# Influence of Heart Rate on Image Quality and Radiation Dose Exposure in Coronary CT Angiography

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# Influence of Heart Rate on Image Quality and Radiation Dose Exposure in Coronary CT Angiography

*Thomas J. Stocker, MD • Jonathon Leipsic, MD • Marcus Y. Chen, MD • Stephan Achenbach, MD • Juhani Knuuti, MD, PhD • David Newby, MD, PhD • Jörg Hausleiter, MD*

From the Medizinische Klinik und Poliklinik I, Ludwig-Maximilians-Universität, Marchioninistrasse 15, Munich 81377, Germany (T.J.S., J.H.); DZHK (German Center for Cardiovascular Research), Partner Site Munich Heart Alliance, Munich, Germany (T.J.S., J.H.); Department of Medical Imaging and Division of Cardiology, University of British Columbia, Vancouver, Canada (J.L.); National Heart, Lung, and Blood Institute, National Institutes of Health, Bethesda, Md (M.Y.C.); Department of Cardiology, Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany (S.A.); Department of Clinical Physiology, Nuclear Medicine and PET and Turku PET Centre, Turku University Hospital, Turku, Finland (J.K.); and Department of Cardiology, Royal Infirmary, University of Edinburgh, Edinburgh, Scotland (D.N.). Received January 28, 2021; revision requested February 22; revision received April 8; accepted April 21. **Address correspondence to** J.H. (e-mail: *joerg.hausleiter@med.uni-muenchen.de*).

Conflicts of interest are listed at the end of this article.

See also the editorial by Schoepf and Decker in this issue.

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The diagnostic value of coronary CT angiography (CTA) strongly depends on image quality, and radiation dose should be as low as reasonably achievable. Heart rate was identified as an independent predictor for coronary CTA image quality and radiation exposure (1,2). However, scanner and protocol improvements may bring to question the importance of heart rate control, and the optimal heart rate for patients undergoing coronary CTA is currently unclear. In this subanalysis of the Prospective Multicenter Registry on Radiation Dose Estimates of Cardiac CT Angiography in Daily Practice, or PROTECTION VI (3,4), we aimed to identify the optimal heart rate in coronary CTA allowing for best image quality and radiation dose reduction.

## Materials and Methods

We consecutively included the first 50% of coronary CTA examinations from each PROTECTION-VI study site enrolled between March and December 2017 (clinical trial registration number NCT02996903). All study sites were in control of their CT protocols. Images from CTA were evaluated in a core laboratory by a blinded CTA scan reader with 5 years of experience. A second reader, also with 5 years of experience, re-evaluated 20% of CTA studies that were adequately distributed among study sites (interrater reliability coefficient, 0.81), and a senior CT scan reader with 15 years of experience was consulted in cases of divergent results ($n$ = 53). Image quality of each coronary artery (left main artery, left anterior descending artery, left circumflex artery, and right coronary artery) was categorized (1, nondiagnostic; 2, adequate; 3, good; 4, excellent). Representative grading for the right coronary artery is demonstrated in Figure 1. Subsequently, the image quality score for each coronary CTA scan was calculated by averaging the image quality of all four coronary arteries. The signal-to-noise ratio, contrast-to-noise ratio, and dose-length product were analyzed as described in a previous study (5). Variables are expressed as medians with interquartile ranges (IQRs). Groups were compared using the Dunn Kruskal-Wallis multiple-comparison test, and $P$ values were adjusted with the Bonferroni method. Linear

$P < .05$ was considered indicative of a statistically significant difference.

## Results

We analyzed 1911 patients from 57 study sites. The median patient age was 59 years (IQR, 50–68 years); 831 (43%) were women. All major manufacturers were included (837 patients [44%] were imaged with Siemens equipment, 557 [29%] with GE Healthcare, 275 [14%] with Canon, and 242 [13%] with Philips). The median heart rate was 60 beats per minute (IQR, 55–66 beats per minute); 1798 patients (94%) were in sinus rhythm (unspecified in 12 patients), and 1370 patients (72%) received beta blocker therapy before undergoing coronary CTA. The median image quality score was 3.5 (IQR, 3.0–3.75), the median signal-to-noise ratio was 14 (IQR, 11–18), and the median contrast-to-noise ratio was 11 (IQR, 8–15). The median dose-length product was 170 mGy · cm (IQR, 99–310 mGy · cm). The CT scan mode was associated with radiation exposure (retrospective helical: 376 mGy · cm; prospective axial: 107 mGy · cm; prospective helical: 46 mGy · cm; $P < .001$).

Patients were grouped by heart rates in intervals of five beats per minute (≤45 beats per minute: 59 patients; 46–50 beats per minute: 158 patients; 51–55 beats per minute: 362 patients; 56–60 beats per minute: 475 patients; 61–65 beats per minute: 358 patients; 66–70 beats per minute: 249 patients; 71–75 beats per minute: 101 patients; >75 beats per minute: 149 patients). The median image quality score was higher in patients with a heart rate below 60 beats per minute (image quality score, ≥3.5) than in those with a heart rate above 60 beats per minute (Fig 2, *A*) (all $P < .01$). Linear regression analysis demonstrated an improvement of image quality with heart rate reduction (effect on image quality score: +0.18 per 10–beat per minute decrease in heart rate, $P < .001$), and the effect was confirmed in a multivariable model that included various CT scanner specifications (Table). The median

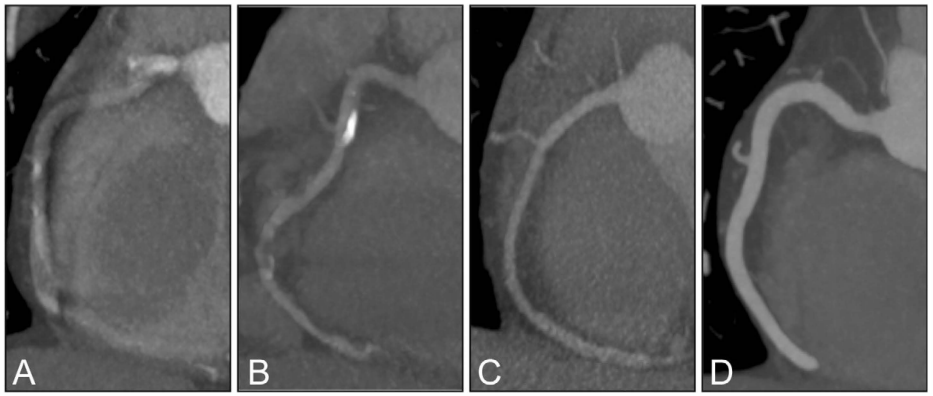


**Figure 1:** CT angiographs show representative grading of the image quality for the right coronary artery. *A*, Grade 1 (nondiagnostic); *B*, grade 2 (adequate); *C*, grade 3 (good); *D*, grade 4 (excellent).

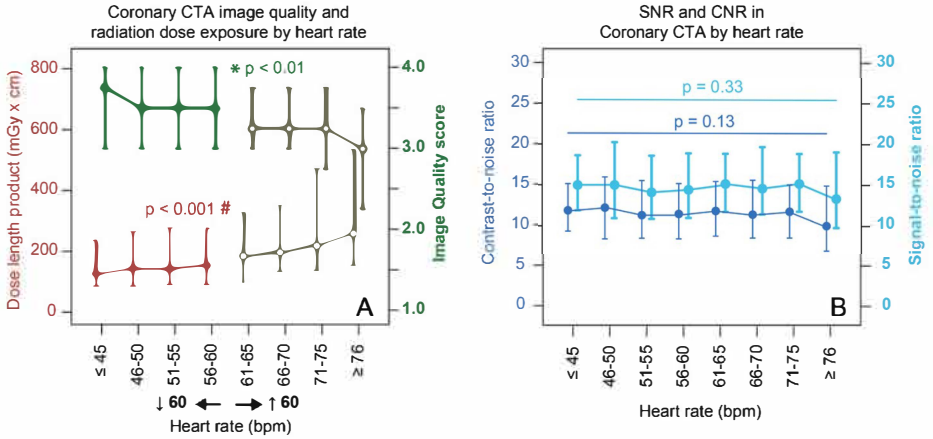


**Figure 2:** *A*, Lower heart rate is associated with improved image quality and reduced radiation dose exposure in coronary CT angiography (CTA). Median image quality score (green lines [top]) and median dose-length product (red lines [bottom]) of coronary CTA images were separately calculated in heart rate groups of five–beat per minute (bpm) intervals. Multiple comparison testing identified a significantly improved image quality score (median image quality score, ≥3.5; all $P < .01$) and lower radiation dose exposure (median dose-length product, <170 mGy · cm; all $P < .001$) in patients with heart rate below 60 beats per minute when compared with those with heart rates above 60 beats per minute. * = Median image quality score in patients with heart rates of 56–60 beats per minute versus 61–65 beats per minute: 3.5 versus 3.25; $P < .01$. # = Median dose-length product in patients with heart rates of 56–60 beats per minute versus 61–65 beats per minute: 152 mGy · cm versus 183 mGy · cm; $P < .001$. Dots represent the medians, and vertical lines illustrate interquartile ranges. *B*, Signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) are independent from heart rate in coronary CTA. Signal-to-noise ratios (light blue line [top]) and contrast-to-noise ratios (dark blue line [bottom]) were similar in all heart rate groups. Dots represent the medians, and vertical lines illustrate interquartile ranges.

rhythm but did not reach significant difference (3.5 vs 3.25, respectively; $P = .06$). The quantitative image quality parameters of signal-to-noise ratio and contrast-to-noise ratio were similar between all heart rate groups (Fig 2, *B*). The median dose-length product was below the threshold of 170 mGy · cm only in patients with a heart rate below 60 beats per minute (Fig 2, *A*). In a linear regression analysis, the dose-length product was reduced by 48 mGy · cm per 10–beat per minute decrease in heart rate ($P < .001$).

## Discussion

The results from this international, multivendor, real-world analysis confirm the notion that heart rate has significant influence on image quality in coronary CT angiography (CTA). The results suggest that cardiologists and radiologists should aim for a lower patient heart rate to obtain the best image quality and simultaneously allow for lower radiation dose in coronary CTA imaging. Therefore, the use of beta blockers should be considered in the absence of contraindications for heart rate control

**Effect of Heart Rate Reduction and CT Scanner Specifications on Image Quality of Coronary CT Angiograms**

| Parameter | Univariable Analysis | | Multivariable Analysis | |
|---|---|---|---|---|
| | Effect | *P* Value | Effect | *P* Value |
| Heart rate (per 10–beat/min decrease) | 0.18 (0.13, 0.23) | <.001* | 0.18 (0.13, 0.23) | <.001* |
| CT gantry rotation time (≤280 msec) | 0.31 (0.16, 0.46) | <.001* | 0.36 (0.01, 0.71) | .05 |
| CT detector width (reference: 128–192 sections) | | | | |
| ≤64 sections | −0.56 (−0.85, −0.26) | <.001* | −0.21 (−0.60, 0.17) | .28 |
| 256–320 sections | −0.16 (−0.33, 0.01) | .07 | −0.40 (−1.00; 0.20) | .19 |
| CT scan mode (reference: retrospective helical) | | | | |
| Prospective axial | 0.07 (−0.14, 0.28) | .53 | −0.06 (−0.21, 0.09) | .43 |
| Prospective helical | 0.36 (0.12, 0.59) | <.05* | 0.18 (0.03, 0.32) | .10 |
| CT manufacturer (reference: GE Healthcare) | | | | |
| Siemens | 0.22 (0.03, 0.42) | <.05* | −0.10 (−0.67, 0.47) | .73 |
| Philips | −0.01 (−0.18, 0.16) | .95 | 0.02 (−0.16, 0.36) | .82 |
| Canon | −0.02 (−0.18, 0.18) | .89 | −0.02 (−0.23, 0.19) | .85 |

Note.—Unless otherwise specified, data are the effect on image quality score, with 95% CIs in parentheses.

* Statistically significant difference.

and reduction of heart rate variability. On the basis of our findings, we recommend beta blockers, especially in patients with heart rates above 75 beats per minute, while beta blockers might be carefully considered in patients with heart rates between 60 and 75 beats per minute to increase the likelihood for best image quality—even with modern high-resolution CT scanners.

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