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The Search Patterns of Abdominal Imaging Subspecialists for Abdominal Computed Tomography: Toward a Foundational Pattern for New Radiology Residents

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ABSTRACT

Objectives: The routine search patterns used by subspecialty abdominal imaging experts to inspect the image volumes of abdominal/pelvic computed tomography (CT) have not been well characterized or rendered in practical or teachable terms. The goal of this study is to describe the search patterns used by experienced subspecialty imagers when reading a normal abdominal CT at a modern picture archiving and communication system workstation, and utilize this information to propose guidelines for residents as they learn to interpret CT during training.

Material and Methods: Twenty-two academic subspecialists enacted their routine search pattern on a normal contrast-enhanced abdominal/pelvic CT study under standardized display parameters. Readers were told that the scan was normal and then asked to verbalize where their gaze centered and moved through the axial, coronal, and sagittal image stacks, demonstrating eye position with a cursor as needed. A peer coded the reported eye gaze movements and scrilling behavior. Spearman correlation coefficients were calculated between years of professional experience and the numbers of passes through the lung bases, liver, kidneys, and bowel.

Results: All readers followed an initial organ-by-organ approach. Larger organs were examined by drilling, while smaller organs by oscillation or scanning. Search elements were classified as drilling, scanning, oscillation, and scrilling (scan drilling); these categories were parsed as necessary. The greatest variability was found in the examination the body wall and bowel/mesentery. Two modes of scrilling were described, and these classified as roaming and zigzagging. The years of experience of the readers did not correlated to number of passes made through the lung bases, liver, kidneys, or bowel.

Conclusion: Subspecialty abdominal radiologists negotiate through the image stacks of an abdominal CT study in broadly similar ways. Collation of the approaches suggests a foundational search pattern for new trainees.

Keywords: Search pattern, Abdominal computed tomography, Expert

INTRODUCTION

How subspecialty abdominal imaging experts routinely inspect the volume of images in an abdominal/pelvic computed tomography (CT) study is poorly understood.[1-5] Such knowledge, however, has practical value for the training of radiology residents, the identification of blind spots and sources of systematic error, and the improvement of work efficiencies.[2]

Three studies have attempted to characterize search in abdominal/pelvic CT (henceforth, only "abdominal CT").[1,6] In two studies, the subjects were radiology residents. In one of these, the residents provided a verbal report while their scroll behavior (without eye tracking) was tracked.[6] In the second study, the residents' eye movements were tracked by a device mounted under a single laptop computer.[1] In the third study, seven non-specialty radiologists were recruited at a general radiology conference and asked to search for lymphadenopathy on abdominal CT studies while their gaze was tracked.[7] None of the studies was performed at a picture archiving and communication system (PACS) workstation.

One approach to identify optimized search patterns is to study the strategies employed by domain experts. Eye tracking is certainly ideal with regard to identifying the vagaries of eye gaze, but it is not altogether obvious how this complex information might be best distilled and translated into training protocols. Details of expert search patterns can also be acquired by verbal report, a method that is easily transferred to training. The goal of this study is to ascertain how readers with expertise in abdominal imaging undertake the search task using current PACS. Such an analysis might suggest a foundational pattern useful for the instruction of novice readers.

MATERIAL AND METHODS

This study was conducted under the auspices of the quality assurance program at our institution. Twenty-two abdominal imaging specialists in academic practice were recruited as part of a quality assurance program to demonstrate their search pattern on a normal abdominal CT study. There were seven fellows at the end of their training and 15 faculties. For the 15 faculties, the number of years following fellowship ranged from 4 years to 37 years (mean 19 years, median 18 years).

To identify the readers' routine search pattern, a test abdominal/pelvic CT was selected that contained no distractors, such as a salient finding, abnormality, or surgical changes. This CT had been performed on a 37-year-old female with no known diseases who presented with low-grade abdominal pain which subsequently resolved without incident. Readers were made aware of these circumstances before beginning their search pattern.

The CT volumes were displayed on a PACS station under the following technical parameters: Window width 400, level 50, slice thickness 3.75 mm, reconstruction diameter 440 cm, matrix 512 × 512 pixels, and pixel size 0.86 mm. The magnification of the image was such that a 1 cm liner measurement on the screen corresponded to a 2 cm linear measurement on the anatomic image.

As the readers examined the study, they were asked to simultaneously verbalize in detail where their gaze fixated and moved through the image stack. The study included axial, coronal, and sagittal projections, which the reader could examine in any order they wished. When needed, the readers were asked to clarify their eye position by a cursor pointer on the screen. Coding of the verbal reports was made by a single interviewer, an abdominal radiologist with 30 years post-fellowship experience, on a spreadsheet with categories of the organs and quadrants of the abdomen and pelvis.

Patterns of inspection were classified as drilling, scanning, oscillation, and scrilling as appropriate. Drilling is defined as a concentrated focus on limited area of the image while scrilling through the image stack along the Z-axis (volumetric depth).[2,5,6] Radiologists drill in different modes, and these were categorized as full runs (full passes through the image volume) and half runs (partial passes through the image volume). Full runs of the image stack to obtain an overall or global impression of the study were termed holistic or gestalt passes.[6]

Scanning is performed over one to three images slices and consists primarily of sweeping, side-to-side eye movements (in the X and Y planes of the image).[5] Oscillations are the rapid up-and-down scrilling/drilling movements within a narrow range of slices over the area of interest.[6,8,9]

Eye gaze movements that did not fall into simple drilling or scanning categories were classified in the hybrid category denoting simultaneous scanning and drilling. This has been termed scan drilling or "scrilling."[10] In this study, modes of scrilling were observed that required subcategories. These were coined as roaming (the gaze is allowed to move about without predetermined design while drilling through the image stack) and zigzagging (the gaze moves across and back while drilling through the image stack).

For each organ and anatomic region, the number of drilling or scanning passes was recorded. If an anatomic area – such as the body wall – was not specifically mentioned, the interviewer would ask for clarification.

Spearman correlation coefficients were calculated between years of professional experience and the numbers of passes through the lung bases, liver, kidneys, and bowel.

A nominal two-sided $P < 0.05$ was regarded as statistically significant.

RESULTS

Axial images

All of these readers followed an initial organ-by-organ approach that included intentional focused evaluation of the lung bases, liver, spleen, adrenal glands, pancreas, gallbladder, bile ducts, kidneys, aorta/retroperitoneum, urinary bladder, external iliac lymph nodes/vessels, and prostate/uterus.

Organs were examined either by drilling or scanning. In the axial plane, organs studied by drilling in half runs included the lung bases, liver, spleen, heart/anterior mediastinum, and kidneys [Table 1]. Anatomic areas subject to drilling in full runs included the retroperitoneum, body wall, and bowel [Table 2]. The number of unidirectional (up or down) drilling passes within the organs varied considerably; for example, the number of passes through the liver varied from two to six. The vessels were studied in the axial plane by drilling in full runs.

The years of experience of the readers did not correlated to number of passes made through the lung bases, liver, kidneys, or bowel. Correlation coefficients were calculated to be: Lung bases ($r = -0.22$, $P = 0.32$), liver ($r = -0.04$, $P = 0.84$), kidneys ($r = -0.29$, $P = 0.18$), or bowel ($r = -0.24$, $P = 0.28$).

Table 1: In-line drilling of the abdominal organs in axial section: Number of unidirectional (up or down) passes for 22 abdominal imaging specialists.

Anatomic site	Number of radiologists	Percent of drillers (%)	Number of passes	Number of drillers by passes	Percent of drillers by passes (%)
Lung bases	22	100	2	11	50
			3	2	9
			4	8	36
			6	1	5
Heart/anterior	22	64	1	11	50
Mediastinum			2	3	14
			0	8	36
Liver	22	100	2	6	27
			3	8	36
			4	7	32
			6	1	5
Spleen	22	100	1	7	32
			1.5	3	14
			2	12	55
Kidneys	22	100	1	12	55
			2	9	41
			4	1	5
Retroperitoneum	22	100	1	17	77
			2	5	23

Table 2: A suggested primary search pattern for abdominal computed tomography for novice readers.

Anatomic region	Imaging planes	Techniques	Special comments
Lower chest	Axial	Drill in four quadrants	Inspect pulmonary arteries and breasts
Liver	Axial	Drill × 4	
Vasculature	Axial	Trace	Portal veins, superior mesenteric vein, and splenic vein
Biliary tree	Axial	Trace out	
Pancreas	Axial	Scan/oscillate	
Spleen	Axial	Drill × 2	
Adrenals	Axial	Scan/oscillate	
Kidneys	Axial	Drill axial × 2	
Retroperitoneum	Axial	Drill × 1	Follow aorta to common iliac vessels to groin bilaterally
GI tract/central abdomen	Axial	Scroll the small bowel/central abdomen	Trace out appendix, esophagus-stomach-duodenum sweep, and colon. Inspect perirectal area
Bladder, ovaries, prostate	Axial	Oscillate/drill	
Body wall/peripheral abdomen	Axial	Drill in four quadrants (ant, post, right, and left)	Full runs (top to bottom)
Bones	Axial	Drill × 2	Drill pelvis in halves
Kidneys/diaphragm	Coronal	Scan	
Mesentery/small bowel/colon	Coronal	Scroll × 2	
Uterus	Sagittal	Scan	Note endometrial thickness
Spine	Sagittal	Scan	
Vasculature	Sagittal	Scan	Ostia of celiac, superior mesenteric artery

All readers scanned the pancreas and the adrenal glands. All readers used either oscillations or half runs during inspection of the gallbladder, hepatic vessels, and bile ducts.

The full lengths of some structures were routinely traced. These structures and the percentage of radiologists who traced these out were the colon (86%), portal vessels (86%), superior mesenteric vein (73%), appendix (68%), duodenum (68%), stomach (64%), ureters (50%), terminal ileum (45%), ribs (45%), bile ducts (41%), splenic vein (41%), pulmonary arteries at the lung bases (32%), superior mesenteric artery (32%), and internal iliac veins (23%).

Some structures were specially and intentially inspected by some radiologists, while others included these in broader sweeps over the anatomic area. The structures and the percentage of radiologists who looked intentionally for them were the appendix (91%), terminal ileum (73%), ovaries (77%), gastroesophageal junction (32%), and breasts (23%).

Idiosyncratic areas of special focus for only a single reader (1/22) included the left upper quadrant fat, ileocolic vein, and gonadal veins (in axial plane); the pelvic floor and omentum (in sagittal plane); and the diaphragm and inferior mesenteric artery (in coronal plane).

The greatest variability was found in strategies to examine the body wall and bowel/mesentery. Radiologists examined the body wall in a variety of patterns that ranged from one quadrant to all four quadrants. The anterior wall was examined specifically in 95% of readers; the posterior, right, and left sides were directly examined less frequently (68%, 45%, and 45%, respectively) [Figure 1]. The bowel/central abdomen was examined by drilling by 32% (7/22) of radiologists and by scrilling by 68%. Of the drillers, four made two passes, two made three passes, and one made four passes. Of the 15 scrollers, 12 (80%) made one pass, 2 (13%) made two passes, and 1 (7%) made four passes. These 15 readers either let their gaze roam through the center scan (14/15, 93%) or descend the center of scan in more of a zigzagging fashion (1/15, 7%).

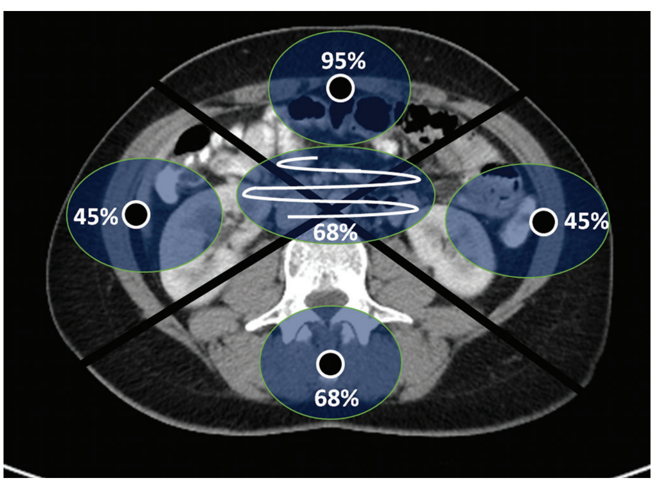

Figure 1: Inspection of the body wall by quadrants. Percentage of readers who focused on each anatomic region (anterior, posterior, right, left) in their routine search of the body wall. The center circle indicates the percentage of readers who examined the central abdomen/bowel by scrilling

Coronal images

On coronal images, the bowel examined routinely by 20/23 (91%) radiologists, and of these, only 2 (10%) used a predetermined in-line drilling pattern, while the others allowed their eyes to scroll. The other organs routinely inspected in the coronal plane include the kidneys (82% of radiologists), femoral heads (23%), liver (18%), spleen (14%), bile ducts (14%), and diaphragm (5%).

Gestalt first passes were made by 3/22 (14%), and gestalt final last passes were made by 8/22 (36%). Of those who made a final last pass, five did so in the coronal plane only, and three did so in both the axial and coronal planes.

Sagittal images

The sagittal images were primarily used for the spine (100% of radiologists), with less consistent attention given to the uterus (55%), spinal canal (23%), bladder (23%), celiac/superior mesenteric artery origins (9%), diaphragm (9%), omentum (5%), and pelvic floor (5%).

On routine cases, the bones were examined in bone windows in the axial and sagittal planes for all radiologists (100%) and in the coronal plane by 23%.

DISCUSSION

This study reveals that expert radiologists negotiate through the image stacks of an abdominal CT study in broadly similar ways but also display salient dissimilarities and idiosyncrasies. All readers began with an initial organ-by-organ path that included the major organs. The larger organs were drilled, while those shallower in the axial plane were scanned (e.g., the pancreas).

Readers used various combinations of drilling, scanning, and oscillations. Drilling is performed by concentrating focus on limited area of the image while scrilling through the image stack, and appears to be best suited to long and deep dives through a thicker organ or anatomic region.[1,8,11]

Scanning, sweeping across an image, appears best applied to organs that are oriented in the plane of viewing. The pancreas, for instance, lies horizontally on axial images and can be covered much more efficiently by scanning than repeatedly drilling its thin depth. Some organs are better drilled in one axis and scanned in another. For instance, the spine was drilled in the axial slices, but scanned in the sagittal plane.

Scrilling behavior through the complex interior landscapes of the abdomen and pelvis CT, however, confounds simple description and requires a more complex language than has been used to characterize search in earlier studies.[1] For instance, radiologists drill in different modes, and these have been categorized as oscillations, half runs, full runs, and interruptions.[1,6,8,9,12] Full runs seem to reflect with global search (gestalt or holistic); half runs and oscillations reflect more focused search and cognitive processing.[6,8]

The hybrid process, scrilling or scan drilling, also needs to be parsed to accurately capture and describe. Patterns of scrilling appear to encompass varying degrees of predetermined method. The terms roaming and zigzagging were coined to expand the vocabulary of scrilling. Most readers used a scrilling method that they described as letting the gaze roam with less disciplined focus while drilling through the image stack, alert for an undefined something to catch their attention (roaming). One reader described a zigzagging approach, whereby the gaze crossed the images repeatedly as the image stack was drilled.

Of interest, many of the readers methodically traced out the length of structures such as the bile ducts and bowel. All readers had specific anatomic stations that they visited as part of their search pattern though some readers had developed highly idiosyncratic search variations presumably based on experience (especially misses), early advice, reasoned strategy, and closely held beliefs and opinions.

Based on the distillation of these methods, we propose a standard search pattern that might be taught to novice readers [Table 2]. At present, new learners of abdominal CT are often given only vague or idiosyncratic guidance on which to construct their own initial search pattern which is modified over time by trial and error. This is certainly not the only pattern that could be reasonably proposed but it is a useful place to start.

From the literature on pulmonary nodule detection, it is known that eye gaze must fall within approximately 3 cm (50 pixels) of a 0.5 cm nodule for the nodule to be seen.[9] This estimate, however, might vary by observer, study, presentation, image magnification, and what is being examined.[13]

We propose performing full run gestalt (holistic) passes at the beginning and end of the search, as a first scouting pass and final check. Next, the larger organs should be drilled such that the foveal center of focus falls within 3 cm of all parts of that organ. For most patients, the liver might be drilled 3–4 times, the spleen twice, the lung bases twice per side, the kidneys twice each, the retroperitoneum once, and the body wall 4 times. The remainder of the scan could be drilled using full runs in parallel corridors. Obviously, the magnification of the image would need to be adjusted such that the 6 cm diameter drilling corridors are closely apposed for the entire image to fall within the observer's gaze. This requirement, coupled with the recognition that radiologists are largely unaware of where they have (and have not) looked on the image, argues for using straight line drilling that does not veer widely off course to ensure comprehensive search.[14,15]

Strong consideration should be given to tracing out the length of the appendix, bile ducts, the esophagus-stomach-duodenum sweep, and the colon. Intentional examination of the breast seems warranted, considering the relatively high prevalence of malignancy (30%) found in incidentally discovered lesions.[16] Examination of coronal images might include scanning the kidneys and the central abdomen/small bowel, and examination of sagittal images might include scanning the spine and uterus/prostate.

This study has limitations. First, only a normal CT study was used. It is likely that search patterns change in response to different indications, salient findings, complexity, surgical and anatomic changes, and any number of circumstantial, demographic, and historical patient factors. That said, radiologists tend to have a poor understanding of where they have (and have not) looked, which indicate that a standardized, well-defined, foundational search routine is necessary to ensure that all aspects of the study are examined.[2] It is important that the process of search not be improvised with every new case. The more trainees can hew to a single pattern, the more likely they are to avoid such pitfalls as incomplete search and satisfaction of search. Regardless, novice readers must adopt a search pattern of some devising, and using one based on expert practice for the simplest case of a normal CT is arguably a good place to start.

Second, the readers were being closely observed and questioned during the study, which might cause some to modify their habits under observation (the Hawthorne effect). Last, there was only a single interviewer, so inter-interviewer reliability was not calculated.

The next step is to evaluate the efficacy of the proposed search pattern for novice readers and test for improved reading accuracy and lesion detection beyond whatever pattern they had concocted for themselves. A recent study demonstrated that teaching a drilling strategy for reading lung CT improved perceptual performance for the 1st and 2nd year radiology residents.[17] It is likely, therefore, that teaching of search strategies for abdominal CT would also be most efficacious when trainees are early in the process of devising their search pattern, when that pattern is most malleable. How structured reporting might be used to influence the construction and modification of search patterns is as yet unexplored.

CONCLUSION

This is the first study to describe in detail how expert readers routinely conduct search through abdominal CT image volumes. There was considerable commonality in approach with some variation. Based on our findings and the current literature, the constitutive elements of a basic search pattern are identified which might be used for the training of novice readers.

Declaration of patient consent

Patient's consent not required as there are no patients in this study.

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Conflicts of interest

There are no conflicts of interest.

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