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We Built This House; It's Time to Move in: Leveraging Existing DICOM Structure to More Completely Utilize Readily Available Detailed Contrast Administration Information

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Abstract The Digital Imaging and Communications in Medicine (DICOM) standard is the universal format for interoperability in medical imaging. In addition to imaging data, DICOM has evolved to support a wide range of imaging metadata including contrast administration data that is readily available from many modern contrast injectors. Contrast agent, route of administration, start and stop time, volume, flow rate, and duration can be recorded using DICOM attributes [1]. While this information is sparsely and inconsistently recorded in routine clinical practice, it could potentially be of significant diagnostic value. This work will describe parameters recorded by automatic contrast injectors, summarize the DICOM mechanisms available for tracking contrast injection data, and discuss the role of such data in clinical radiology.

Keywords Contrast media · Digital imaging and communications in medicine (DICOM) · Communication · Image data · Information storage and retrieval

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Introduction

Automated contrast injectors (ACI) have become increasingly sophisticated and now offer more refined control on how contrast media is administered for various imaging exams. The advances in CT imaging, with faster scan times and improved resolution, benefit from this increased control and modulation of the contrast administration. However in routine practice, the exact details of volume, flow rates, and agents are rarely leveraged within the radiology department, let alone across the healthcare enterprise. While technologists and administrators may use summary data for logistical purposes (such as to manage contrast inventory), we propose that contrast injection data may have much broader clinical implications.

We will discuss the data yield from a typical ACI. Then, how that information can be stored in DICOM, and thus made available to the enterprise. Additionally, we will discuss how inclusion of the contrast administration information into the imaging metadata can benefit the various stakeholders: patients, physicians, technologists, and administrators.

What is an Automated Contrast Injector

An automated contrast injector is a device that allows for the delivery of intravenous contrast media used in conjunction with a medical imaging device, such as a CT or MRI scanner. For the purpose of this paper, an ACI is the combination of a power injector with a computer interface that can provide precise control of the injection and interface with other information systems. They are most commonly used in CT, MRI, and interventional radiology. Most models will store both contrast and saline, and have the ability to administer each at precise flow rates and volume, either individually or blended. The parameters for each exam are recorded and archived

allowing the user to review details of each exam as well as summary information. Retrieval of recorded data can assist in clinical analysis, for administrative review, be utilized to improve patient safety, and provide data for quality control. The injection data recorded by a modern ACI is summarized in Table 1.

Current Clinical Practice

While the information regarding the contrast injection is fairly detailed, the information that the radiologist receives is usually limited. For example, in the case of an abdominal CT protocol for a liver hemangioma, the abdomen is scanned multiple times after the contrast has been administered. Instead of using chronological details of when the abdomen was scanned after the contrast was administered, functional modifiers are annotated such as "arterial phase", "portal venous phase", and "delayed phase." Paradoxically, the technical imaging protocol will outline fairly precise delay times to be used in scanning after contrast injection. As a result, the only confirmation the radiologist has as to the accuracy of the image timing is to reference anatomic solid organ enhancement patterns and correlate those visual references with the titled labels for each sequence. It may be more informative for the radiologist to know that the images viewed in "arterial phase" were acquired 26.5 s after contrast was injected, rather than looking for aortic and cortical renal enhancement, especially when the timing in a particular patient may be earlier or later than expected or labeled.

Table 1 Summary of information typically recorded by an automated contrast injector

Data
Date
Time of injection
Set pressure limit
Filled contrast volume
Filled saline volume
Contrast injected volume
Saline injected volume
Extravasation detected
Pressure limit occurred
Minimum pressure
Maximum pressure
Average pressure
Contrast name
Contrast cost
Contrast concentration
Saline cost
Injection duration
Software version

There is no standard convention for the inclusion of contrast information within the radiology report. However, this information is important for several reasons. The billing department needs to know if contrast was given for an exam, because reimbursement rates depend on whether or not contrast was given. Proper documentation of contrast administration is increasingly of importance as intravenous contrast is considered by the Joint Commission of accreditation as a medication, and they routinely review departmental guidelines for policy on contrast administration documentation.

The documentation for contrast administration for most departments is provided in two ways. The radiologist will normally state in the technique portion of the report whether the exam was conducted without contrast or with contrast, or both. The technologist will also document the type and amount of contrast administered, usually in the form of a handwritten log book. There is a significant gap in the amount of information that is actually recorded for contrast administration and the abundance of information available from a modern ACI. Some departments have begun to bridge that gap. Information from the ACI is summarized into a single page which is screen captured and saved as a DICOM image for inclusion into the patient's images. Thus, the image is retained as a separate series in the PACS archive and associated with a specific exam. The image can be viewed as a separate series at the radiologist view station. This method is currently used in our institution for contrast-enhanced CT exams and has also been described by others [2]. It contains the total volume of contrast injected and the flow vs. time curve. A drawback to this method is that the original data utilized to create the image are not typically retained in a computer readable format. Automatic analysis of these data would require conversion from screen capture form back into numerical form, much akin to work described by Cook et al. applying optical character recognition to CT dose screen captures [3].

Structured Representation of Contrast Injector Data Using DICOM

There are several options for inclusion of contrast injector data using the DICOM standard, ranging from summary data screen captures, as just described, to DICOM structured reports.

DICOM

The DICOM standard has evolved to support a wide range of imaging modalities and metadata. The current DICOM standard can store contrast administration data that is readily available from many modern contrast injectors as metadata in

designated fields. Table 2 summarizes how the current DICOM standard incorporates information related to contrast administration.

When contrast administration data is populated as DICOM attributes, these data can be displayed at the image review workstation or retrieved for analysis. A possible suggestion for implementation at the work station would be to include the contrast agent type and total volume injected. Some hospitals are requiring this information to be included on the final radiology report for billing purposes. Manual entry of the contrast information is inherently at risk for human error. Another implementation that would be helpful would be the inclusion of an accurate time after initial contrast administration at the imaging station. A proposed screen shot of such an implementation is given in Fig. 1.

By using standard DICOM tags to record injection metadata, image viewing systems could display such metadata at the PACS client.

Storing the data directly using DICOM attributes represents one solution to preserve the data and properties of the contrast administration. A substantial proportion of the information available from the ACI can be stored in the DICOM tags. Most data values can be entered directly into the appropriate attributes from ACI output, such as flow duration, contrast/bolus volume, and start and stop time. Some data values can be obtained with a relatively simple calculation such as flow rate and contrast bolus stop time. Flow rate would be injected volume (contrast volume and/or saline volume) divided by injection duration. Contrast bolus stop time would be the time of injection plus the injection duration. The values for contrast usage, agent information (administered, detected, phase, and sequence), route, ingredient code, and concentration currently require a specific implementation that are not currently available.

Table 2 Summary of DICOM tags and attributes related to contrast administration

DICOM tag (group, element)	DICOM attribute
(0018, 0010)	Contrast/bolus agent
(0018, 0012)	Contrast/bolus agent sequence
(0018, 0015)	Contrast/bolus administration route
(0018, 1040)	Contrast/bolus route
(0018, 1041)	Contrast/bolus volume
(0018, 1042)	Contrast/bolus start time
(0018, 1043)	Contrast/bolus stop time
(0018, 1044)	Contrast/bolus total dose
(0018, 1046)	Contrast flow rate
(0018, 1047)	Contrast flow duration
(0018, 1048)	Contrast/bolus ingredient code
(0018, 1049)	Contrast/bolus ingredient concentration
(0018, 9337)	Contrast/bolus agent number
(0018, 9338)	Contrast/bolus ingredient code sequence
(0018, 9340)	Contrast/bolus profile sequence
(0018, 9341)	Contrast/bolus usage sequence
(0018, 9342)	Contrast/bolus agent administered
(0018, 9343)	Contrast/bolus agent detected
(0018, 9344)	Contrast/bolus agent phase

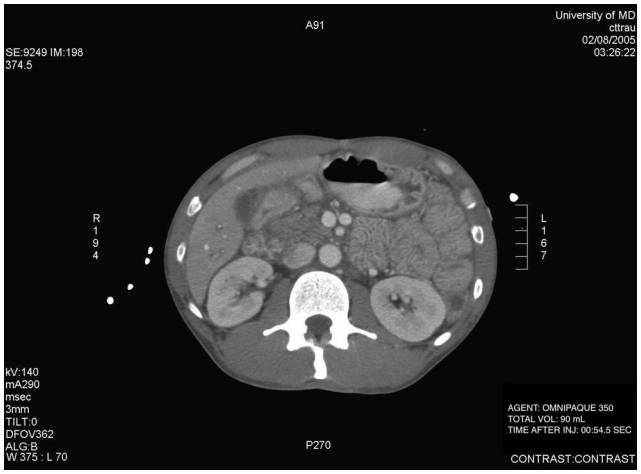

Fig. 1 Suggested implementation of contrast injector data into a CT exam

A more comprehensive implementation of ACI data could be done using a DICOM structured report. Currently, there is an ongoing effort within working group 6 through the development of supplement 164 to create The Substance Administration DICOM Structured Report. DICOM's concept of a structured report is different from the "structured reporting" radiologists typically refer to in reference to utilizing a template in the interpretation and reporting of an imaging exam. DICOM structured reports are service-object pair (SOP) classes within the DICOM standard which define how data needs to be processed. DICOM structured reports are very specific in the tasks they are defined to accomplish and are thus named according to their function. For example, the need to integrate digitized data flow within the cardiac catheterization laboratory lead to the creation of the Quantitative Arteriography and Ventriculography Structured Reports, and the need to formalize documentation of radiation exposure during CT imaging lead to the creation of the CT Radiation Dose Reporting (Dose SR). The Substance Administration DICOM Structured Report is intended to cover how agents (contrast, radiopharmaceuticals, etc.) are introduced into the circulatory system in a controlled fashion. A structured report for contrast administration will provide systematic inclusion of contrast data in radiology reports. It will also allow for search, storage and retrieval of information, and comparison of similar data elements. DICOM structured reports support free text entry, as well as structured information, such as flow rates and pressure reading over time. The Substance Administration DICOM Structured Report will have separate components for preset injection protocols, customized injection protocols, and delivered injection parameters which describe administration events, flows, pressure, timings,

physiochemical attributes, and pharmacological attributes of agent administration, as well as consumables related to the administration. In addition, injection metadata contained in DICOM structured reports could also be consumed by clinical applications outside of radiology.

Implementation of the Substance Administration DICOM Structured Report could have many workflow advantages over current capability. For example, deviation of present injection protocols verses delivered injection parameters could be easily tracked by looking up into the related structured reports for an examination. It would allow for greater flexibility in analytics, assuming availability of the above data in PACS, one could easily look up list of abnormally delivered injections for a specific time period filtered by various criteria, such as catheter gauge size.

Integration with the healthcare enterprise would also allow the capture of current clinical data. This could be incorporated into a department protocoling work flow and made available prior to the exam. The exam could be protocoled using unique clinical factors of a patient pertinent to the exam, and the protocol could be modified. Patient age, weight, BMI, current renal function, and last contrast exam protocol could be extracted and presented to the technologist and injection parameters could be modified for those patient specific factors in an automated or semi-automated fashion.

Discussion

The data now available from the next generation of informatics enabled contrast injectors can only be utilized by all stake holders if that information is stored in a retrievable format. Unfortunately, there are significant challenges to implementing this information in clinical practice. The largest challenge lies in the need for a vendor neutral common cross-platform level of communication. Cross-platform systems, including the contrast injector, the imaging modality, and the PACS must have common ground on which the information can be accessed and utilized.

Decreased Dosing and Cost

Decreasing the dose of contrast media to a patient and decreasing costs of contrast usage are synergistic efforts. Departments are continuously looking for ways to operate more efficiently and decrease their operational costs. This has become more important as reimbursement for radiology exams has continued to decline. Effective and efficient use of contrast media during contrast enhanced CT exams can be more closely scrutinized, and cost savings can be realized using the data from ACIs. The use of contrast media that is drawn up but not utilized represents a tremendous opportunity to achieve cost savings. One study looking prospectively at consecutive contrast enhanced CT exams documented 11 mL of contrast media waste per exam, for example [4]. Another group was able to realize cost savings by using decreased volume of contrast media used by administering a higher concentration of contrast. [5] Once contrast injector data is incorporated into the imaging metadata, it could be of potential benefit for radiology and hospital administrators. Clear and accurate documentation of contrast dose and administration is of increasing concern for hospitals as they conform to joint commission standards and National Patient Safety Goals [6].

Improve Quality and Safety

The benefit for the interpreting radiologist would be more detailed information about the contrast bolus at the viewing station. The role of contrast injection data in clinical radiology can be briefly detailed in the following two scenarios, an extravasation event and CT pulmonary angiography.

Contrast extravasation occurs when the contrast is administered, but errantly is injected within the soft tissues near the access site, but not into the vessel. If the contrast injector information is available, it can allow the radiologist to better troubleshoot the reasons for the contrast extravasation. More detailed information will reveal patterns in patient selection, equipment usage, or technique that were previously unnoticed. In a recent prospective study of 52 extravasations, catheter gauge, location of the injection site, and age of the patient were related to increased risk of extravasations [7]. It should be noted that catheter type and gauge, as well as location of injection site are not current attributes in DICOM, but could be included in The Substance Administration DICOM Structured Report.

CT pulmonary angiography is a common exam conducted to determine if there is thrombus within the pulmonary arteries. Precise timing of the contrast bolus is needed to adequately opacify the pulmonary arteries. While there are aids to assist in timing of the bolus, such as automated bolus tracking, nondiagnostic exams still occur due to inadequate opacification of the pulmonary arteries. It has been postulated that one cause is transient dilution of contrast from the inferior vena cava [8] or from a patent foramen ovale [9]. If more accurate contrast injection information was available, it may allow the radiologist and technologist to better assess why the exam was nondiagnostic and prevent future occurrences.

Optimization of protocols for contrast enhanced CT exams represent are another area in which detailed contrast injector data can have significant benefit. Department protocols are usually well established for most exams and are primarily initiated on specific time delay or coordinated with bolus tracking software. However, assessment of their efficacy is retroactively based on image quality. Quite often the parameters of the

injection for the exam in question are not known. This topic is highlighted in a recent review article on intravenous contrast medium administration and scan timing, indicating that more exact control of contrast injection is needed to optimize advantages in new CT scanners [10]. To further support this need, recent research has shown improved detection of hypervascular liver lesions was observed when using patient-tailored scan delay times when compared to fixed scan delay times [11].

Stored and retrievable contrast injector data will allow the injector parameters to be reviewed and correlated with image quality. This could lead to better refinement of imaging protocols with the goal to both reduce contrast dose and improve image quality.

The technologist may also benefit from stored contrast injector data in a retrievable format. Should there be a concern over image quality due to enhancement characteristics of the image, the technologist could review the data with the imaging to better troubleshoot possible causes. This could result in an improved contrast injection plan the next time that the patient receives the same study resulting in the improvement in image quality. A lead technologist could also review injector data parameters for a group of technologists and review for technique patterns and identify outliers or best practice patterns for others to learn from. Retrievable contrast injector data could also better facilitate contrast usage patterns and allow for better identification of areas of potential overdose or waste and better anticipate resupply needs. When the technologists have access to retrievable contrast injector data, they will have reliable quantitive measures to troubleshoot problems, improve technique, and monitor supplies.

Conclusion

Modern automated contrast power injectors can provide very detailed information on the contrast bolus. This detailed information can be stored using DICOM mechanisms, but in routine clinical practice this information is either not stored in any database or in a summary screen capture format which is of limited utility. Now is the time to leverage this information, by either populating available DICOM elements or through DICOM structured reports. There is clear benefit to be obtained immediately which can be used for intepretation of radiology exams by providing more accurate contrast information to the radiologist and other providers. Additionally, there is clear benefit to technologists to allow for better refinement of protocols and troubleshoot difficult exams. Administrators will be able to better monitor contrast administration usage to keep department costs down. Furthermore, an accumulating database of accurate contrast data would assist in the future with data mining for quality assurance and clinical research. The ability to couple accurate, detailed contrast administration data with the exam images has been significantly limited in the past. However, tracking contrast injection metadata will benefit radiologists, technologists, administrators, researchers and most importantly, patients.

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