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Original Article */ Özgün Makale*

Dual-energy computed tomography pulmonary angiography with ultra-low dose contrast administration: Comparison of image quality with standard computed tomography pulmonary angiography

Ultra düşük doz kontrast uygulaması ile dual enerji bilgisayarlı tomografi pulmoner anjiyografi: Görüntü kalitesinin standart bilgisayarlı tomografi pulmoner anjiyografi ile karşılaştırılması

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ABSTRACT

Background: This study aims to compare quantitative and qualitative image quality between standard computed tomography pulmonary angiography and dual-energy computed tomography pulmonary angiography protocols.

Methods: Between September 2017 and August 2018, a total of 91 consecutive patients (34 males, 57 females; mean age: 65.9±15 years; range, 37 to 91 years) who were referred for computed tomography pulmonary angiography were randomly imaged with either a standard or dual-energy protocol. Standard protocol (n=49) was acquired with a 64-slice multidetector computed tomography scanner using 60 mL contrast media (18 g iodine). A third-generation dual-energy computed tomography scanner was utilized to acquire dual-energy computed tomography pulmonary angiography and simultaneous lung perfusion imaging (n=42), which required 40 mL contrast media (12 g iodine). Two radiologists reviewed images separately to determine interobserver variability. Attenuation and noise in three central and two segmental pulmonary arteries were measured; signal-to-noise ratio and contrast-to-noise ratio were calculated. A five-point scale was utilized to evaluate image quality and image noise qualitatively.

Results: The standard protocol required a significantly higher amount of iodine. Comparison of two groups employing quantitative measurements (attenuation value in five pulmonary arteries, mean attenuation value, mean background noise, signal-to-noise ratio, and contrast-to-noise ratio) and employing qualitative measurements (five-point scale scores of image quality and image noise) revealed no significant difference between dual-energy and standard groups (p>0.05). Qualitative and quantitative evaluations demonstrated low interobserver variability.

Conclusion: Dual-energy computed tomography pulmonary angiography protocol delivers image quality equal to standard protocol, while requiring less amount of iodinated contrast medium and providing simultaneous lung perfusion imaging to contribute the diagnosis of pulmonary embolism.

Keywords: Computed tomography angiography, contrast media, dual-energy computed tomography, lung perfusion, pulmonary artery.

ÖZ

Amaç: Bu çalışmada, standart bilgisayarlı tomografi pulmoner anjiyografi ve dual enerji bilgisayarlı tomografi pulmoner anjiyografi protokolleri kantitatif ve kalitatif görüntü kalitesi yönünden karşılaştırıldı.

Çalışma planı: Eylül 2017 - Ağustos 2018 tarihleri arasında bilgisayarlı tomografi pulmoner anjiyografi için sevk edilen toplam 91 ardışık hasta (34 erkek, 57 kadın; ort. yaş: 65.9±15 yıl; dağılım, 37-91 yıl) standart veya dual enerji protokollerinden birine randomize edildi. Standart protokol (n=49), 60 mL kontrast madde (18 g iyot) kullanılarak 64 kesitli çok dedektörlü bilgisayarlı tomografi cihazı ile elde edildi. Dual enerji bilgisayarlı tomografi pulmoner anjiyografi (n=42), 40 mL kontrast madde (12 g iyot) kullanılarak ve eş zamanlı akciğer perfüzyon görüntülemesi elde edilerek üçüncü nesil dual enerji bilgisayarlı tomografi cihazında elde edildi. İki radyolog, gözlemciler arası değişkenliği belirlemek için görüntüleri ayrı ayrı inceledi. Üç ana ve iki segmental pulmoner arterde atenüasyon ve gürültü ölçüldü; sinyal-gürültü oranı ve kontrast-gürültü oranı hesaplandı. Görüntü kalitesini ve görüntü gürültüsünü kalitatif olarak değerlendirmek için beş puanlık bir ölçek kullanıldı.

Bulgular: Standart protokolde anlamlı düzeyde daha yüksek miktarda iyot gerekti. Kantitatif ölçümler (beş pulmoner arterde atenüasyon değeri, ortalama atenüasyon değeri, ortalama arka plan gürültüsü, sinyal-gürültü oranı ve kontrast-gürültü oranı) ve kalitatif değerlendirme (görüntü kalitesinin ve görüntü gürültüsünün değerlendirildiği beş puanlık ölçek puanları) sonuçlarının karşılaştırması dual enerji ve standart grupları arasında anlamlı bir fark olmadığını ortaya koydu (p>0.05). Kalitatif ve kantitatif değerlendirmeler, gözlemciler arası düşük değişkenlik gösterdi.

Sonuç: Dual enerji bilgisayarlı tomografi pulmoner anjiyografi protokolü, standart protokole eşit görüntü kalitesi sağlarken, daha az miktarda iyotlu kontrast madde gerektirir ve pulmoner emboli tanısına katkı sağlayan eş zamanlı akciğer perfüzyon görüntülemesi elde edilmesini sağlar.

Anahtar sözcükler: Bilgisayarlı tomografi anjiyografi, kontrast madde, dual enerji bilgisayarlı tomografi, akciğer perfüzyonu, pulmoner arter.

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Computed tomography pulmonary angiography (CTPA) is the current modality of choice for the diagnosis of pulmonary embolism.[1] However, this diagnostic procedure requires the administration of iodinated contrast media, which presents a risk of contrast-induced nephropathy (CIN). Most of the patients with suspected pulmonary embolism are elderly and already prone to renal failure.[2]

Low-kilovoltage CT scanning allows improved enhancement of the iodine-induced contrast as the attenuation of iodine-based contrast medium increases with reduced X-ray energy due to iodine's high relative atomic number.[3,4] However, the reduction of kilovoltage causes an increase in image noise and potentially low image quality.[5] Dual-energy CT allows to create virtual monochromatic images at low- and high-energy levels, generating a set of images optimized in contrast and noise.[6] Besides CTPA, simultaneous lung perfusion imaging is available in dual-energy CTPA (DE-CTPA).[7,8] Previous studies have investigated the diagnostic value of DE-CTPA, focusing on the value of additional perfusion imaging.[9,10]

In the present study, we aimed to compare quantitative and qualitative image quality between standard CTPA and DE-CTPA, where the latter offers advantages of ultra-low-dose contrast medium administration and additional lung perfusion imaging.

PATIENTS AND METHODS

Patient selection and CT scanning

This single-center, retrospective study was conducted at Başkent University Faculty of Medicine, Ankara, Department of Radiology between September 2017 and August 2018. A total of 91 consecutive patients (34 males, 57 females; mean age: 65.9±15 years; range, 37 to 91 years) referred to the radiology department from an external center for CTPA were included. The patients were randomly assigned to either a 64-slice multidetector CT scanner (Somatom® go.All; Siemens Healthineers, Forchheim, Germany) or a third-generation dual-energy multidetector CT scanner (Somatom® Force; Siemens Healthineers, Forchheim, Germany). Exclusion criteria were as follows: suboptimal image

Table 1. Patient characteristics, scanning parameters, and contrast medium volume

Parameter	Dual-energy CTPA (n=42)	Standard CTPA (n=49)
Age (year)*	67±14	65±17
Sex		
Female	25	32
Male	17	17
Scanning parameters		
Number of X-ray sources	2	1
Tube voltage (kVp)	90 (tube A)/150 (tube B)	70
Reference tube current (effective mAs)	60 (tube A)/46 (tube B)	303
Rotation time (sec)	0.25	0.33
Pitch	0.55	0.80
Collimation (mm)	0.60	0.70
Mean effective dose (mSv)	5.82	6.15
Contrast injection parameters		
Total iodine (gr)**	12	18
Volume (mL)	40	60
Injection rate (mL/sec)***	3.5 mL/sec (followed by 40 mL saline at an injection rate of 4 mL/sec)	3.5 mL/sec (followed by 40 mL saline at an injection rate of 4 mL/sec)
Bolus tracking (region of interest in ascending aorta; threshold: 100 HU)	Yes	Yes

CTPA: Computed tomography pulmonary angiography; HU: Hounsfield Units; * Data are given in mean ± standard deviation, unless otherwise specified; ** Iohexol 300 mg iodine per milliliter (Kopaq®, Onko-Koçsel, Istanbul, Türkiye); *** Contrast material was injected through antecubital vein.

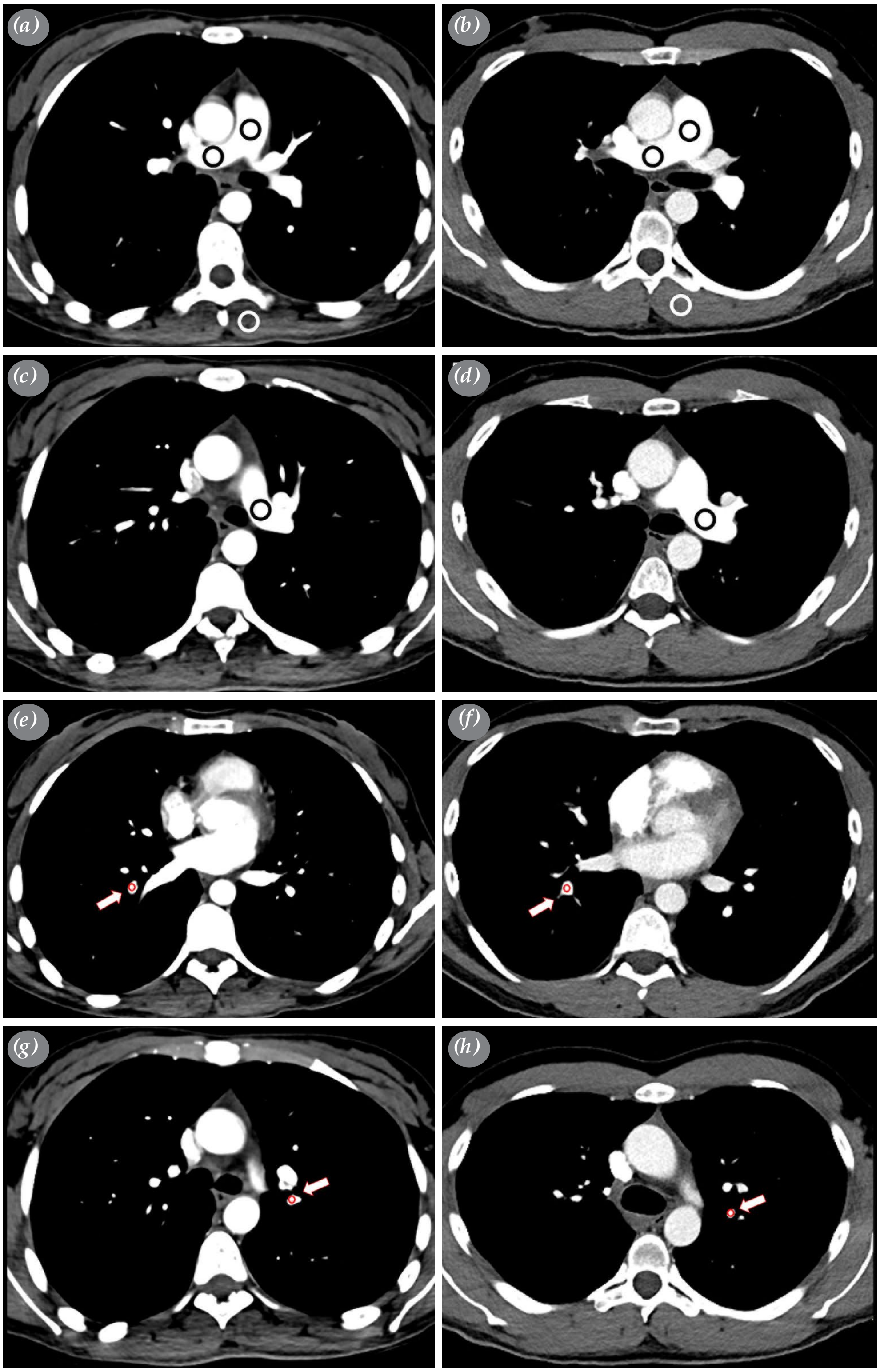

Figure 1. Axial computed tomography pulmonary angiography (CTPA) images of standard CTPA (a, c, e, g) and dual-energy CTPA (b, d, f, h) demonstrating example region of interest (ROI) placement on the main pulmonary artery (PA), right PA [(**a**) and (**b**)], black circles), left PA [(**c**) and (**d**), black circles], right posterior basal segmental PA [(**e**) and (**f**), red circles and arrows)], left apical-posterior PA [(**g**) and (**h**), red circles and arrows], and paraspinal muscle group [(**c**) and (**b**), white circles) for measurements.

Table 2. Five-point scale for subjective evaluation of pulmonary arterial enhancement and noise

Scale and score		Description
Image quality (pulmonary arterial enhancement)		
	1	Poor, nondiagnostic opacification
	2	Suboptimal insufficient opacification
	3	Limited but sufficient opacification
	4	Sufficient and good opacification
	5	Excellent opacification
Image noise		
	1	Major noise, nondiagnostic image
	2	Major noise, suboptimal evaluation
	3	Moderate noise, sufficient for diagnosis
	4	Minor noise, not effective in diagnosis
	5	None perceivable

quality and the presence of pulmonary embolism, as the clot within the pulmonary artery (PA) would prevent attenuation measurement. Image acquisition started just above the thoracic inlet and included the upper abdomen. All patients were scanned in the supine position while breath-holding after deep inspiration with both arms extended overhead. Patient characteristics and scanning protocols for both CT scanners are summarized in Table 1.

Image reconstruction and data collection

Image reconstruction and evaluation were performed on a dedicated workstation (Syngo.via, Version 3.0, Siemens Healthineers AG, Erlangen, Germany). The DE-CTPA image reconstruction and evaluation were performed with monochromatic images of 40 KeV for optimal enhancing following transfer of raw data to workstation. Virtual monochromatic images of DE-CTPA scan were reconstructed using Mono+ application of the Syngo.via workstation. Standard CTPA scan images were reconstructed with a standard reconstruction algorithm.

Two radiologists reviewed images retrospectively, blinded to scanner information, and separately to determine interobserver variability. First, quantitative measurements in Hounsfield Units (HUs) were acquired by manually placing a circular region of interest (ROI) on the main PA, right PA, left PA, right posterior basal segmental PA, left apical-posterior PA, and paraspinal muscle group (Figure 1). The ROI sizes were 1 cm^2 each on main PA, left PA, right PA and widest possible on left apical-posterior PA, and right posterior basal segmental PAs. The mean attenuation was calculated by averaging the values of the five pulmonary arteries. Image noise was determined as the standard deviation of the main PA attenuation in HU. The signal-to-noise ratio (SNR) and the contrast-to-noise (CNR) ratios were calculated according to the following formulas: SNR = mean attenuation/mean noise and CNR = (mean attenuation - paraspinal muscle attenuation)/(mean noise). For qualitative evaluation, a five-point scale was used (Table 2).[11] Mean values were calculated for statistical analysis. Age and sex data were retrieved from the Picture Archiving and Communication System (PACS).

Statistical analysis

Statistical analysis was performed using the IBM SPSS version 25.0 software (IBM Corp., Armonk, NY, USA). Descriptive data were expressed in mean and standard deviation (SD) for continuous variables and in number and frequency for categorical variables. The Shapiro-Wilk test was used to evaluate the normality assumption for enhancement values. Five-point scale scores were presented in median with 25% and 75% interquartile range (IQR). Comparison between the two scanner groups was performed using the Mann-Whitney U test and Kruskal-Wallis test. The Dunn's multiple comparison tests were used, if a significant result was found with the Kruskal-Wallis test. The Bland-Altman analysis was performed to determine interobserver variability for continuous variables. A p value of <0.05 was considered statistically significant.

RESULTS

There was no statistically significant difference between the two groups regarding sex and age ($p>0.05$). The standard CTPA protocol required a significantly higher amount of iodine administration than the DE-CTPA protocol. Comparison of two groups employing quantitative measurements (attenuation value in five PAs, mean attenuation value, mean background noise, SNR, and CNR) revealed no significant difference ($p>0.05$) (Table 3). Five-point scale scores for the qualitative evaluation of each CTPA group were expressed as a median of 5. There was no significant difference between subjective evaluation scores of image quality (pulmonary arterial enhancement) and image noise between DE-CTPA and standard CTPA groups ($p>0.05$) (Table 3).

Interobserver agreement for qualitative parameters (image quality and image noise) was high (>88%). Regarding quantitative measurements (attenuation value in five PAs, mean attenuation

Table 3. Comparison of quantitative measurements and five-point scale scores of dual-energy CTPA and standard CTPA, by two independent observers

		Parameter		Dual-energy CTPA Mean±SD	Dual-energy CTPA Median	Dual-energy CTPA Q1-Q3	Standard CTPA Mean±SD	Standard CTPA Median	Standard CTPA Q1-Q3	*p*
Radiologist 1	Quantitative	Attenuation (HU)	Main PA	461.9±178.6			502±178.7			0.183
			Right PA	463.6±179.3			489.7±168.9			0.274
			Left PA	448±170			477.4±163.6			0.252
			Right posterior basal segmental PA	454.9±215.1			491.6±168.8			0.069
			Left apical-posterior segmental PA	434.6±204.3			486±177			0.047
			Paraspinal muscle	49.1±10			48.3±10.5			0.981
		Mean attenuation (HU)		452.6±179.9			489.4±168			0.779
		Mean background noise (HU)		22.8±3.2			21.8±4.7			0.956
		SNR		19.9±7.9			22.4±7.7			0.779
		CNR		17.7±8			20.2±7.7			0.617
	Qualitative	Five-point scale score	Image quality		5	5-5		5	5-5	0.351
			Image noise		5	4-5		5	4-5	0.302
Radiologist 2	Quantitative	Attenuation (HU)	Main PA	454.3±166.9			511±129.6			0.077
			Right PA	449.1±177.2			471.7±158.3			0.536
			Left PA	451±129			453.4±169.9			0.949
			Right posterior basal segmental PA	457.2±201.3			488.6±160.4			0.423
			Left apical-posterior segmental PA	443.8±186.5			493.3±194.2			0.213
			Paraspinal muscle	45.9±14.2			49.1±11.4			0.137
		Mean attenuation (HU)		441.6±169.3			442.1±168.1			0.977
		Mean background noise (HU)		24.7±3.9			23.9±5.1			0.399
		SNR		18.3±6.2			23.4±19.1			0.081
		CNR		19.3±3.9			17.7±5.2			0.097
	Qualitative	Five-point scale score	Image quality		5	5-5		5	5-5	0.346
			Image noise		5	4-5		5	4-5	0.335

CT: Computed tomography; SD: Standard deviation; Q1: 25th percentile; Q3: 75th percentile; CTPA: Computed tomography pulmonary angiography; PA: Pulmonary artery; HU: Hounsfield unit; SNR: Signal-to-noise ratio; CNR: Contrast-to-noise ratio.

value, mean background noise, SNR, and CNR), interobserver correlation was also high (r >0.90) and differences between measurements were low (mean differences <9%; SD <18%). Therefore, qualitative and quantitative evaluations demonstrated low interobserver variability (Table 4).

DISCUSSION

The current study results demonstrated that CTPA acquired with a dual-energy CT protocol provides imaging with equal quality to a standard CTPA protocol, while significantly reducing the required iodine amount. Previous study results in the literature

Table 4. Agreement limits and correlation values for quantitative and qualitative measurements

	Parameter		r-value	Subjects within agreement limits (%)
Quantitative	Attenuation (HU)	Main PA	0.93	93
		Right PA	0.93	89
		Left PA	0.92	89
		Right posterior basal segmental PA	0.92	86
		Left apical-posterior segmental PA	0.91	82
		Paraspinal muscle	0.91	92
	Mean attenuation (HU)		0.88	90
	Mean background noise (HU)		0.90	93
	SNR		0.89	90
	CNR		0.89	90
Qualitative	Five-point scale score	Image quality	0.99	98
		Image noise	0.96	96

PA: Pulmonary artery; HU: Hounsfield unit; SNR: Signal-to-noise ratio; CNR: Contrast-to-noise ratio.

are compatible with our findings. Yuan et al.[11] compared quantitative and subjective image quality and radiation dose between standard and DE-CTPA. They reported DE-CTPA with image reconstruction at 50 keV allowed a significant reduction in iodine dose, while improving the intravascular signal intensity and maintaining SNR. A systematic review by Aldosari and Sun[12] evaluated 13 articles comparing both low radiation dose and low contrast medium dose CTPA protocols to standard CTPA protocols. The quantitative evaluation revealed higher, lower, or no change in image quality compared to the standard CTPA protocol, with a majority of no change in image quality. The subjective assessment showed similar image quality in 11 studies between low-dose and standard CTPA groups and improved image quality in a study with low-dose CTPA. In our study, we achieved equivalent image quality quantitatively and qualitatively with virtual monochromatic images of 40 KeV, with a lower dose of iodinated contrast medium.

Contrast-induced nephropathy is a potential complication of procedures requiring the injection of iodinated contrast material, which presents as an acute deterioration in renal function following contrast media administration. Although CIN is usually a reversible form of acute renal failure, it is considered a limitation of CTPA in patients who are prone to renal insufficiency.[13] High contrast volume and iodine dose (gram iodine) is an independent risk factor for CIN, besides patient-related risk factors.[14,15] Therefore, utilizing a CTPA protocol with lower contrast media volume and iodine dose would lower the risk of CIN after the procedure.

The CTPA protocols with low-tube voltage have been suggested to improve contrast enhancement while reducing radiation dose due to better absorption close to the k-edge of iodine.[4,16] This technique significantly increases the attenuation value of the iodinated contrast material, particularly with the vascular lumen. However, this is accompanied by an increase of X-ray attenuation, which increases the image noise, particularly in patients with higher body mass index. The DE-CTPA allows rapid switching between low- and high-tube voltages and the acquisition of low- and high-energy datasets simultaneously. Therefore, monochromatic images are available for the better visualization of the vascular lumen while requiring less amount of contrast media and maintaining low image noise.

Dual-energy CT allows the characterization of materials based on their photoelectric absorption properties on low- and high-energy data sets.[7] This principle is employed to reconstruct color-coded iodine maps of dual-energy CT lung perfusion imaging, which correlates with lung blood volume.[8] There are multiple reports in the literature on the contributing value of dual-energy CT lung perfusion imaging in the diagnosis of pulmonary embolism.[9,17-20] The DE-CTPA protocol offers the advantages of a CTPA protocol that requires ultra-low dose contrast administration with equal image quality to standard CTPA and simultaneous lung perfusion imaging, contributing to diagnostic accuracy.

Nonetheless, the current study has some limitations. This is a single-center, retrospective study which lacked subject-specific radiation dose data. Also, as the investigation was focused on image quality, any study with pulmonary embolism was excluded. Therefore, the diagnostic power of each protocol and the potential effect of a thrombus in the pulmonary vascular system on the image quality were unable to be evaluated.

In conclusion, dual-energy computed tomography pulmonary angiography protocol delivers image quality equal to standard computed tomography pulmonary angiography, protocol while requiring less amount of iodinated contrast medium and providing simultaneous lung perfusion imaging.

Ethics Committee Approval: The study protocol was approved by the Baskent University Institutional Ethics Review Board (date: 12.01.2021, no: KA21/04). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Patient Consent for Publication: A written informed consent was obtained from each patient.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions: Idea and concept: K.H., P.C.; Design; K.H., P.C.; Control/supervision: K.H., D.K.; Data collection: K.M.H., G.K.; Analysis and interpretation: P.C.; Literature review: K.H., P.C.; Writing the article: P.C.; Critical review: K.H., D.K.; References: P.C.; Materials: K.H., P.C., K.M.H., G.K.

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