Computed Tomography techniques for the evaluation of Intestine

Understanding the imaging of abdomen and its interpretation

Manjunath K N, PhD

Faculty in Computer Science and Engineering, Manipal Academy of Higher Education
(Formerly Consultant, SIEMENS Healthineers, India and Germany), knm_mit@yahoo.com
ORCID - 0000-0001-8239-4047

Presentation outline

- Introduction to Gastroenterology
- CT imaging
- DICOM standard
- Scanning protocol
- Case studies
- Image source

Introduction (1/3)

Discipline and domain

CT imaging is used to find abnormalities in intestine. The clinical task includes Radiology, Gastroenterology and Medical Image Processing disciplines.

Case study

Colon polyp analysis using CT images is discussed.

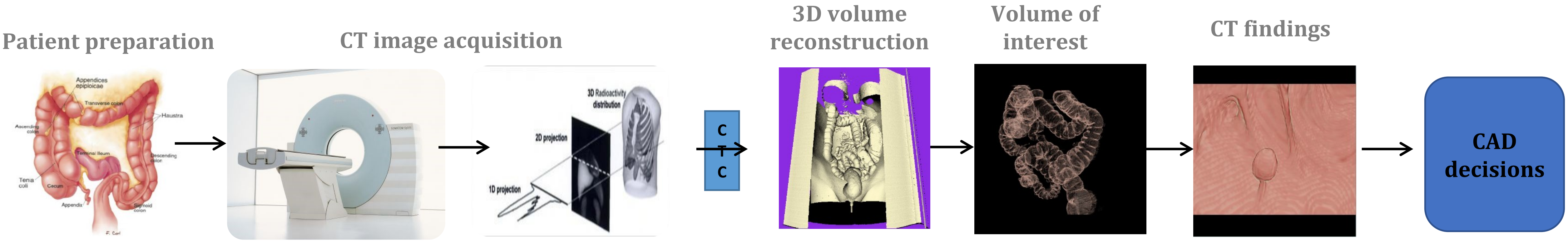


Fig 1. CT imaging workflow from patient preparation to diagnosis (Image source: Sliesenger [1], SIEMENS [2], Kalender [3])

Objective

Measurement of polyps in intestine

Imaging modality

Computed Tomography and Magnetic Resonance Imaging

Introduction (2/3) - Polyps and colon cancer

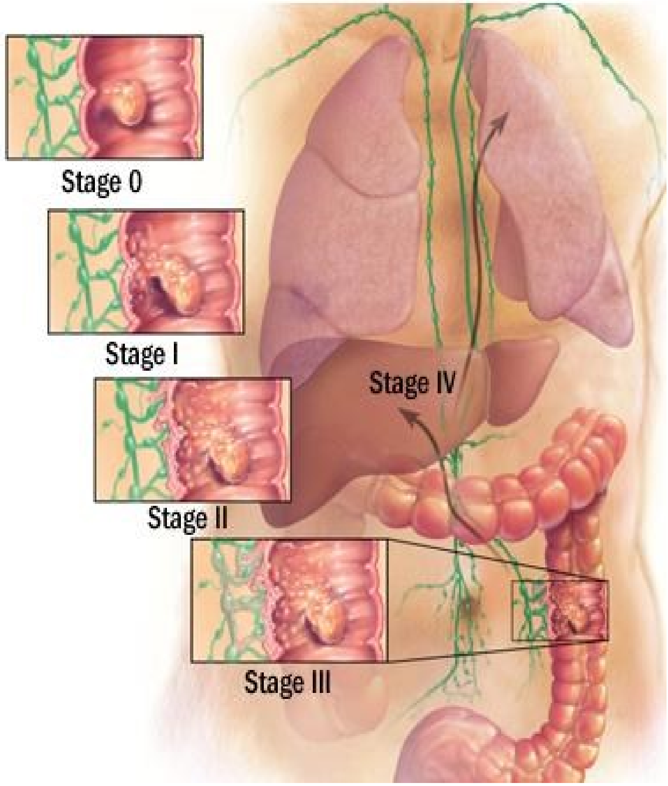
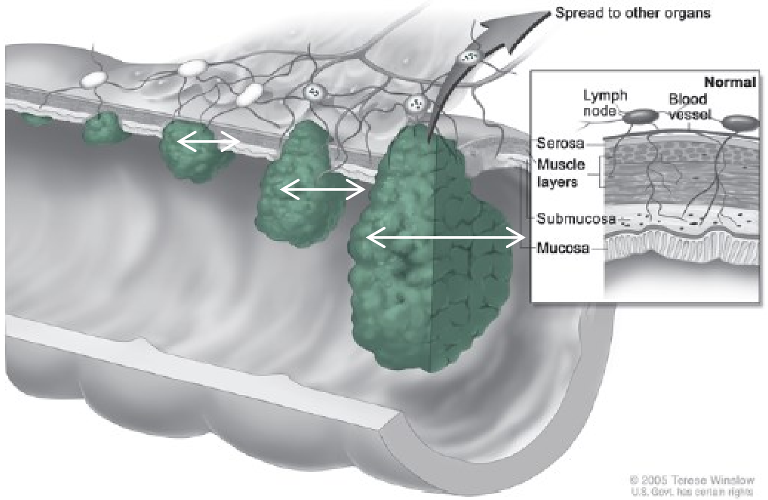
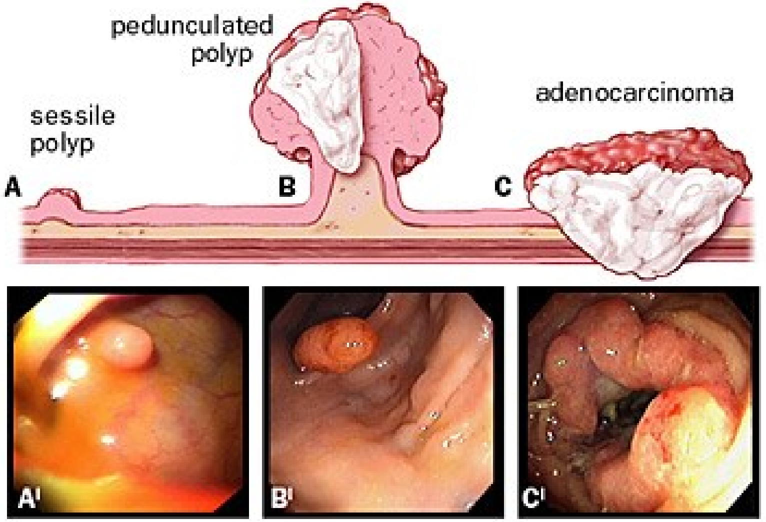


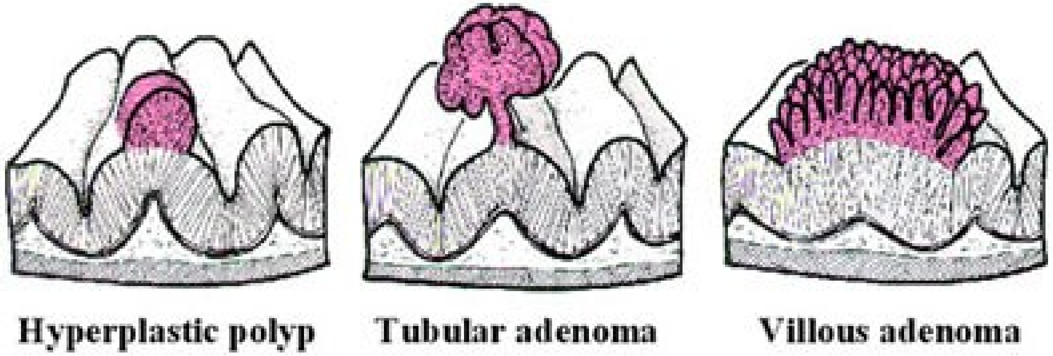
Fig 2. Different segments of Large Intestine and cancer stages (www.mayoclinic.com)



Growth of smaller polyps into colon cancer (Terese winslow)

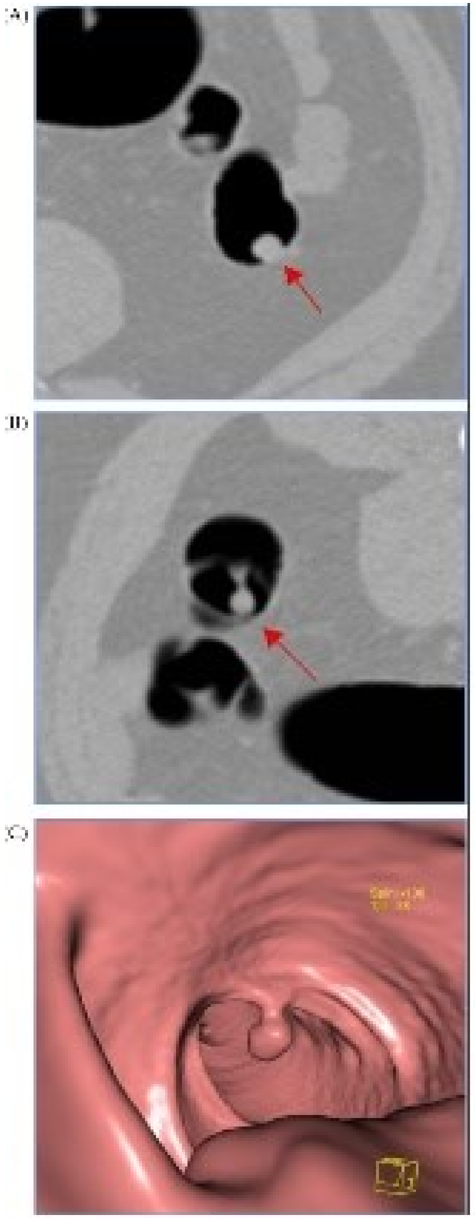


Graphical illustration of polyp growth (John Hopkins Cancer center)



Microscopic view of the polyp (www.altair.chonnam.ac.kr)

Introduction (3/3) – Polyp diagnosis



- CT Colonography is the imaging technique used to find the polyps of large intestine.
- It is a replacement for the conventional colonoscopy method which is invasive and painful.

← CTC

Colonoscopy

Patient preparation → CT scan / Colonoscopy

CT scan → Computer assisted decisions → Biopsy

Colonoscopy → Biopsy → Results interpretation

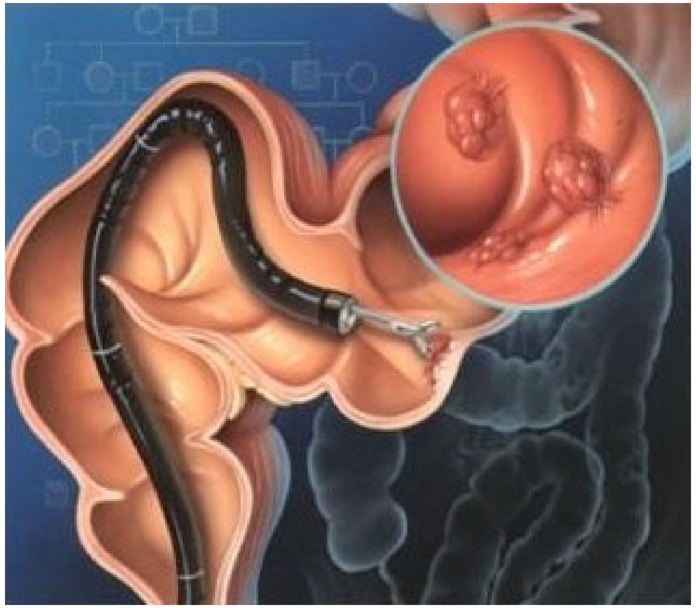
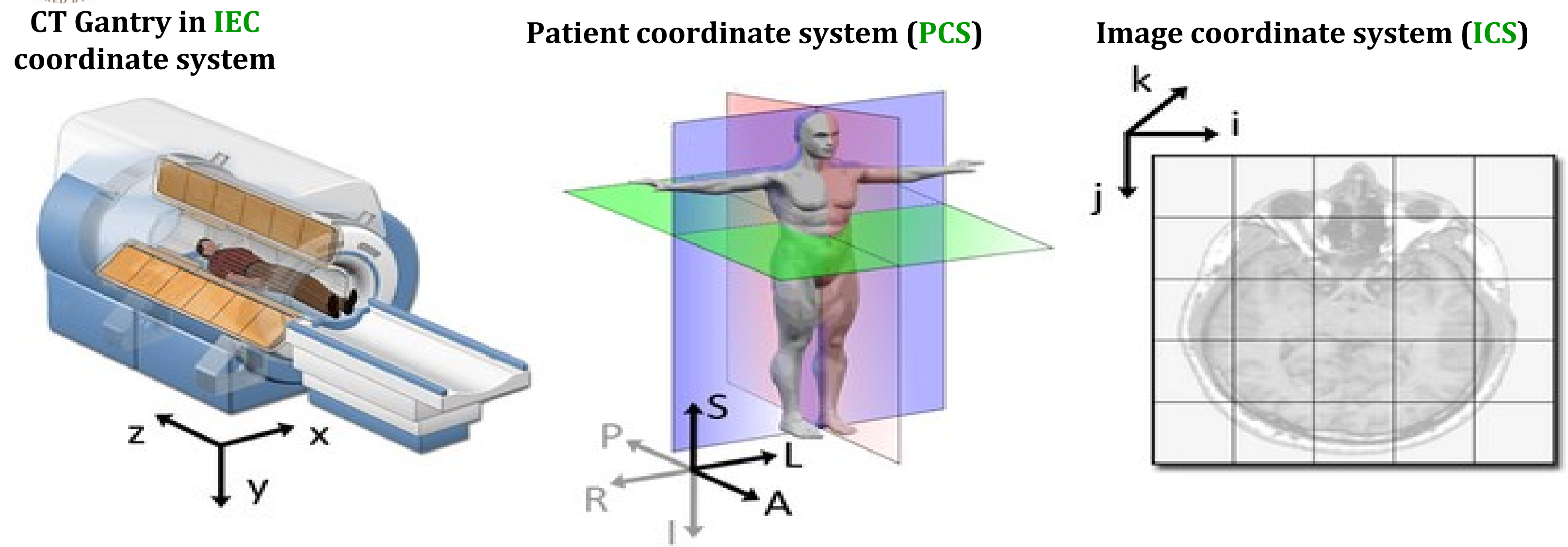


Fig 3.1. CT Colonography and the Colonoscopy procedure workflow (www.journey-with-crohns-disease.com)

Fig 3.2: Small polyp in the intestine shown on 2D MPR and the 3D volume rendered image (www.journey-with-crohns-disease.com)

CT imaging (1/7) - Image acquisition



Axis representation

$z = S = k$,
$Y = P = j$,
$x = L = i$

Axis between coordinate systems conversion is done using transformation matrices ($A.x=B$)

Fig 4.1: Representation of patient in difference coordinate systems

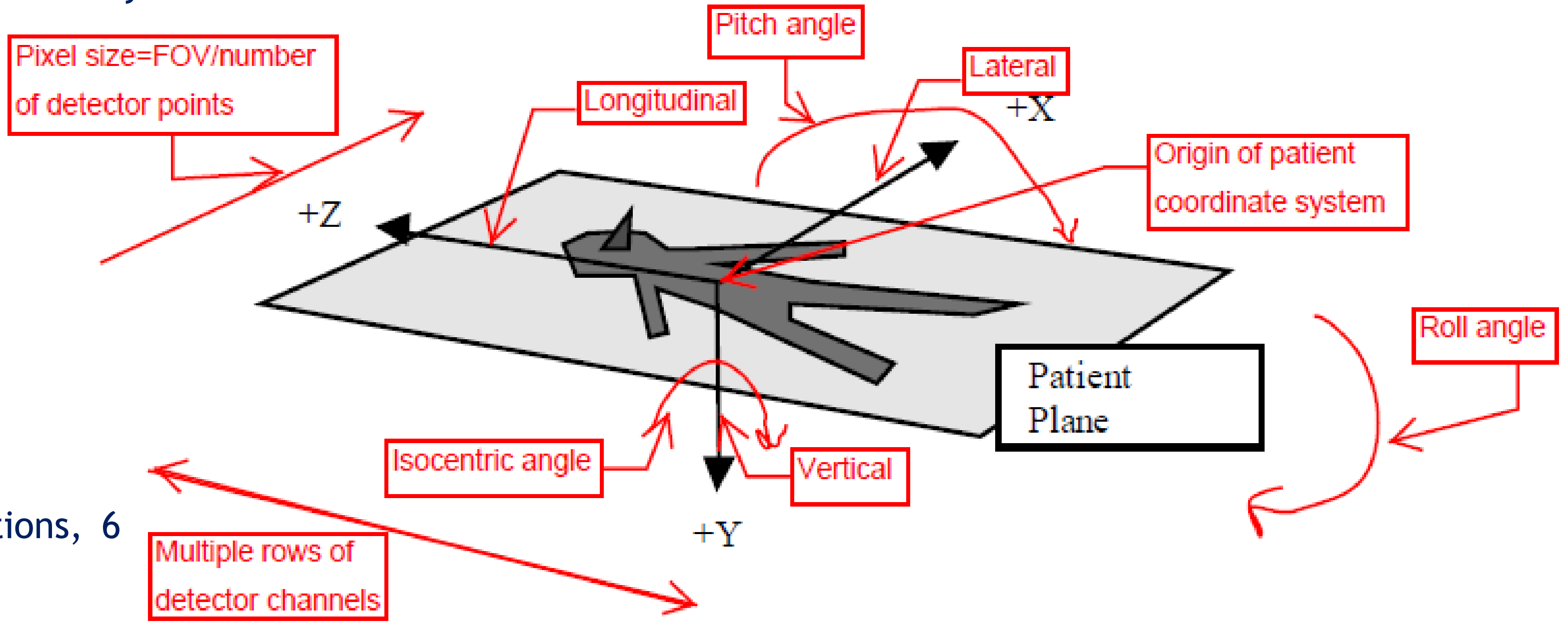


Fig 4.2: Definition of 6 degrees of freedom (6 rotations, 6 translations (PS 3.3, DICOM Chapter 3, 2020b [4])

CT imaging (2/7) – Patient positions

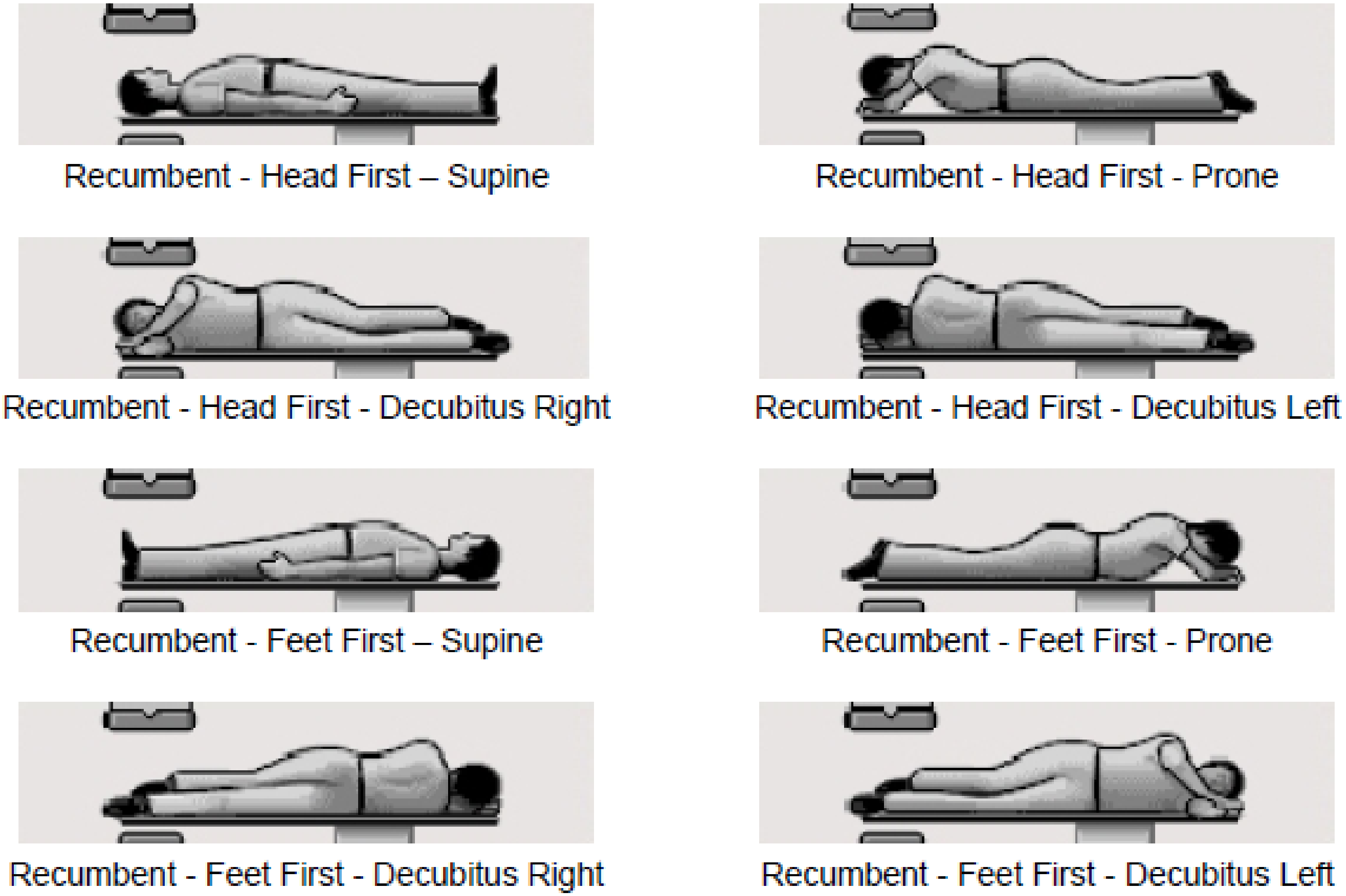


Fig 5. Different patient positions for CT and MRI scan (Chapter 3, DICOM [4])

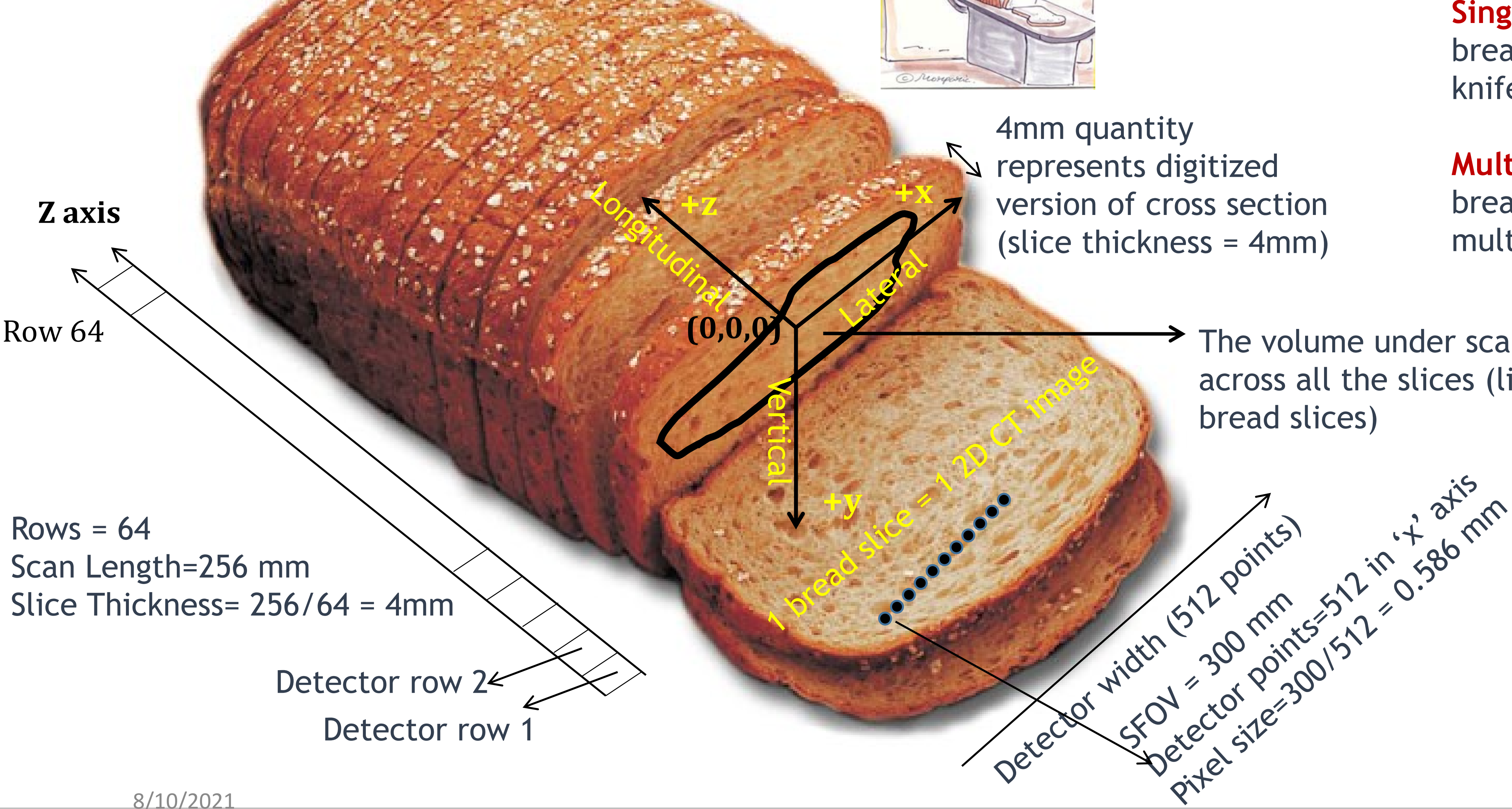
- Patient position is determined based on the clinical task.
- In Head First positions, head is near to the rotating CT gantry.
- In Feet First positions, the feet is near to the rotating CT gantry.
- These positions are defined as per the IEC coordinate system.
- This is employed in CT, MRI, PET and US modality.
- To avoid body movement, a fixation device is usually used.
- For abdomen scan, HFS, HFP, FFS and FFP positions are employed.

CT imaging (3/7) - Analogy of slicing the anatomy

Fig 6. Slicing the 3D anatomy into 2D axial plane

Single slice: When one bread **slice** is cut from one knife at a time.

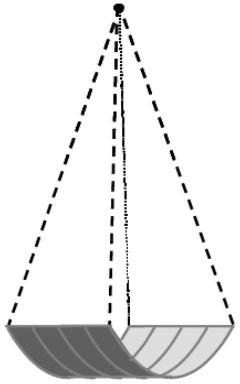
Multi slice: When multiple bread **slices** are cut from multiple knives at a time.



4mm quantity represents digitized version of cross section (slice thickness = 4mm)

The volume under scan which is spanned across all the slices (like the Tutti frutti in all bread slices)

Rows = 64
Scan Length=256 mm
Slice Thickness= 256/64 = 4mm



Example of 4 slices

CT imaging (4/7) - Scanning parameters

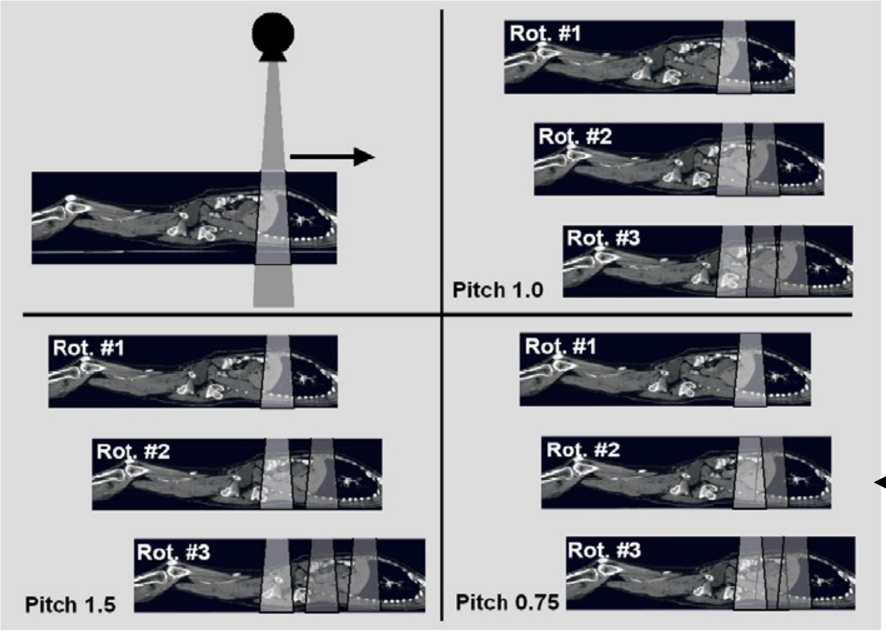
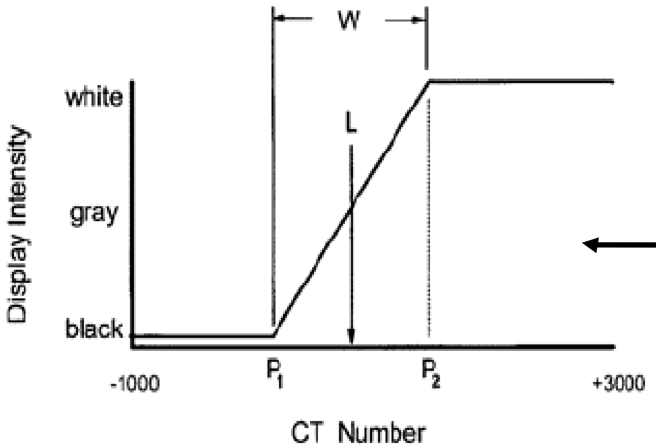
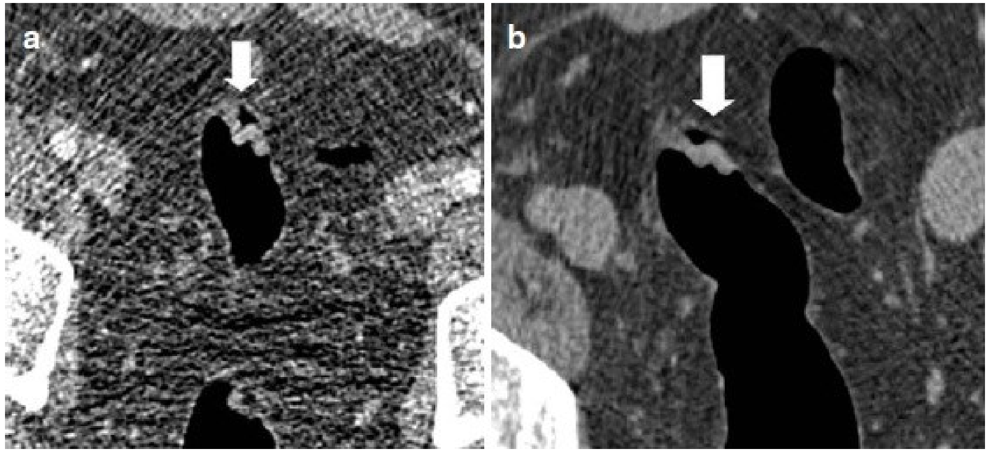


Fig 7. Scanning parameters and their impact on image quality ([2] [3])

Impact	Thin slice (eg: 0625mm)	Thick slice (eg: 1.25mm)
Volume reconstruction	Excellent	Good
Scan time	More	Less
Image quality	Excellent	Better
Geometric efficiency	Reduced	Increased

- mA
- Scan time
- Slice thickness
- kVp (Peak kilo voltage)
- Window center and width





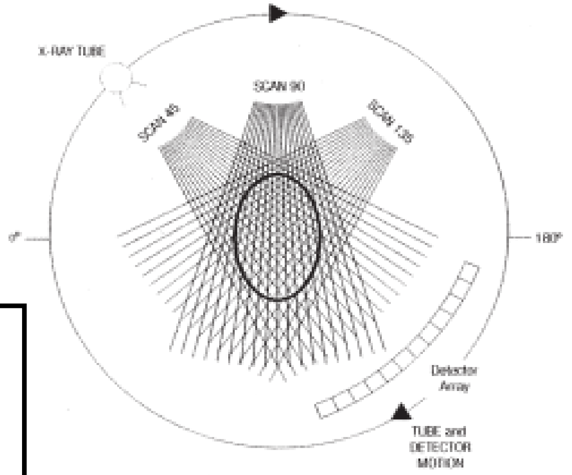
Less mA, more noise(Philippe Lefere, et.al [5])

CT imaging (5/7) - Projections to pixel

Image reconstruction from projection

Fig 8. Conversion of projection data to pixels in 2D (source: Wili Kalender)

Projection data → **(1)** →



↓ Convolution back projection / Iterative Reconstruction

CT numbers → **(2)** →

Substance	CT numbers
Air	24
Fat	904
Water	1024
Muscle	1084
Contrast	1154
Bone	1424

↓ HU = CT * rescale slope + y intercept

Hounsfield Unit (-1024 to +3072 scale) → **(3)** →

Substance	HU
Air	-1000
Fat	-120
Water	0
Muscle	+40
Contrast	+130
Bone	+400

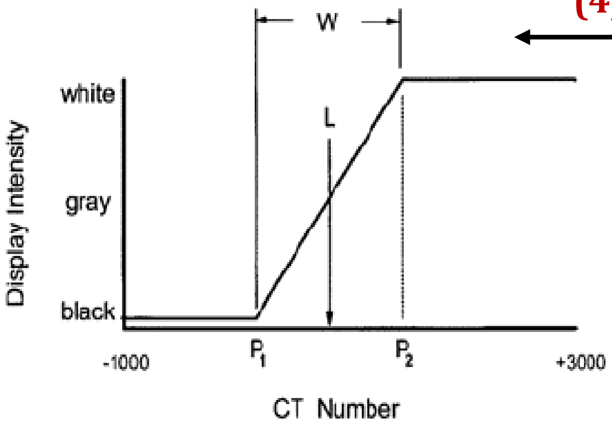
↓

$$\text{pixel value} = 0 \text{ if CT number} \le C - 0.5 - \frac{w-1}{2}$$

$$\text{pixel value} = \left(x - \frac{c-0.5}{w-1} + 0.5\right) * (ymax - ymin) + ymin$$

$$\text{pixel value} = 255 \text{ if CT number} > C - 0.5 + \frac{w-1}{2}$$

(4) →



Pixel → **(5)** →

$$keV \Rightarrow \mu_t(x,y,z) \xrightarrow{1000 * \frac{\mu_t - \mu_w}{\mu_w - \mu_{air}}} CTnumber(x,y,z) \xrightarrow{CT*m+intercept} HU(x,y,z) \xrightarrow{\frac{HU-P1}{W} * 2^{i-1}} f(x,y)$$

CT imaging (6/7) – Varying the window settings

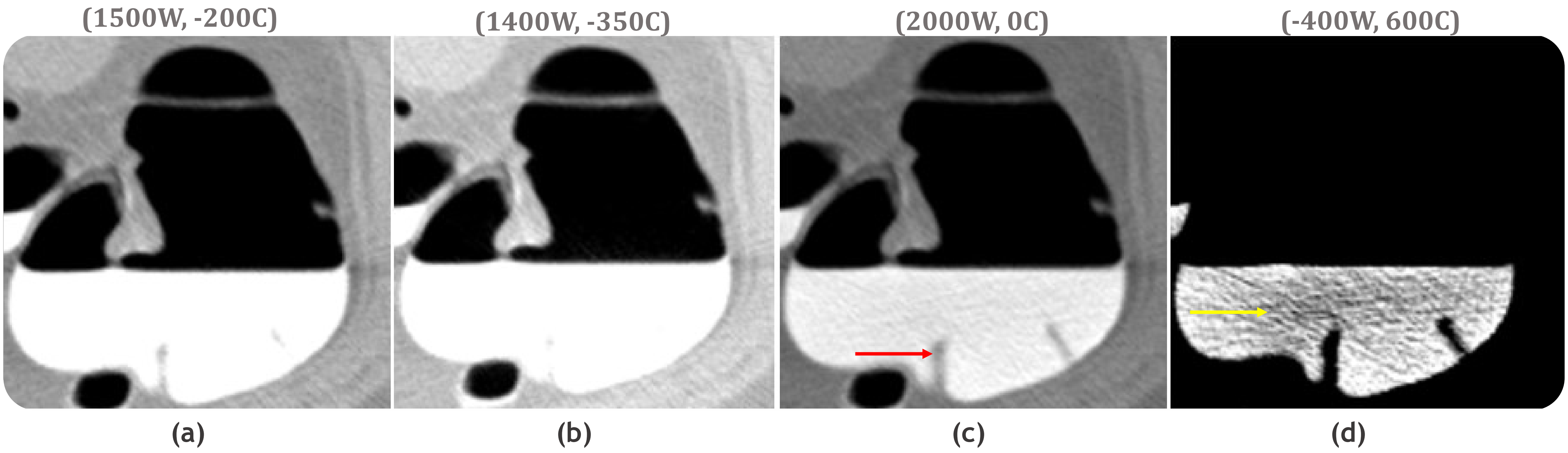


Fig 9: The floating oral contrast which appears as white color pixels. Colonic structures are submerged in it. They are visible with difference window values. **d)** Shows the fecal matter traces which appear as noise within the contrast.

- Window values (window center – C and windows width – W) can be varied to see the desired Hounsfield values (HU)
- Not all 4072 HU values can be simultaneously displayed on monitor due to limit in intensities display.
- Anatomies are predominantly visible with specific W, C.

CT imaging (7/7) - Imaging artifacts

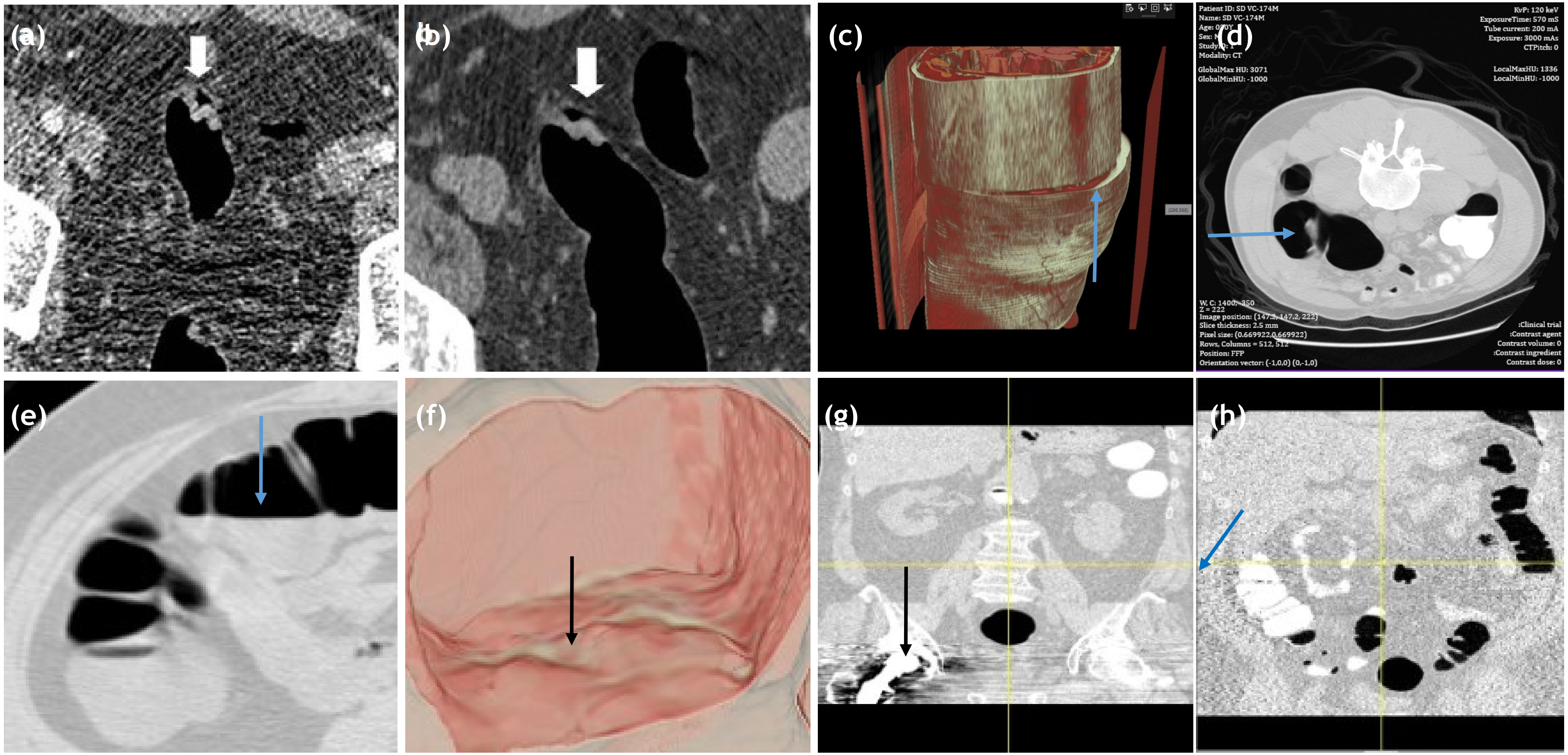


Fig 10: The artifacts in abdominal imaging. They lead to bad diagnostic quality images. **a)** Quantum noise due to less photons, **b)** Quantum noise is reduced with proper mA, **c)** Sudden drift in the image position due to a quick body movement during CT scan, **d)** Motion artefact, fuzzy boundary can be observed near the Hasutral fold, **e, f)** Partial volume effect due to overlapping intensities of multiple objects, hence cannot differentiate the undigested food and the polyps, **g)** streak artifiact, **h)** patient body outside the scan field of view

DICOM protocol

Abdoman.dcm

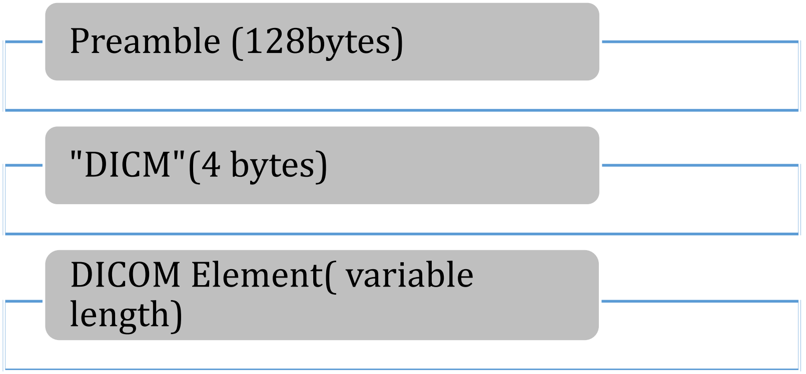
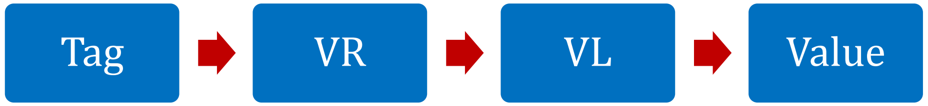


Fig 11. File content of DICOM file



One DICOM Data element

Description is not part of .dcm file. It is from PS3.3 document for the corresponding tag.

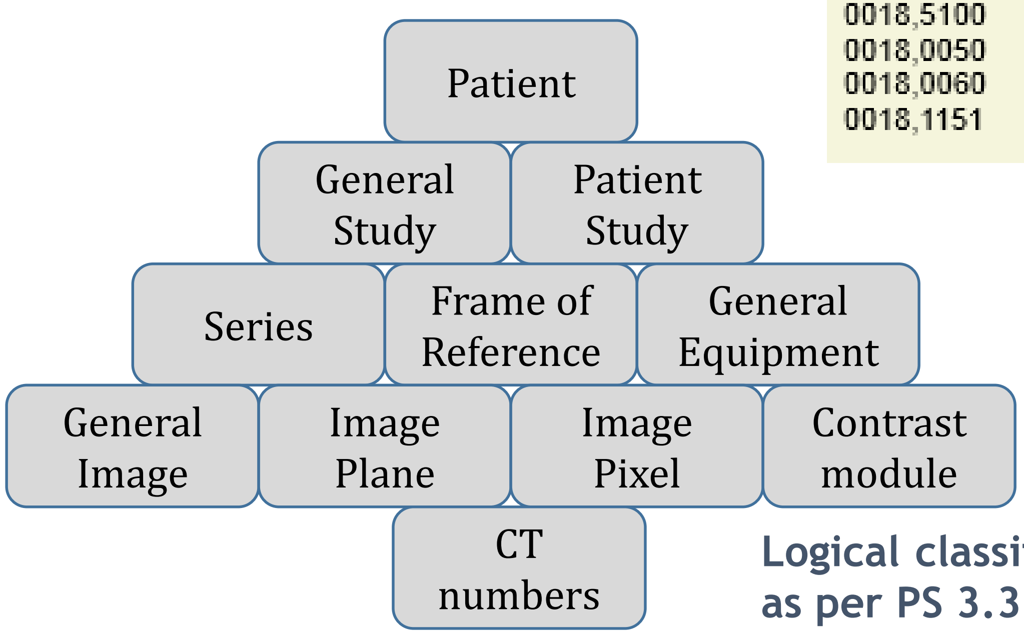
Tag	VR	VM	VL	Description	
0028,0030	DS	0	18	Pixel Spacing	0.625000\0.625000
0018,0090	DS	0	10	Data Collection Diameter	500
0018,5100	CS	0	4	Patient Position	FFS
0018,0050	DS	0	8	Slice Thickness	1.25
0018,0060	DS	0	4	KVP	120
0018,1151	IS	0	4	X-ray Tube Current	200

General Image module

Example of a data elements

...
...
...
...
...
and so on

Grouping



Logical classification of patient information and the image details as per PS 3.3, DICOM

Scanning protocol and ideal acquisition parameters

Abdomen scan steps

1. Patient preparation (Oral contrast - Mannitol)
2. Patient positioning + Intravenous Contrast administration (Iopromide solution)
3. CT scanogram (topogram) for defining Scan Field Of View (along x and z axis)
4. Review SFOV
5. Image acquisition in HFS and HFP
6. Approval and interpretation
7. Archival to PACS

Scan phases
- Pre contrast
- Arterial
- Portal venous
- Delayed

(based on clinical task)

"Perfect balance between the exposure parameters gives the good image quality and the values are task dependent and the geographical regions"

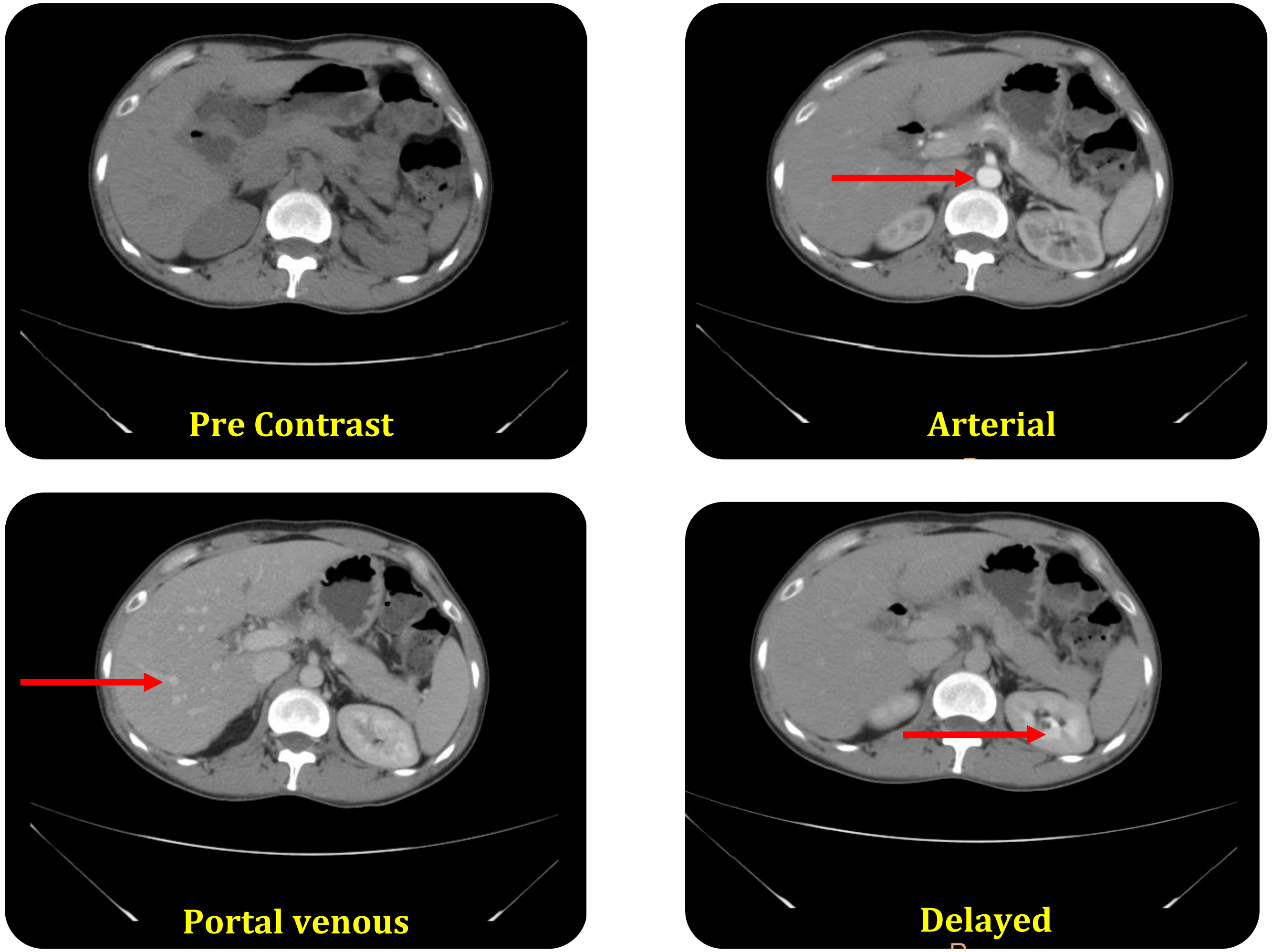
- Walter Huda, MD, Medical University of South Carolina (https://doi.org/10.1007/s40134-014-0080-x)

For a colon scan, on an average,

- mA = 200 mA
- Slice thickness = 0.5 mm to 1 mm
- kVp (Peak kilo voltage) = 120 Kv
- Window center and width = W:2000, C:0
- CTDI $_{VOL}$ = 15 mGy
- Effective dose = ~6 mSv

Varying kVP α μ [CTNumber (m, n, p) ⟶ HU (m, n, p) ⟶ f (m, n, p)]

Case studies (1/5) - Different phases CT acquisition



Scanning protocol

Study description	CT Abdomen
Tube voltage (KvP)	120 kV
Exposure time	800 ms
Tube current	281 mA
Slice thickness	5.0 mm
Patient position	FFS

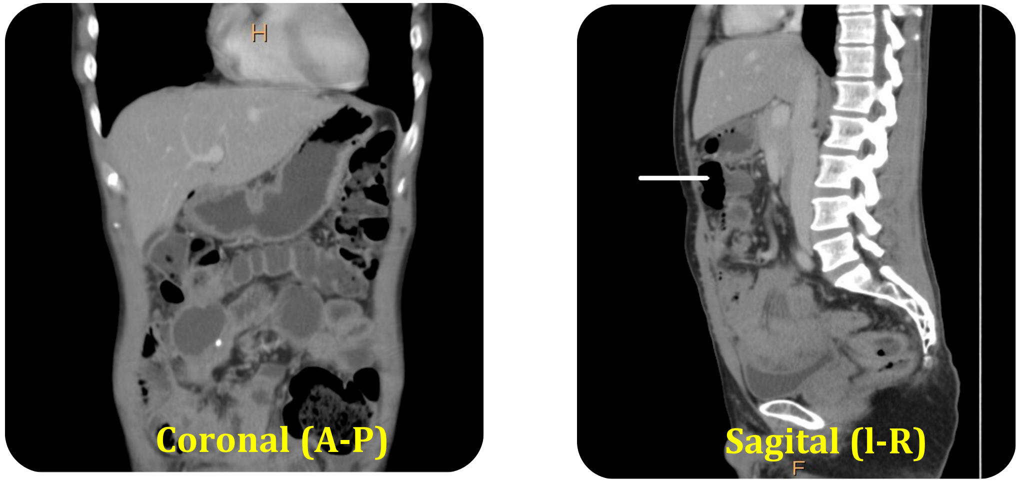
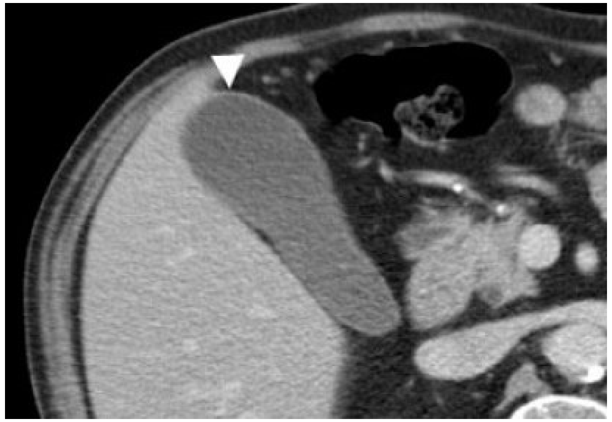


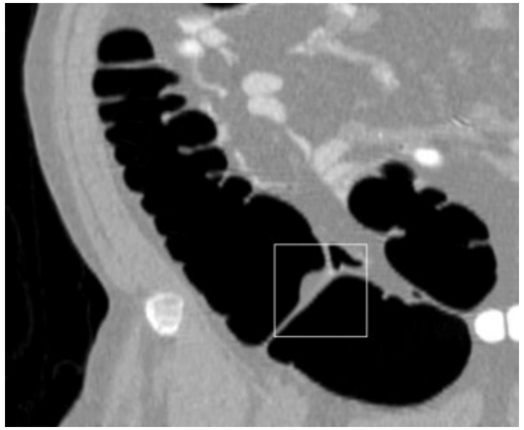
Fig. 12: Different phases of abdominal CT scan (axial views and other MPR planes). Tissues which absorb oral contrast at different time shows the different HU. Arteries are predominantly visible in arterial phase. Hepatic veins are more visible in portal venous phase (Image source: Kasturba Hospital, Manipal).

Case studies (2/5) - Different clinical cases

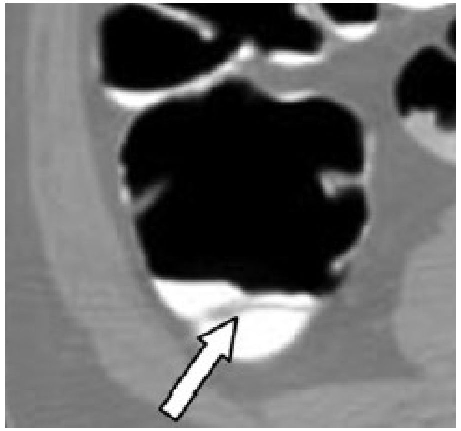


Normal gall bladder
(www.radiologyassistant.nl)

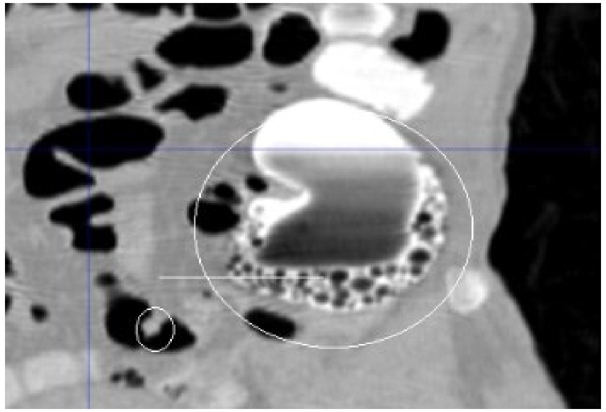
Abnormal gall bladder
(www.radiologyassistant.nl)



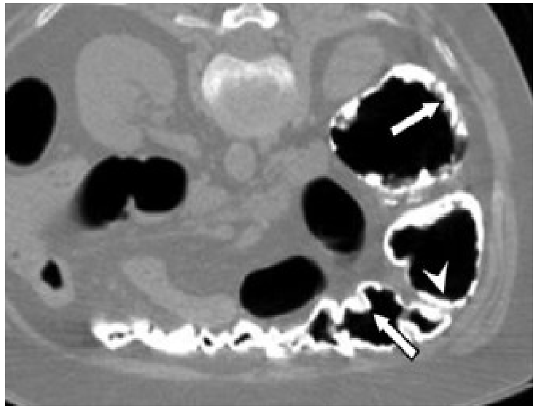
Polyp on Haustral fold



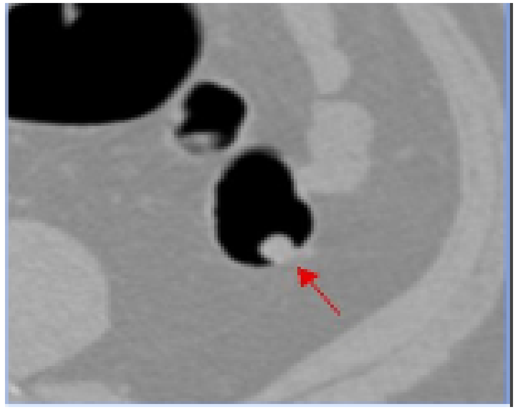
Submerged Haustral fold
(Source: Wenli Cai [7])



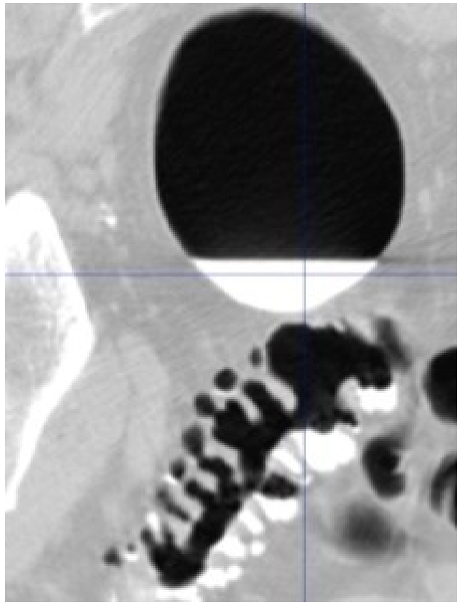
Untagged fecal matter and air



Inflammations
(www.Crohnsdisease.com)



Polyp growth
(Radiographics Journal, RSNA)



Floating oral contrast

Fig 13: Difference cases of colon abnormalities (on axial and coronal images)

Case studies (3/5) - Different cases of CT colonography

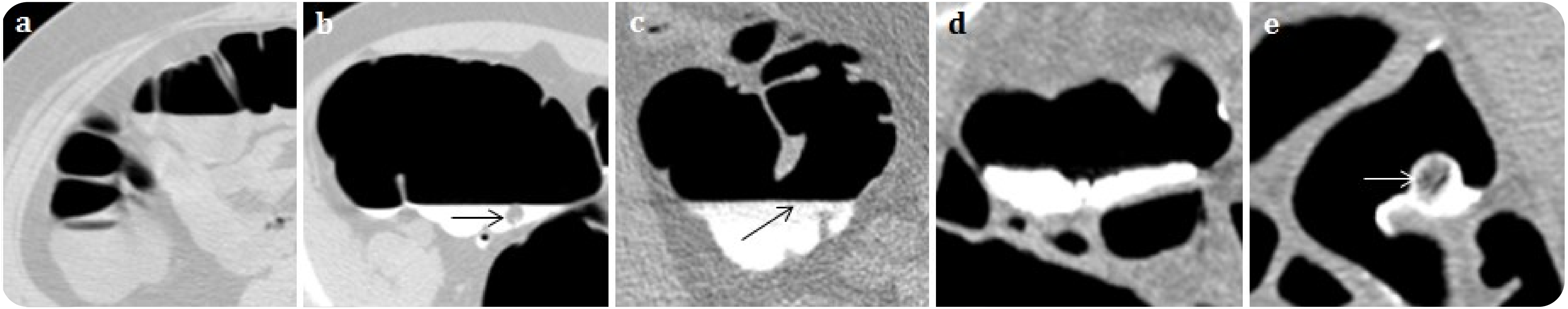


Fig 14. Different clinical cases of CT colonography technique. Fecal tagged images viewed with window values W,C = 1400, -350 (https://shodhganga.inflibnet.ac.in/handle/10603/180708)

(a) Plain CT where the colonic structures, undigested food, fecal matter and other debris cannot be differentiated due to uniform HU.
(b) Full dose colon preparation which shows a submerged polyp and homogeneous HU for contrast.
(c) Medium dose which shows heterogeneous HU near air-contrast boundary.
(d) Homogenous HU of tagged fecal material due to absorption of oral contrast
(e) Tagging agent removed completely and the polyp surrounded by tagged fecal material.

Case studies (4/5) - Different cases in CT Colonography

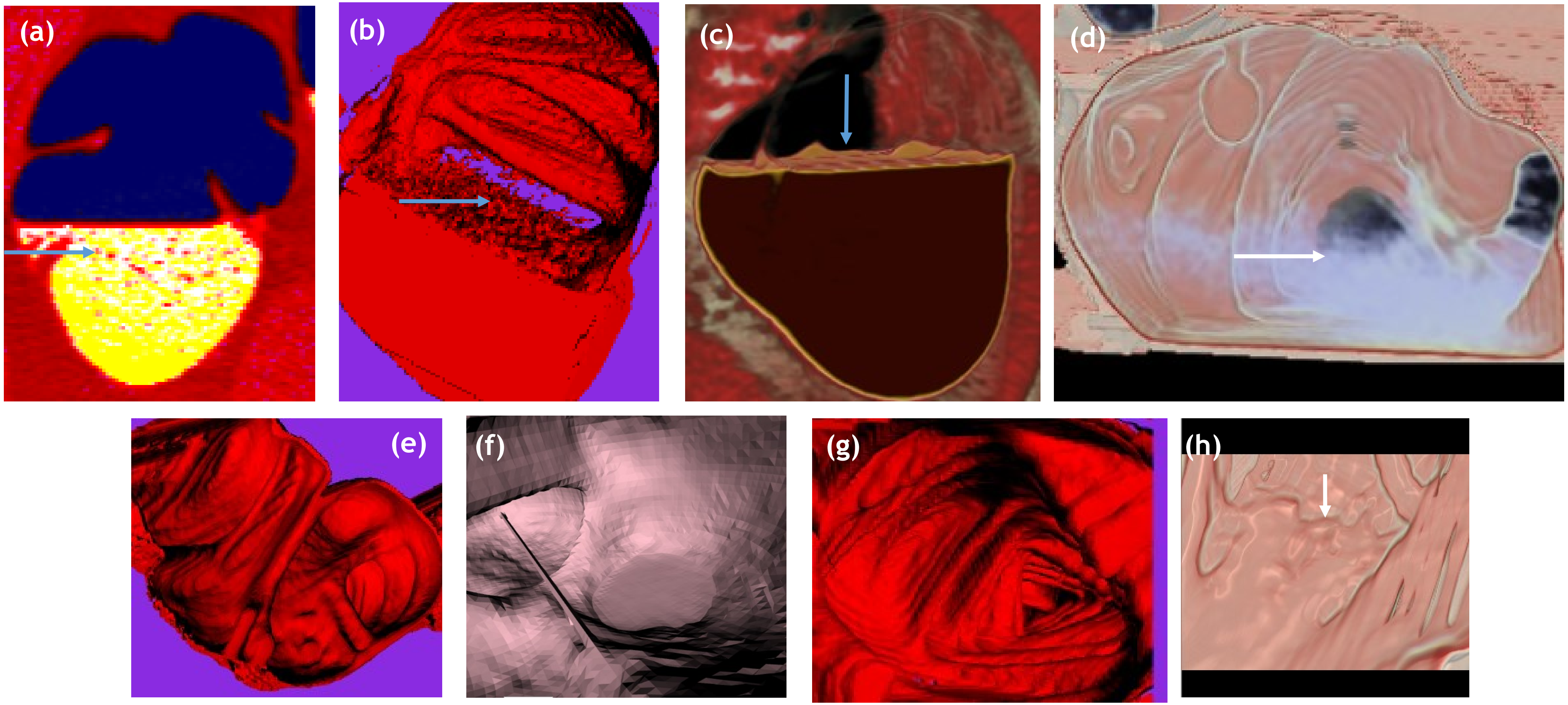


Fig 15. Different clinical cases of virtual colonoscopy technique.
(a, b) The floating fecal traces appears as noise near the air-contrast boundary on axial MPR and surface rendered image
(c) On direct volume rendered image
(d) The CO2 used for distending the colon appears as cloud patches on direct volume rendered image
(e) The Splenic flexure cross section, (f) A needle, (g) Transverse colon, (f) Similar to (a)

Case studies (5/5) - Visualization of colon and polyps in 3D

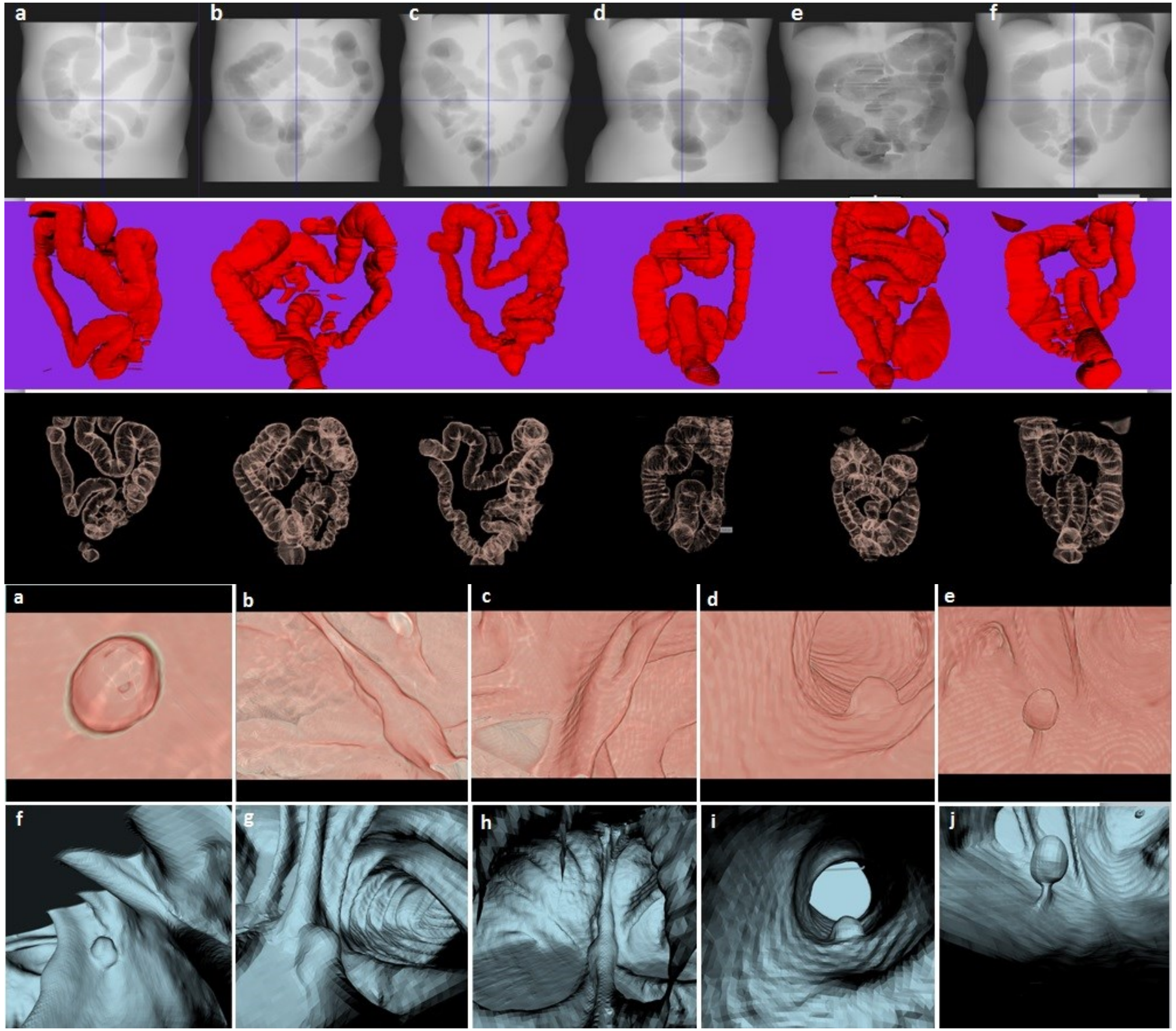


Fig 16. Colon visualization in 3D

DRR: Artificially reconstructed 2D image from 3D volume in coronal plane [8]

Surface rendered image of segmented colon using Marching cube algorithm

Direct volume rendered image of segmented colon using color transfer function

Direct volume rendered image of endoluminal view of colon (cases of colon cancer, bulged haustral fold, sessile and pedunculated polyps respectively)

Surface rendered image of endoluminal view of colon (cases of small polyp, polyp on Haustral fold, swollen Haustra, sessile polyp in sigmoid colon and a pedunculated polyp respectively)

Image source

Submit Your Data | Access The Data | Help | CANCER IMAGING ARCHIVE | About Us | Research Activities | News

TCIA data ... CT, digital histopathology, etc) or research focus. Supporting d... as patient outcomes, treatment details, genomics and image analyses are also provided when available. Try using the filter box above the table to quickly find collections of interest using keywords. Column headers can also be clicked to change the sorting method.

Show 125 entries   Previous Next   Filter table: colon

Collection	Cancer Type	Location	Species	Subjects	Image Types	Supporting Data	Access	Status	Updated
CPTAC-COAD	Colon Cancer	Colon	Human	106	Pathology	Clinical, Genomics, Proteomics	Public	Ongoing	2021-02-02
CRC_FFPE-CODEX_CellNeighs	Colorectal Cancer	Colon	Human	35	Pathology, High-dimensional CODEX images	Clinical, Image Analyses	Public	Complete	2020-09-04
PDMR-997537-175-T	Adenocarcinoma Colon	Colon	Mouse	24	MR, SR	Clinical	Public	Complete	2020-06-01
TCGA-COAD	Colon Adenocarcinoma	Colon	Human	25	CT, Pathology	Clinical, Genomics	Public	Complete	2014-10-14
CT Colonography (ACRIN 6664)	Colon Cancer	Colon	Human	825	CT	Image Analyses	Public	Complete	2011-10-31

Also, refer Grand challenges dataset:

https://grand-challenge.org/challenges/

Dataset

More than 10TB of medical images of CT, MRI, PET, RT Objects. Maintained by National Institute of Health (**NIH**), National Cancer Institute (**NCI**), Walter Reed Army Medical center (**WRAMC**), and Washington School of Medicine (**WSM**), United States [9]

Procedure to download

- Install the downloader
- Install JDK latest
- Select the dataset and download manifest file
- Open manifest file, UI pops up
- Select the folder and click download images

Cancer facts and figures (NCI, USA) gives the cancer statistics of all anatomies and all geographical areas (country wise)

Conclusion

- CT imaging is widely used to find the abnormalities of intestine.
- Every country has its own scanning protocols and recommended scanning parameters.
- Variation of scanning parameters is purely based on clinical task.
- Continuous CT scan (>50mSv) itself can lead to cancer.
- CT Colonography is a promising technique which is a replacement for colonoscopy.
- Both 2D and 3D rendering methods are used while analyzing the images.
- Size and shape of the tumor can be measured on CT using morphological image processing.

References

1. Sleisenger, Mark, F., Lawrence, SF. and Lawrence, JB. (2010). Gastroenterology and liver diseases. 9th ed. Philadelphia: Elsevier, pp. 2158.
2. www.siemens.com, Siemens Medical Solutions, (2020). Clinical application guide. [Online] Available at: www.medical.siemens.com [Accessed March. 2021].
3. Kalender, WA. (2006). X-ray computed tomography. Phys. Med. Biol, 51(13), pp. 29-43.
4. http://medical.nema.org, (2019). National Electrical Manufacturer's Association (NEMA). [Online] Available at: http://medical.nema.org/dicom/2013/output/chtml/part06/chapter_B.html#table_B.1-1, [Accessed 19 June. 2021].
5. Lefere, P. and Gryspeerdt, S. (2011). CT colonography: avoiding traps and pitfalls. Insights Imaging, 2(1), pp. 57-68. DOI: 10.1007/s13244-010-0054-3.
6. Huda, W. (2015). CT Radiation Exposure: An Overview. Current Radiology Reports, pp. 1-16. DOI: 10.1007/s40134-014-0080-x.
7. Cai, W., Kim, SH., Lee, JG. and Yoshida, H. (2012). Virtual colon tagging for electronic cleansing in dual-energy fecal-tagging CT colonography. In: Conf Proc IEEE Eng Med Biol Soc. [Online] San Diego, CA: IEEE, pp. 3736-9. Available at: http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=6346779 [Accessed 18 June. 2016]. DOI: 10.1109/EMBC.2012.6346779.
8. Manjunath KN, Siddalingaswamy PC, Gopalakrishna Prabhu K (2016). An Improved Method of Colon Segmentation in Computed Tomography Colonography Images Using Domain Knowledge. J. Med. Imaging Health Inf., American Scientific Publishers, 6(4), 916-24, DOI: http://dx.doi.org/10.1166/jmihi.2016.1786
9. www.cancerimagingarchive.net, (2019). National Cancer Institute (NCI). [Online] Available at: https://public.cancerimagingarchive.net/ncia/login.jsf [Accessed 27th June, 2021].

Acknowledgements