 patient with tetralogy of Fallot, 1 patient with anomalous left coronary artery from the pulmonary artery (**Fig. 3**). A total of 10 CT examinations were performed in these 9 patients. The indications for the CT study (count – 9) were poor

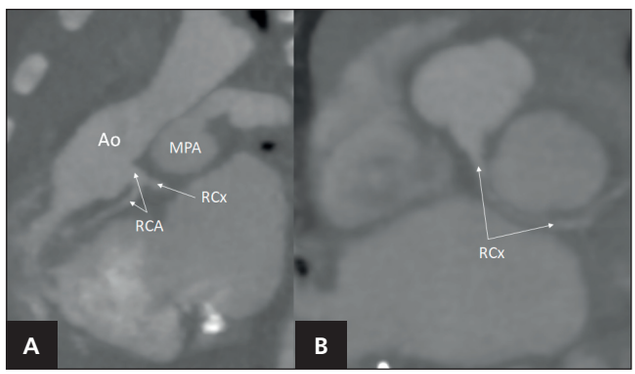

Fig. 2 – D-transposition of great arteries. (A, B) Modified sagital view – Origin of circumflex artery from the right coronary artery and its course. RCA – right coronary artery; RCx – circumflex artery.

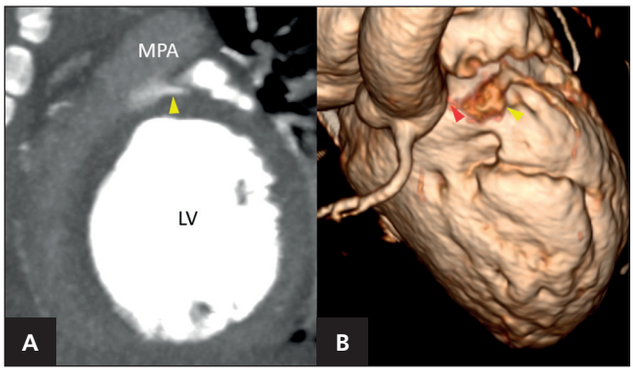

Fig. 3 – ALCAPA. Sagital view – Origin of left coronary artery from the main pulmonary artery root (yellow arrowhead). VRT reconstruction – missing left coronary origin from the aortic root (red arrowhead). Origin of left coronary artery from the main pulmonary artery (yellow arrowhead).

Table 3 – Demographic data of the patients

Demographic data	Induced apnea gr.	Non-induced apnea gr.
Sex		
Girls	4	7
Boys	5	4
Age (d)	20.4 (1–75)	41 (3–256)
Weight (g)	3.59 (2.9–4.5)	4.8 (2.7–8.7)
Heart rate (beats per minute)	125.5 (100–166)	124.5 (98–156)

Gr. – group.

Table 4 – Coronary artery image quality score

Induced apnea group				
	RCA	**LCA**	**LAD**	**RCx**
1	9	9	9	8
2	1	1	1	2
3	0	0	0	0
4	0	0	0	0
Non-induced apnea group				
	RCA	**LCA**	**LAD**	**RCx**
1	2	2	2	2
2	6	6	6	6
3	3	3	3	3
4	0	0	0	0

visualization of the coronary arteries by transthoracic echocardiography before surgery and suspected ALCAPA in patients with acute left heart failure. Additionally, 1 CT examination was performed in the early postoperative period due to the patient's desaturation and poor left ventricular function. The age range of the patients was 2 to 75 days, with a mean age of 20.4 days. The heart rate of the patients during the CT scanning ranged from 100 to 166 beats per minute, with a mean of 125.5 beats per minute.

CCTA with induced apnea was compared to 11 CCTA examinations performed in 11 patients before April 2022. The age range of this patients' group was 3 to 256 days, with a mean age of 41 days. The heart rate during scanning ranged between 98 to 156 beats per minute, with a mean of 124.5 beats per minute. All examinations were under general anesthesia but without induced apnea. The diagnosis included 3 patients with tetralogy of Fallot, 5 patients with D-transposition of great arteries, and the rest were patients with suspiction of anomalous origin of left coronary artery with acute heart failure.

Statistical methods

Statistical analysis included the calculation of means and ranges.

Results

Various congenital cardiac abnormalities were observed in the children undergoing induced apnea. Absent or minimal motion artifacts were seen in most of the studies (90%). The image quality was excellent in the majority of the CT examinations. The quality of coronary artery imaging is shown in **Table 4**. The majority of patients had an image score of 1, with only 1 study receiving a score of 2. It appears that coronary artery imaging was very good with apnea, according to the radiologist's experience. The heart rate does not seem to impact the visibility of coronary arteries in this patient group. The best phase for visualizing the entire course of the coronary arteries was between 30–50%. However, in 1 patient, the visibility of the left main coronary artery, left anterior descending, and circumflex artery was better in the 70–80% phase.

CCTA with induced apnea was compared to 11 CCTA examinations performed before April 2022. The image quality in this earlier patient group was inferior to that of the induced apnea group. Motion artifacts were absent or minimal in 50% of the studies. Only two patients received an image score of 1; the majority of patients (6 patients) received an image score of 2, with the remaining patients receiving an image score of 3 (3 patients).

Discussion

The increasing use of CCTA in the assessment of newborns with congenital heart disease is driven by its distinct advantages over other imaging modalities. CT offers superior spatial resolution, allowing for detailed visualization of the complex cardiac anatomy, including the coronary arteries, which are often challenging to evaluate using echocardiography alone.[8] Furthermore, CT provides a comprehensive, three-dimensional perspective that is invaluable in surgical planning and the development of personalized treatment strategies.[9] The findings from this study underscore the feasibility and potential clinical utility of CCTA as an important diagnostic tool in the evaluation of children under one year of age with coronary artery abnormalities.

The present study demonstrates that volumetric CCTA with induced apnea allows for the accurate detection of the various types of coronary anomalies. The use of induced apnea during the CT acquisitions was critical in minimizing motion artifacts and optimizing image quality. The excellent image quality achieved in the majority of studies, with most patients receiving the highest score for coronary artery visualization, highlights the effectiveness of this approach. The timing of the CT acquisition during the cardiac cycle is another important factor in determining the quality of coronary artery imaging.[10] The optimal phase for visualizing the entire course of the coronary arteries was found to be between 30–50% of the cardiac cycle. However, in one patient, the visibility of the left main coronary artery, left anterior descending, and circumflex artery was better in the 70–80% phase, emphasizing the need for individualized adjustments based on patient-specific factors, such as heart rate and others, to achieve the best possible imaging outcomes.[11–13]

The present study highlights the feasibility and potential clinical utility of CCTA in the evaluation of newborns with coronary artery anomalies. The use of induced apnea and optimized CT acquisition parameters were key in achieving excellent image quality and visualization of the coronary arteries, which can enhance diagnostic accuracy and inform personalized treatment strategies.

Given the promising findings of this study, future research should focus on evaluating the diagnostic performance of CCTA in larger cohorts of newborns with congenital heart disease, as well as assessing the long-term clinical outcomes. To achieve high-quality images in children, radiologists must optimize techniques for the child, CT scanner, and clinical indication.

Conclusions

CCTA with induced apnea represents a feasible and effective imaging modality for evaluating newborns with congenital heart disease. The ability to achieve excellent image quality and detailed visualization of the coronary arteries underscores the utility of this technique in informing clinical decision-making and surgical planning for these patients.

Conflict of interest

Author declare no conflict of interest.

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There are currently no funding sources in the list.

Ethical statement

The present study followed international and national regulations and was in agreement with the Declaration of Helsinki, and ethical principles. Our institution does not require ethical approval for reporting individual cases or case series.

Informed consent

Written informed consent was obtained from the patient and his wife for their anonymized information to be published in this article.

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