Machine QA data standardization through online collaborative systems

Rodney D. Wiersma

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- Very complicated machines that if not operating properly could cause serious injury to patients.

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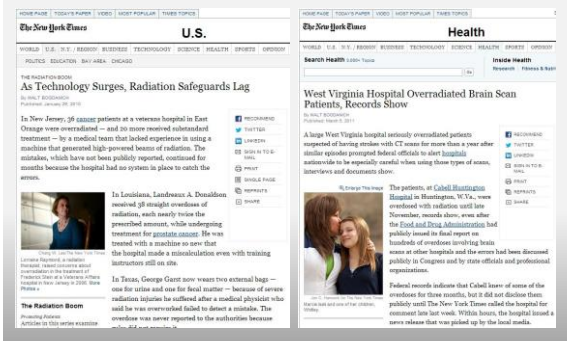

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American Association of Physicists in Medicine (AAPM) Guidelines

- TG-51 LINAC Dose Output
- TG-66 QA for CT scanners
- TG-114 MU Calculations
- TG-119 Treatment planning systems
- TG-120 IMRT QA
- TG-142 medical linear accelerators

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Task Group 142 report: Quality assurance of medical accelerators[a)]

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Daily QA ~ 30 minutes

TABLE I. Daily.

Procedure	Machine-type tolerance		
	Non-IMRT	IMRT	SRS/SBRT
Dosimetry			
X-ray output constancy (all energies) Electron output constancy (weekly, except for machines with unique e-monitoring requiring daily)		3%	
Mechanical			
Laser localization	2 mm	1.5 mm	1 mm
Distance indicator (ODI) @ iso	2 mm	2 mm	2 mm
Collimator size indicator	2 mm	2 mm	1 mm
Safety			
Door interlock (beam off)		Functional	
Door closing safety		Functional	
Audiovisual monitor(s)		Functional	
Stereotactic interlocks (lockout)	NA	NA	Functional
Radiation area monitor (if used)		Functional	
Beam on indicator		Functional	

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Monthly QA ~ 4 hours

TABLE II. Monthly.

Procedure	Machine-type tolerance: Non-IMRT	IMRT	SRS/SBRT
Dosimetry			
X-ray output constancy			
Electron output constancy		2%	
Backup monitor chamber constancy			
Typical dose rate[a] output constancy	NA	2% (@ IMRT dose rate)	2% (@ stereo dose rate, MU)
Photon beam profile constancy		1%	
Electron beam profile constancy		1%	
Electron beam energy constancy		2%/2 mm	
Mechanical			
Light/radiation field coincidence[b]		2 mm or 1% on a side	
Light/radiation field coincidence[b] (asymmetric)		1 mm or 1% on a side	
Distance check device for lasers compared with front pointer		1mm	
Gantry/collimator angle indicators (@ cardinal angles) (digital only)		1.0°	
Accessory trays (i.e., port film graticle tray)		2 mm	
Jaw position indicators (symmetric)[c]		2 mm	
Jaw position indicators (asymmetric)[d]		1 mm	
Cross-hair centering (walkout)		1 mm	
Treatment couch position indicators[e]	2 mm/1°	2 mm/1°	1 mm/0.5°
Wedge placement accuracy		2 mm	
Compensator placement accuracy[f]		1 mm	
Latching of wedges, blocking tray[g]		Functional	
Localizing lasers	±2 mm	±1 mm	<±1 mm
Safety			
Laser guard-interlock test		Functional	
Respiratory gating			
Beam output constancy		2%	
Phase, amplitude beam control		Functional	
In-room respiratory monitoring system		Functional	
Gating interlock		Functional	

[a]Dose monitoring as a function of dose rate.
[b]Light/radiation field coincidence need only be checked monthly if light field is used for clinical setups.
[c]Tolerance is summation of total for each width or length.
[d]Asymmetric jaws should be checked at settings of 0.0 and 10.0.
[e]Lateral, longitudinal, and rotational.
[f]Compensator-based IMRT (solid compensators) require a quantitative value for tray position (wedge or blocking tray slot) set at a maximum deviation of 1.0 mm from the center of the compensator tray mount and the cross hairs.
[g]Check at collimator/gantry angle combination that places the latch toward the floor.

Yearly QA ~ 4 days

TABLE III. Annual.

Procedure	Machine-type tolerance: Non-IMRT	IMRT	SRS/SBRT
Dosimetry			
X-ray flatness change from baseline		1%	
X-ray symmetry change from baseline		±1%	
Electron flatness change from baseline		1%	
Electron symmetry change from baseline		±1%	
SRS arc rotation mode (range: 0.5-10 MU/deg)	NA	NA	Monitor units set vs delivered: 1.0 MU or 2% (whichever is greater) Gantry arc set vs delivered: 1.0° or 2% (whichever is greater)
X-ray/electron output calibration (TG-51)		±1% (absolute)	
Spot check of field size dependent output factors for x ray (two or more FSs)		2% for field size <4×4 cm², 1% ≥4×4 cm²	
Output factors for electron applicators (spot check of one applicator/energy)		±2% from baseline	
X-ray beam quality (PDD10 or TMR20/10)		±1% from baseline	
Electron beam quality (R50)		±1 mm	
Physical wedge transmission factor constancy		±2%	
X-ray monitor unit linearity (output constancy)	±2% ≥5 MU	±5% (2-4 MU), ±2% ≥5 MU	±5% (2-4 MU), ±2% ≥5 MU
Electron monitor unit linearity (output constancy)		±2% ≥5 MU	
X-ray output constancy vs dose rate		±2% from baseline	
X-ray output constancy vs gantry angle		±1% from baseline	
Electron output constancy vs gantry angle		±1% from baseline	
Electron and x-ray off-axis factor constancy vs gantry angle		±1% from baseline	
Arc mode (expected MU, degrees)		±1% from baseline	
TBI/TSET mode		Functional	
PDD or TMR and OAF constancy		1% (TBI) or 1 mm PDD shift (TSET) from baseline	
TBI/TSET output calibration		2% from baseline	
TBI/TSET accessories		2% from baseline	
Mechanical			
Collimator rotation isocenter		±1 mm from baseline	
Gantry rotation isocenter		±1 mm from baseline	
Couch rotation isocenter		±1 mm from baseline	
Electron applicator interlocks		Functional	
Coincidence of radiation and mechanical isocenter	±2 mm from baseline	±2 mm from baseline	±1 mm from baseline
Table top sag		2 mm from baseline	
Table angle		1°	
Table travel maximum range movement in all directions		±2 mm	
Stereotactic accessories, lockouts, etc.	NA	NA	Functional
Safety			
Follow manufacturer's test procedures		Functional	
Respiratory gating			
Beam energy constancy		2%	
Temporal accuracy of phase/amplitude gate on		100 ms of expected	
Calibration of surrogate for respiratory phase/amplitude		100 ms of expected	
Interlock testing		Functional	

The report of Task Group 100 of the AAPM: Application of risk analysis methods to radiation therapy quality management

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Some key points from TG-100

To prevent failures in RT a QA program should have:

- Standardized procedures.
- Adequate staff, physical, and IT resources.
- Adequate training of staff.
- Maintenance of hardware and software resources.
- Clear lines of communication among staff.

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QA Standardization

Procedure standardization

- Well tested QA procedures that are uniformly used across different medical centers to ensure patient safety and to allow comparison of results.
- **STATUS: partially addressed**
  - *Task groups have limited user input and feedback.*
  - *Do not keep pace with rapid technology changes*.

Data standardization

- a common vocabulary is needed to communicate between people and computer systems.
- **STATUS: not addressed**

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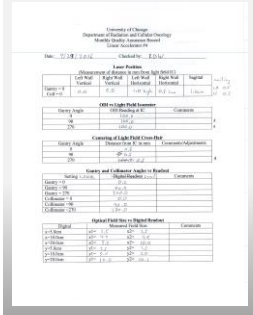
Paper



- **Data is safe with redundant backup systems.**
- **Data can be easily extracted remotely for analysis.**
- **Many types of data (DICOM) can be stored.**
- **Complex algorithms can be used on the QA system.**
- **The QA system is operating system independent.**
- **Data is in a standardized format allowing comparison across multiple institutes.**
- **Data taking procedures are standardized.**

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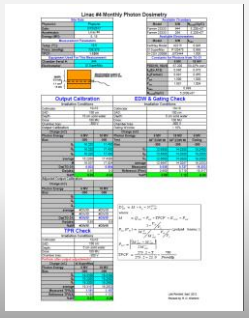
Excel



- Data is safe with redundant backup systems.
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- Complex algorithms can be used on the QA system.
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Software

- Data is safe with redundant backup systems.
- Data can be easily extracted remotely for analysis.
- Many types of data (DICOM) can be stored.
- Complex algorithms can be used on the QA system.
- The QA system is operating system independent.
- Data is in a standardized format allowing comparison across multiple institutes.
- Data taking procedures are standardized.

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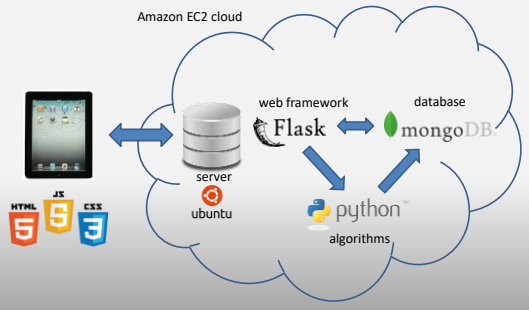
Methods



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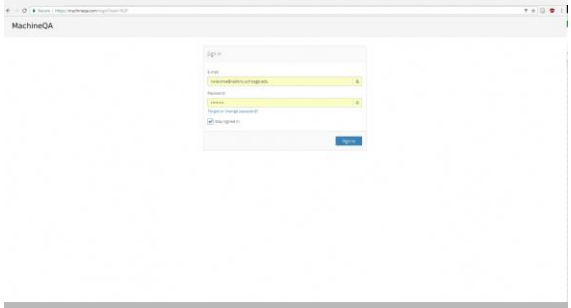

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Procedure Standardization

- QA protocols (forms) can be easily created by any user or groups of users (social collaboration).
- All forms can be shared with the group or community.
- Preexisting QA forms can be either forked or upgraded.
- Metrics are used to track the performance of QA forms to indicate popularity.
- The hypothesis is: ***Through multiple user collaboration certain forms will gain widespread popularity and form a type of QA standardization.***

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Forms

- Forms can be considered a box that hold a set of parameters.
- All users can create or modify forms.
- The owner can set sharing privileges.

class Form:
    author = the owner
    sharing = private, group, institute, or public
    devices = a list of compatible devices (truebeam, trilogy,)
    tags = a list of tags (mv, mechanical, dosimetry, etc.)
    version = version of form

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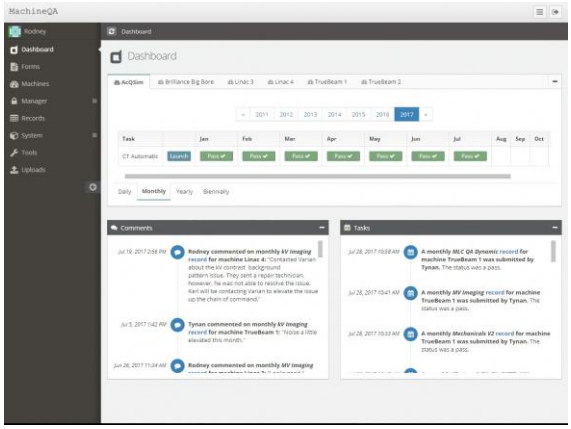
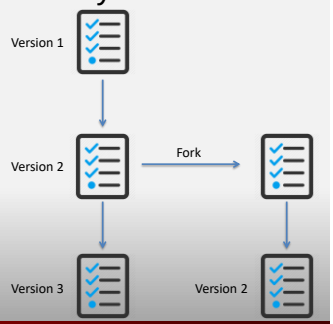


Form Version Control System

- Users can socially collaborate on building QA protocols.
- Users can comment on forms.
- Any changes to a form that is in use will result in a new version.
- To customize a form a user must first fork it.



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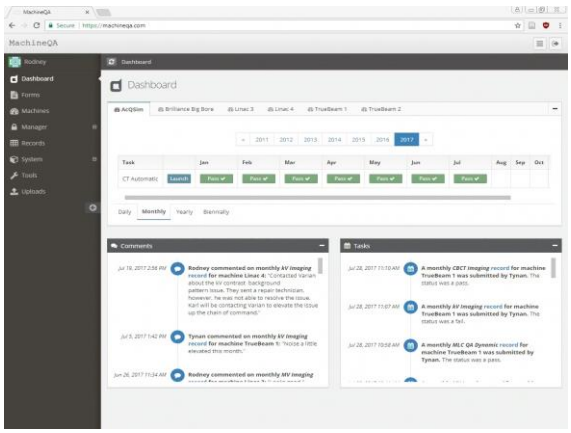
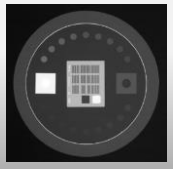


Database

- Structured Query Language (SQL) must have a fixed schema. Issues with dynamically changing content.



ID	date	author	contrast 1	contrast 2	constrat 3	contrast 4	contrast 5
1	jan	Rodney	345	200	176	150	127
2	feb	Bill	345	200	176	150	127
3	mar	Bob	345	200	176	150	127
4	apr	Rodney	345	200	176	150	127
5	jun	Todd	345	200	176		
6	jul	Max	345	200	176		
7	aug	John	345	200	176	150	127
8	sept	Jack	345	200	176	150	127
9	oct	Jack	345	200	176	150	127
10	nov	Jack	345	200	176	150	127

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Database

- MongoDB was first released in 2009 and is a schema less database system.
- Instead of tables each entry is similar to a Javascript Object Notation (JSON) like object.
- The number of fields, content and size of the document can be differ from one document to another.
- Allows embedding of data files (DICOM, JPEG, PDF, etc.).

```
{
  "firstName": "John",
  "lastName": "Smith",
  "isAlive": true,
  "age": 25,
  "address": {
    "streetAddress": "21 2nd Street",
    "city": "New York",
    "state": "NY",
    "postalCode": "10021-3100"
  },
  "phoneNumbers": [
    {
      "type": "home",
      "number": "212 555-1234"
    },
    {
      "type": "office",
      "number": "646 555-4567"
    },
    {
      "type": "mobile",
      "number": "123 456-7890"
    }
  ],
  "children": [],
  "spouse": null
}
```

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Tasks

- Tasks assign a form and users to a machine.
- Created by the group manager.
- Allow notification to task members (e-mail) when a task is completed.

class Task:
  form = a specific form
  machine = a specific machine
  users = a list of users assigned to the task

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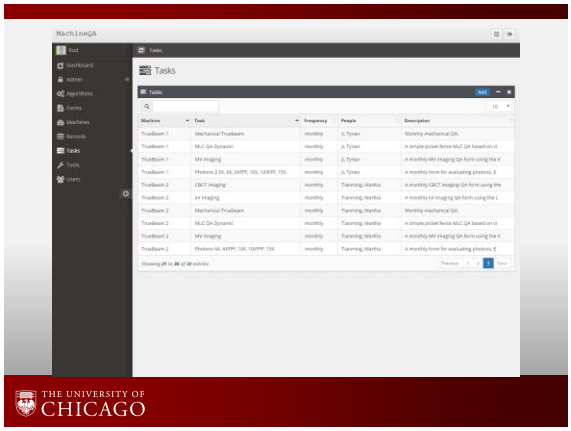

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Records

- Save a QA task's values to the database.
- Created by all users.

class Record:
author = the user who created the record
approver = the user who approved the record
form = the form
machine = the specific machine QA was performed on.
status = pass, warning, fail, or incomplete
values = list of parameters together with associated inputs.

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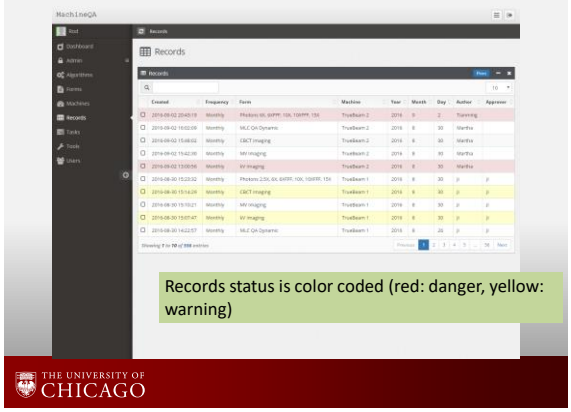

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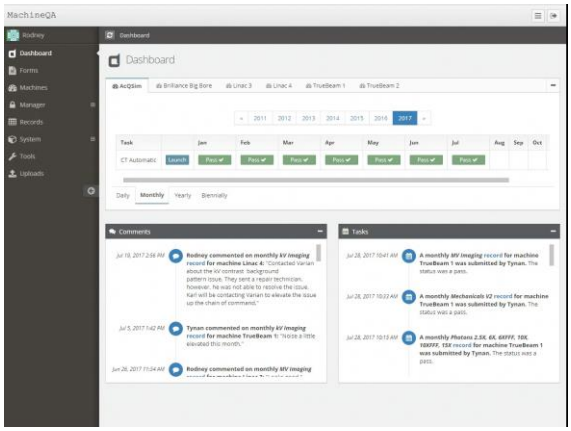

Modules

- Any user can contribute algorithms provided that they are written in Python.
- Algorithms are run as asynchronous jobs based on a queue system in order not to interfere with web site responsiveness.
- Communication of data between algorithms and the website are through JSON.

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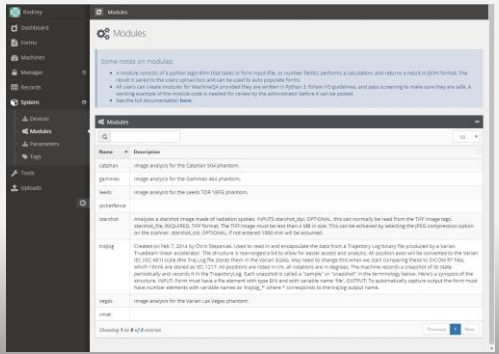

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Universal phantom algorithm

- Use of Scalable Vector Graphics (SVG) is an XML-based vector image format for two-dimensional graphics.
- Allows both phantom structure and function to be defined in a single file.

```
<svg height="180" width="180">
        <circle id="body" type="body" shape="circle" cx="90" cy="90" r="90" />
        <circle id="contrast_1" type="contrast" margin="2" width="2" shape="circle" cx="38" cy="59" r="3.75" />
        <circle id="contrast_2" type="contrast" margin="2" width="2" shape="circle" cx="47.5" cy="47" r="3.75" />
        <circle id="contrast_3" type="contrast" margin="2" width="2" shape="circle" cx="60" cy="37.5" r="3.75" />
        <circle id="intensity_center" type="intensity" shape="circle" cx="120" cy="90" r="3.75" />
        <circle id="intensity_top" type="intensity" shape="circle" cx="90" cy="21" r="3.75" />
        <circle id="intensity_right" type="intensity" shape="circle" cx="159" cy="90" r="3.75" />
        <circle id="intensity_bottom" type="intensity" shape="circle" cx="90" cy="159" r="3.75" />
        <circle id="intensity_left" type="intensity" shape="circle" cx="21" cy="90" r="3.75" />
        <rect id="mtf" type="mtf" shape="rect" x="46" y="79" width="11" height="22" />
</svg>
```

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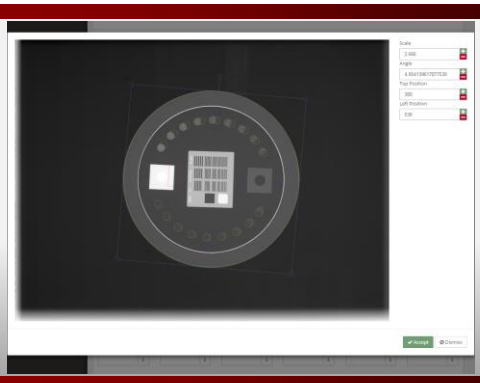

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CT

Gammex

LINAC kV

Leeds

SI QCkV-1

LINAC MV

Las Vegas

PTW EPID QC

SI QC-3

LINAC CBCT

CatPhan

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QA Standardization

Procedure standardization

- Well tested QA procedures that are uniformly used across different medical centers to ensure patient safety and to allow comparison of results.
- **STATUS: partially addressed**
  - *Task groups have limited user input and feedback.*
  - *Do not keep pace with rapid technology changes*.

Data standardization

- a common vocabulary is needed to communicate between people and computer systems.
- **STATUS: not addressed**

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Data Standardization

- Need a method to find specific QA data across many user created QA forms.

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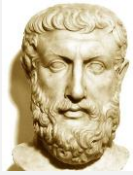
Ontology

- *Traditionally a branch of philosophy that deals with questions concerning what entities exist and how such entities may be grouped, related within a hierarchy, and subdivided according to similarities and differences.*
- *Describes a set of entities and their relationships (X marriedTo Y; or A worksFor B; or C locatedIn D, etc).*



Parmenide (515 BC) was among the first to propose an ontological characterization of nature.

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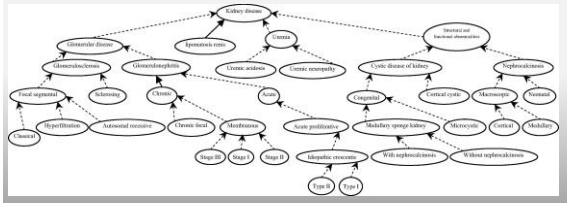
Taxonomy

- *Taxonomy is a hierarchy of concepts*
- Systemized Nomenclature of Medicine - Clinical Terms (SNOMED-CT)



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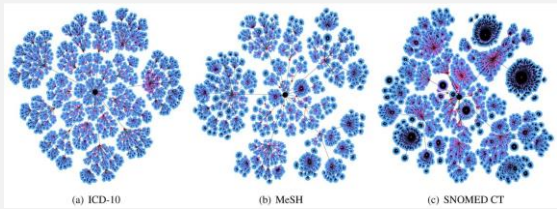

(a) ICD-10 (b) MeSH (c) SNOMED CT

International Classification of Diseases (ICD)
- Concepts: 12,417
- Depth: 4 levels
- Relations: 12,416

Medical Subject Headings (MeSH)
- Concepts: 80,689
- Depth: 14 levels
- Relations: 112,463

Systemized Nomenclature of Medicine (SNOMED)
- Concepts: 440,408
- Depth: 16 levels
- Relations: 440,408

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Digital Imaging and Communications in Medicine (DICOM)

- It was developed by the DICOM Standards Committee, whose members are part of the American College of Radiology (ACR) and The National Electrical Manufacturers Association (NEMA).
- NEMA holds the copyright to this standard.

0018,0037	TherapyType
0018,0038	InterventionStatus
0018,0039	TherapyDescription
0018,003A	InterventionDescription
0018,0040	CineRate
0018,0042	InitialCineRunState
0018,0050	SliceThickness
0018,0060	KVP
0018,0070	CountsAccumulated
0018,0071	AcquisitionTerminationCondition
0018,0072	EffectiveDuration
0018,0073	AcquisitionStartCondition
0018,0074	AcquisitionStartConditionData
0018,0075	AcquisitionEndConditionData
0018,0080	RepetitionTime
0018,0081	EchoTime

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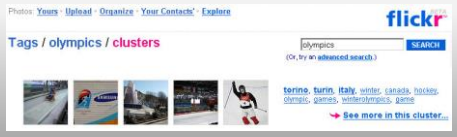
Folksonomy

- Classification system based on keywords that establish categories without stipulating or necessarily deriving a hierarchical structure of parent-child relations among different tags.
- Widely used on the internet for classifying photos, videos, podcasts, tweets, scientific papers and others (Flickr and Twitter).
- Tags are a single word electronic label.



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Data Standardization

- A QA input parameter is defined as a **combination** of lower case tags. Example: “image” “mv” “contrast”
- The hypothesis is: ***The total amount of parameters need to define all QA inputs will converge to a finite set over time.***

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Tags

- To make QA data human friendly in terms of searching and identification a combination of predefined ‘Tags’ are attached to each QA input parameter.
- To prevent misspellings, synonyms, singular/plural and compound words only certain people can create tags.

class Tag:
id = 12-byte hexadecimal (507f1f77bcf86cd799439011)
name = 20 character string (image, mv, contrast, etc...)

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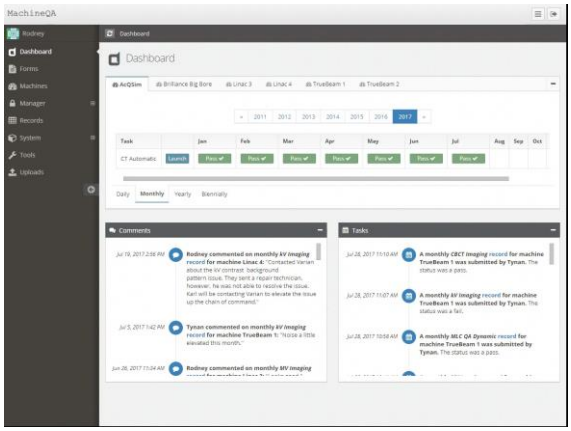

Parameters

- Parameters form the entire basis of the QA system.
- Each QA input is tied to a specific parameter.

class Parameter:

id = 12-byte hexadecimal (507f1f77bcf86cd799439011)
type = file, number, string, etc.
tags = A **combination** of tags (image, mv, contrast, etc...)

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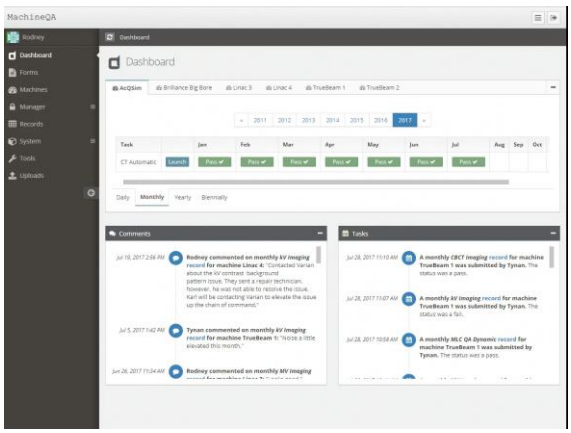

Legal and Security

- From discussions with HIPAA and IT groups data storage on a cloud server is permissible provided that there is absolutely no chance of patient data residing on the cloud.
- Encrypted communications (HTTPS).
- Weak passwords forbidden.
- Passwords are encrypted.
- Login attempts are rate limited.
- Cross-Site Request Forgery (CSRF) protection.
- Non-SQL database avoids SQL injection.
- Automatic daily backups of database.

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Conclusion

- A unified QA data management system has been successfully created and put into clinical use.
- Online social collaboration has shown to be effective at forming QA protocols.
- To test the concept of social standardization of QA protocols more medical centers and users need to added to the system.

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Acknowlegments

- All my colleagues at the University of Chicago
- The pylianc project by James Kerns https://github.com/jrkerns/pylinac

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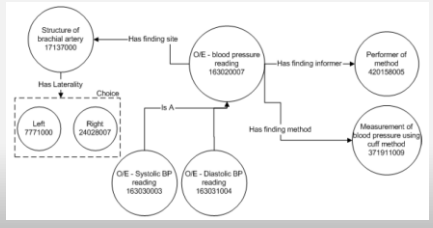
Systemized Nomenclature of Medicine - Clinical Terms (SNOMED-CT)



Relationships in SNOMED-CT are modelled as a triple of (concept, attribute, concept).

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