Automatic Extraction of Comprehensive Cardiac CT Angiography Parameters: A Novel Program with High Accuracy and Efficiency

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Abstract We tested the accuracy and efficiency of a novel automated program capable of extracting 15 cardiac computed tomography angiography (CTA) parameters from clinical CTA reports. Five hundred cardiac CTA reports were retrospectively collected and processed. All reports were prepopulated with a structured template per guideline. The program extracted 15 parameters with high accuracy (97.3 %) and efficiency (84 s). This program may be used at other institutions with similar accuracy if its report format follows the Society of Cardiovascular Computed Tomography (SCCT) guideline recommendation.

Keywords Algorithm \cdot Database management \cdot Data extraction \cdot Efficiency \cdot Radiation dose

Introduction

Per the recommendation of the American College of Radiology (ACR), radiation dose parameters, such as computed tomography dose index (CTDI) and dose-length product (DLP), should be archived to establish exam appropriateness and to optimize exam protocols [1]. ACR initiated the Dose Index Registry as a national effort to provide exam standardization and feedback to individual institutions [1]. To facilitate data transmission, several software programs have been developed to enable automatic extraction of dose parameters from Digital Imaging and Communications in Medicine (DICOM) images or its metadata [2, 3]. Radiation exposure in a cardiac CT angiography (CTA) exam is a result of complex interaction among multiple factors, such as the ECG synchronization method, kVp used, patient's body mass index (BMI), heart rate, etc. Given the variety of information that is needed to create a comprehensive cardiac CTA registry, manual data extraction can be time-consuming and may not be feasible in centers with high volume or limited resources. Natural language process (NLP), a field that studies the interaction between human languages and computers, has had broad applications in radiology and may be utilized in cardiac CTA report processing [4, 5]. In this manuscript, we describe a novel automated program capable of extracting 15 cardiac CTA-related parameters from clinical CTA reports. We tested its efficacy and accuracy against manual extraction.

Methods

Our institutional review board granted a waiver for this retrospective quality assurance research. The Health Insurance Portability and Accountability Act (HIPAA) compliance was maintained throughout the study.

Patient Population and Exam Protocols

We retrospectively collected 500 consecutive cardiac CTA reports from October 2012 to April 2013. Text reports, patient age, and gender were downloaded from the radiology report search application (RENDER, Massachusetts General Hospital, Boston, MA) used at our institution in Excel format (Fig. 1a). All cardiac CTAs were performed on multi-detector 64-detector-row or higher scanners under direct physician supervision. A cardiac CTA report template (Fig. 2) was set to automatically populate as part of the default report associated with the relevant exam codes in the radiology information

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| d | A | | | В | C | D | | E | F | | G | D | 4 | | А | | В | | | С | | D | |
|------|--------------|-----|-----|-------------|------|----------|-------|----------|----------|---------|----------|--------|-------|----------|----------|-------|-----------|-----|---------|------------|-------|---------|-------|
| | COMP DATE | | | MRN | AGE | SEX | REP | ORT | | | | D | 1 | categor | Y. | sea | rch optio | on | Searc | h start | Sea | rch end | |
| , | faketime1 | | | fakeid1 | 69 | M | Add | endur | n Begir | s Out | side in | | 2 | MRN | | + | | | 1 | | + | | |
| - | fakatima2 | | | fakoid2 | 50 | | EVA | M. Du | Imonar | Voin | CTAI | - | 3 | age | | + | | | 1 | | + | | |
| 2 | Idketimez | | | Idkeluz | 55 | IVI | EAA | IVI. PU | monar | y vem | CIAI | | 5 | COMP | DATE | + | | | 0 | | + | | |
| 4 | faketime3 | | | fakeid3 | 73 | м | EXA | M: Ca | rdiac Cl | Angio | ograph | 1 | 6 | scan ty | be | + | | | 2 Prog | am Type1 | | | |
| 5 | faketime4 | | | fakeid4 | 37 | M | EXA | M: Ca | rdiotho | racic C | T with | | 7 | meanH | 2 | | | | 1 Prog | ram_Heart | Rate | | |
| 6 | faketime5 | | | fakeid5 | 38 | F | EXA | M: Ca | rdiac CT | Angio | graph | | 8 | minHR | | | | | 1 | | | | |
| 7 | faketime6 | | | fakeid6 | 64 | M | FXA | M: Pu | Imonar | v Vein | CTA II | | 9 | max HR | | | | | 1 | | | | 1 |
| | fakatima7 | | | fakoid7 | 22 | E | EVA | M. Ca | diac CT | Angie | aranh | | 10 | contras | t (cc) | | | | 1 Prog | ram_Contr | ast | | |
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| 0 | faketime9 | | | fakeid9 | 74 | F | EXA | M: Pu | Imonar | y Vein | CTA II | | 13 | betablo | cker | | | | 1 | | | | |
| 11 | faketime10 | | | fakeid10 | 79 | M | EXA | M: Car | rdiac CT | Angio | graph | | 14 | height | | + | | | 1 PATIE | NT HEIGH | · : | | |
| 12 | faketime11 | | | fakeid11 | 73 | F | FXA | M: Pu | Imonar | v Vein | CTA II | | 15 | RMI | | + | | | 1 PATE | NI WEIGH | | | |
| ~~ | - difetiment | | | - anceroara | | | 2.01 | | | , | • | - | 17 | kv | | + | | | 1 Tube | notential: | kVn | | |
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| | | | | | | | | | | | | | 21 | pro | | | | | 1 | | | | |
| | | | | | | | | | | | | | 22 | flash | | 12 | | | 1 | | | | |
| - 11 | A | В | С | [| > | E | F | G | н | 1 | J | K | | L | M | N | 0 | P | Q | R | S | Т | U |
| 1 | MRN | age | sex | COMP_DA | TE S | can type | meant | minHR | max HI | contra | flow_r i | nitrog | gl be | etabl h | eight w | eight | BMI | kV | mAs | Total [r | etro | pro | flash |
| 2 | fakeid1 | 69 | 1 | faketime | 1 A | ORTA | 56 | 54 | 61 | 90 | 6 | 600 | D | 0 | 74 | 190 | 24 | 100 | 160 | 296 | 0 | 1 | 0 |
| 3 | fakeid2 | 59 | 1 | faketime | 2 P | ULM VEIN | 63 | 57 | 71 | 100 | 5.4 | (| D | 0 | 69 | 238 | 35 | 120 | 453 | 285 | 0 | 0 | 1 |
| 4 | fakeid3 | 73 | 1 | faketime | 3 N | ATIVE | 55 | 29 | 127 | 175 | 6 | 600 | D | 0 | 69 | 169 | 25 | 120 | 317 | 546 | 0 | 0 | 1 |
| 5 | fakeid4 | 37 | 1 | faketime | 4 A | ORTA | 98 | 93 | 103 | 120 | 5 | (| D | 0 | 67 | 175 | 27 | 120 | 312 | 156 | 0 | 0 | 1 |
| 6 | fakeid5 | 38 | 0 | faketime | 5 N | ATIVE | 52 | 43 | 101 | 90 | 5 | 600 | 0 | 5 | 63 | 156 | 27.6 | 80 | 196 | 58 | 0 | 1 | 0 |
| 7 | fakeid6 | 64 | 1 | faketime | 6 P | ULM VEIN | 72 | 42 | 113 | 100 | 8 | (| D | 0 | 67 | 300 | 47 | 140 | 405 | 392 | 0 | 0 | 1 |
| 8 | fakeid7 | 33 | 0 | faketime | 7 A | ORTA | 48 | 39 | 64 | 90 | 6 | 600 | 0 | 5 | 72 | 160 | 21.7 | 100 | 356 | 88 | 0 | 0 | 1 |
| | | | | | | | | | | | | | | | | | | | | | | | |

122

78 96

85

85 4 5

4.5

4.5

53 42

59 50

62 58 64

PULM VEIN

PULM VEIN

CABG

Fig. 1 Screenshot of input (**a**), parameter (**b**), and output (**c**) file. **a** Input file was downloaded from RENDER; both exam time and patient's MRN were replaced with systematic syntax to protect patient information for this manuscript. **b** Parameter Excel sheet listing variable names and their processing information. Information is listed by category (parameter name), search option (θ to skip, I if output is a number, 2 if output is text), search start (either the upper delimiter if it is a simple number

0 faketime9

1 faketime10

0 faketime11

system (RIS). The template followed the structured reporting format per guidelines [6] and department policies, but reporting physicians had the flexibility to modify the template when appropriate.

Automatic Extraction Program

10 fakeid9

11 fakeid10

12 fakeid11

74

79

73

A program to extract patient and scan parameters (Table 1) was written in Matlab (Version 7.10.0, MathWorks, Inc, Natick, MA, USA). Patient parameters included the average, minimum, and maximum heart rate (beats per minute [bpm]) during image acquisition, patient's height (in inches), weight (in pounds), and BMI (in kilograms per square meter). Scan parameters included scan indication (native coronary assessment, coronary artery bypass grafting [CABG] assessment, aortic assessment, pulmonary vein assessment for pre-atrial fibrillation ablation, or congenital disease evaluation), total contrast administered (in cubic centimeters), contrast flow rate (in cubic centimeters per second), nitroglycerin administered (in micrograms), beta-blocker administered (in milligrams), ECG synchronization used (retrospective ECG gating, prospective ECG triggering, or high-pitch helical prospective ECG triggering), tube voltage (in kilovolt), tube current-time extraction, or name of the sub-program to be directed to), and search end (the lower delimiter for a simple number extraction). Rows of the same color are processed by the same sub-program. **c** Output file listing extracted data by columns as contained in the parameter file. Note an error in the height column (*red arrow*) was most likely due to incorrect formatting (i.e., likely expressed as 5 ft xx in., vs. in.). Gender is listed as *l* if male, *0 if* female

27.4

24.4

24

150

149

0 63 138

120

120 169 483

120

385

238 143

168

0 0

0

1

0

product (in milliampere seconds), and DLP (in milligraycentimeter) per exam.

The time needed to process 500 cases was internally measured by the program. Extraction errors were identified by manually comparing the processed data with its original report. Comparisons were performed by a fellow with 2 years of training in cardiac CT. The accuracies per parameter were then calculated as (the number of correct data entries for each parameter)/(total number of data entries for each parameter). The overall accuracy for all exams was calculated as (the number of all correct data entries)/(total number of data entries). Exams were then divided by their corrected exam indications, and the overall accuracy containing all parameters for each exam indication was calculated as (the number of correct data entries for exams that belong to a specific indication)/(total number of entries for exams that belong to such exam indication). Data entries that were not mentioned in the report and were left as empty cells in the processed data sheet were considered as correct extractions. For any parameter with an accuracy <95 %, the most common reasons for error were noted.

The automatic extraction program is illustrated in Fig. 3 and described in detail below. A pseudo-code is included in Appendix.

EXAM: INDICATIONS: ADDITIONAL HISTORY: PRIOR REVASCULARIZATION: None COMPARISON: TECHNIOUE: Scanner: 128-slice dual-source multidetector CT Acquisition: Scout images, test bolus, __. Delayed images were not acquired. ____ Multiplanar post processing and 3D volume rendering were performed[and interpreted. A maximum width full field of view was also reconstructed and reviewed. Radiation dose protection: Automatic exposure control: Yes; Automatic tube potential selection: Yes; ECG-modulation: Tube potential: 100 kVp / Tube current: ____mAs Total exam exposure: ___ DLP mGy-cm MEDICATION: Blank if no metoprolol CONTRAST: CTA was performed using a 20 cc test bolus followed by _cc of Isovue 370 (iopamidol) at _cc/sec. A 40 cc normal saline flush was injected immediately following each contrast injection. VITAL SIGNS: Before scan rate _____beats per minute, __/__mm Hg; After scan rate ____beats per minute __/__. PATIENT HEIGHT: __in. / PATIENT WEIGHT: __ibs. / BMI: __kg/m2 / BSA: __m2 HEART RATE AND RHYTHM: Rhythm: with average __ BPM during acquisition (range __ to __ bpm). QUALITY: Good. There are ____ uninterpretable segments.

Fig. 2 Part of cardiac CTA report template with relevant patient and scan parameters. Findings, impression, and recommendation sections are not shown

Step 1: Locate Input Excel File

Input data was downloaded from RENDER as an Excel worksheet to the same folder as the automatic extraction program (Fig. 1a). The program generated a list of Excel files in the local folder from which the user could select the input file.

Step 2: Direct Each Parameter to the Appropriate Pathway for Extraction

Parameters were classified as either *numerical* or *categorical*. Numerical parameters were further divided into simple extraction and complex extraction. Simple numerical extraction used pre-specified delimiters and generated one number as an output. For example, DLP was extracted as the number between the phrase "total exam exposure" and "mGy-cm." Delimiters that were used in simple extractions are shown in a snapshot of the parameter Excel file (Fig. 1b). User had the flexibility to modify delimiters as needed. Complex numerical extraction and categorical extraction were directed to its subprograms, which searched for certain text in the report and followed a predefined decision rule. For example, an exam was considered to be performed for the indication of aorta assessment if (1) the phrase "aorta assessment" was present anywhere in the report or (2) aorta measurements such as the ascending aorta diameter were made and mentioned in the report. The predefined decision rules were formulated by a research fellow with 2 years of experience in cardiac CT angiography. Detailed decision rules for each subprogram are illustrated in Appendix, Pseudo-code. All parameter processing information were stored in Excel file [parameter.xslx] (Fig. 1b).

Step 3: Repeat Step 2 until All Parameters are Extracted

Step 2 was repeated until all parameters listed in parameters.xslx were extracted. Processed data were written on an output Excel file as shown in Fig. 1c.

Step 4: Visual Inspection

During our clinical practice, the processed data was then visually inspected for any entry that appeared outside of the physiological range (for example, a height of 5 in.). Such error was then corrected by manual extraction from the clinical report. Correction was not performed for these 500 test cases in this study in order to maintain original output data for accuracy assessment.

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| Table 1Accuracy rate on a parameter basis for 499 patients(excluding one aborted exam) | Parameter extracted | Accuracy (number correct/499) (%) | Commonly noticed reason for inaccurate extraction | | | | | | |
|--|--|-----------------------------------|---|--|--|--|--|--|--|
| | Patient parameters | | | | | | | | |
| | Average heart rate (bpm) | 96.0 | | | | | | | |
| | Minimum heart rate (bpm) | 96.0 | | | | | | | |
| | Maximum heart rate (bpm) | 96.0 | | | | | | | |
| | Height (in.) | 92.6 | Incorrect formatting | | | | | | |
| | Weight (lbs) | 94.8 | Incorrect formatting | | | | | | |
| | BMI (kg/m ²) | 98.2 | | | | | | | |
| | Scan parameters | | | | | | | | |
| | Scan indication* | 98.2 | | | | | | | |
| | Total contrast administered (cc) | 98.2 | | | | | | | |
| | Contrast flow rate (cc/s) | 98.8 | | | | | | | |
| | Amount of nitroglycerin administered (mcg) | 99.8 | | | | | | | |
| | Amount of beta blocker administered (mg) | 100.0 | | | | | | | |
| | ECG synchronization method* | 93.0 | Duplicated entries | | | | | | |
| | Tube potential (kV) | 98.4 | | | | | | | |
| | Tube current-time product (mAs) | 97.8 | | | | | | | |
| | Total DLP (mGy-cm) | 100.0 | | | | | | | |
| | Overall accuracy | 97.3 | | | | | | | |

*Categorical parameters



Fig. 3 Flow chart illustrating the automatic extraction algorithm

Results

Fifteen parameters for 499 patients were successfully extracted with an overall accuracy of 97.3 % on a per data entry basis (Table 1). One aborted exam was excluded from all accuracy calculations. Two parameters were categorical (scan indication and ECG synchronization method) and the other 13 parameters were numerical. The processing time for automatic extraction was 84 s. Accuracy exceeded 95 % for 12 parameters. Three parameters (height, weight, and ECG synchronization method) had accuracies below 95 % but above 90 %. Reasons most often quoted for errors were incorrect formatting (such as in a different unit than inches or pounds) for parameter height and weight, and duplicated entries for the parameter ECG synchronization method (i.e., two consecutive CTA acquisitions were performed with different ECG synchronization methods). Accuracy of each parameter is detailed in Table 1.

Automatic extraction for native, aortic, CABG, and pulmonary vein assessment yielded excellent accuracies (>97 % for all). Congenital disease protocols resulted in a significant lower accuracy rate of 84.8 % in comparison to other scan indications (Table 2).

Discussion

In this paper, we described an automated program capable of extracting 15 parameters from clinical cardiac CTA reports with high accuracy and efficiency. We demonstrated the feasibility of developing a simple extraction program in house to tailor data collection specific to cardiac CTA exams.

Our institution maintained a comprehensive cardiac CTA registry that dated back to the introduction of 64-slice multidetector computed tomography (MDCT) for clinical cardiac CTA [7]. Our initial data collection was performed manually and was labor-intensive. An opportunity for developing an automatic data extraction program came after our department

 Table 2
 Accuracy rate by cardiac CTA scan indication (on a per data entry basis)

| Cardiac CTA exam indication ($n =$ total number of data entries in each exam indication category) | Accuracy rate per data point (%) |
|--|-------------------------------------|
| Native coronary artery evaluation (3,900) | 98.2 |
| Aortic assessment (810) | 97.3 |
| CABG assessment (510) | 98.6 |
| Pulmonary vein evaluation (1,830) | 97.9 |
| Congenital disease protocol (435) | 84.8 |
| | |

adopted the structured cardiac CTA reporting as recommended by guidelines [6]. Structured formatting prompted cardiac imaging specialists to enter exam-related parameters. It minimizes errors and has also made text-searching feasible with our current program [8]. In fact, one of the most common reasons for errors in our extraction was deviation from standard reporting, such as incorrect format and duplicated entries.

Our program has been shown to be highly accurate and efficient. Although we had an error rate of 2.7 % in these 500 consecutive cases, these errors were easily recognizable (such as data beyond a physiological range, etc.) and could be corrected with minimal effort. Specifically, we would like to note that congenital disease protocol was associated with a more than 10 % accuracy gap in comparison to exams performed for other indications. This significantly lowered accuracy may be due to the complexity of congenital diseases, as our imaging specialists modified the exam acquisition and report structure appropriately to answer disease-specific nonroutine questions [9]. In comparison to other metadata or DICOM-based extraction program, our program was able to obtain comprehensive information regarding patient and exam parameters in addition to radiation exposure. This comprehensive information enabled our registry to function beyond record keeping. It provided accessible data for quality improvement initiatives and retrospective research projects without exposing patient's medical history. Although this program was specifically developed for our institution, it may be able to operate with similar accuracy for other institutions if they were to employ structured CTA reports that adhere to the Society of Cardiovascular Computed Tomography (SCCT) guidelines.

Our limitations include reliance on structured reports and inaccuracy when structured templates are not followed. Additionally, our program only extracts, but does not verify, information on the report. Therefore, if a manual error is made in generating the report, our program would have transcribed the information as it is on the report and would have not detected it.

Conclusion

We described an automated program capable of extracting 15 parameters from clinical cardiac CTA reports with high accuracy (97.3 %) and efficiency. This program may be used in other institutions with similar accuracy if CTA reports are structured in a format that follows SCCT guidelines.

Conflict of Interest Authors report no conflict of interest.

Appendix: Pseudo-Code for Programs

Main Program

Load Excel sheet

Label each column with variable names: MRN, age, gender, exam date, and report

Populate data for MRN, age, gender, and exam date (in its original format as in the input file)

Load parameter.xlsx, columns are category, search option, search start, and search end

For jj=6: 22

```
%%Comment: row 6 [scan type] is the first parameter that needs to be processed; this loop
is carried out till the last parameter (the 22^{\mbox{\scriptsize nd}} row) is processed.
        For kk=1: number of patients in the excel sheet
               If search option(jj)==1 %%this will give a number output
                       If search start(jj) doesn't contain the string "Program_"
                                        %%Comment: then this is a simple number extraction
                                n1=find the position of string in search start (jj)
                                n2=find the position of string in search end(jj)
                       output(jj, kk)=find the number in between n1 and n2
                        else
                                %% comment: if start(ii) does contain the string "Program" this will
                                be a complex number extraction
                                Direct to sub-program specified in search start(jj)
                                Output(jj,kk)=output from the sub-program
```

end

```
elseIf search option(jj)==2 %% this variable has output in text format
       direct to sub-program specified in search star(jj)
       Output(jj,kk)=output from the sub-program
    else %% for everything else
              Skip that row
    end %% this finishes extraction for one patient
end % % this finishes extraction for one parameter for all patients
```

end %% this finishes all extractions for all patients

Subprograms

```
Program_Type1: %% for scan indications
```

```
%% there are 5 different scan indications for cardiac CTA: native coronary assessment,
aortic assessment, CABG assessment, congenital disease evaluation, and pulmonary vein evaluation
before atrial fibrillation ablation
```

if aortic measurements (such as ascending diameter, sinotubular junction dimension, etc) are made

```
or if the referring physician wrote "aortic assessment" as scan indication,
       output(ii.kk)="AORTA"
```

```
elseif CABG or bypass graft were mentioned anywhere in the report,
              output="CABG"
elseif scan was labeled as " congenital disease protocol'
              output=CONGENITAL"
elseif scan was labeled as " pulmonary vein scan"
              output="PULMONARY VEIN
else
```

%% if none of above was mentioned output="NATIVE" end % Program_Type1 end here.

Program_HeartRate

%% this sub-program will output the average, minimum, and maximum heart rate %%in beats per minute (bpm)

- Index1=find the position of header "HEART RATE AND RHYTHM:" Index2=find the position of the next header by searching ":" after Index1
- Find numbers between Index1 and Index2
- Sort numbers in ascending order. The middle one is the average heart rate, the smallest is the minimum heart rate, and the largest number is the maximum heart rate Write output

Program Contrast

%% this sub-program calculates the overall contrast agent administered and its

flow rate. Index1=find the position of the header " CONTRAST:" Index2= find the position of the next header by searching ":" after Index1 Between index1 and index2 total contrast=test bolus+ contrast used for CTA acquisition

flow rate = search for a number before the unit "cc/sec' output total contrast and flow rate

Program Med

%% this gives 2 outputs, dose of nitroglycerin in mcg and dose of metoprolol in mg Index1=find the position of the header "MEDICATION:' Index2= find the position of the next header by searching ":" after Index1 Between Index1 and Index2

Search for " nitroglycerin", the number before nitroglycerin is its dose in mcg Search for "metoprolol", the number that immediately proceeds it is its dose in mg. If one or both of the numbers are not found, its corresponding output is 0

Output nitroglycerin dose and metoprolol dose

Program Triggering

%% this programs gives 3 binary outputs for gating methods (retrospective gating, prospecting triggering, and high pitch helical prospective triggering). The program assumes that only 1 CTA is performed and thus three gating methods are mutually exclusive.

Index1=find the position of the header " TECHNIQUE: Index2= find the position of the next header by searching ":" after Index1

Between Index1 and Index2

If the word "retrospective" exists

- Retrospective gating =1
- Elseif the word "high-pitch" or " high pitch" exist
- High pitch prospective helical triggering=1;
- % for everything else, we assume it's prospective triggering
- Prospective triggering=1;

```
End
```

References

- 1. Amis Jr, ES, Butler PF, Applegate KE, Birnbaum SB, Brateman LF, Hevezi JM, Mettler FA, Morin RL, Pentecost MJ, Smith GG, Strauss KJ, Zeman RK: American College of Radiology white paper on radiation dose in medicine. J Am Coll Radiol 4(5):272-284, 2007. doi:10.1016/j.jacr.2007.03.002
- 2. Dave JK, Gingold EL: Extraction of CT dose information from DICOM metadata: automated Matlab-based approach. AJR Am J Roentgenol 200(1):142-145, 2013
- 3. Li X, Zhang D, Liu B: Automated extraction of radiation dose information from CT dose report images. AJR Am J Roentgenol 196(6), 2011
- 4. Friedman C, Alderson PO, Austin JH, Cimino JJ, Johnson SB: A general natural-language text processor for clinical radiology. J Am Med Inform Assoc 1(2):161-174, 1994
- 5. Hripcsak G, Austin JH, Alderson PO, Friedman C: Use of natural language processing to translate clinical information from a database of 889,921 chest radiographic reports. Radiology 224(1):157-163, 2002

- Raff GL, Abidov A, Achenbach S, Berman DS, Boxt LM, Budoff MJ, Cheng V, DeFrance T, Hellinger JC, Karlsberg RP: SCCT guidelines for the interpretation and reporting of coronary computed tomographic angiography. J Cardiovasc Comput Tomograph 3(2):122–136, 2009. doi:10.1016/j.jcct.2009.01.001
- Ghoshhajra BB, Engel LC, Major GP, Goehler A, Techasith T, Verdini D, Do S, Liu B, Li X, Sala M, Kim MS, Blankstein R, Prakash P, Sidhu MS, Corsini E, Banerji D, Wu D, Abbara S, Truong Q, Brady TJ, Hoffinann U, Kalra M: Evolution of coronary computed tomography radiation dose reduction at a tertiary referral center. Am J Med 125(8): 764–772, 2012. doi:10.1016/j.amjmed.2011.10.036
- Ghoshhajra BB, Lee AM, Ferencik M, Elmariah S, Margey RJ, Onuma O, Panagia M, Abbara S, Hoffmann U: Interpreting the interpretations: the use of structured reporting improves referring clinicians' comprehension of coronary CT angiography reports. J Am Coll Radiol, 2013. doi:10.1016/j. jacr.2012.11.012
- Ghoshhajra BB, Sidhu MS, El-Sherief A, Rojas C, Yeh DD, Engel LC, Liberthson R, Abbara S, Bhatt A: Adult congenital heart disease imaging with second-generation dual-source computed tomography: initial experiences and findings. Congenit Heart Dis 7(6):516–525, 2012. doi:10.1111/chd.12008