Imaging in Patients with Crohn's Disease: Trends in Abdominal CT/MRI Utilization and Radiation Exposure Considerations over a 10-Year Period

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Purpose: To study the trends in utilization of computed tomography (CT) and magnetic resonance imaging (MRI) in patients with Crohn's disease and to evaluate changes in CT radiation exposure over a 10-year period.

Methods: In this institutional review board–approved single-institution retrospective study, we included patients who underwent CT and MRIs for evaluation of Crohn's disease between 2006 and 2015. A total of 3196 CTs and 1924 MR scans were performed in 2156 patients (mean age: 34.8 ± 17.71 yr; range: 3–91 yr) for initial diagnosis or follow-up of Crohn's disease between 2006 and 2015. Trends in CT/MR utilization was assessed by comparing the volume of CT/MRI studies performed each year. The changes in CT radiation exposure over the study period were estimated and compared.

Results: The annual combined CT/MR utilization demonstrated a 1.9-fold rise over the last decade (2006: n = 358, 2015: n = 681, $P < 0.001$, r = 0.96). It was predominantly because of a substantial growth (9.2-fold increase) in the MR scan volume (2006: n = 37, 2015: n = 341, $P < 0.001$, r = 0.93), whereas CT volume did not show significant change (2006: n = 321, 2015: n = 340, $P = 0.6$). Over this same period, there was a 59.4% reduction in mean radiation exposure (2006: CT dose index$_{vol}$ 16.9 ± 7.1 mGy, 2015: CT dose index$_{vol}$ 6.87 ± 4.62 mGy, $P < 0.001$).

Conclusions: A 9-fold growth in annual MR scan volume contributed to a nearly 2-fold rise in yearly cross-sectional imaging utilization in Crohn's patients between 2006 and 2015. Rising trend in imaging utilization paralleled a 60% reduction of CT radiation exposure.

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Key Words: Crohn's disease, radiation dose, imaging utilization, computed tomography, magnetic resonance imaging

Crohn's disease (CD) is a chronic inflammatory disease of the gastrointestinal tract, affecting nearly 1.4 million people in the United States with an annual estimated prevalence of 200 cases per 100,000 persons.[1] Despite the bimodal age distribution, it predominantly affects young individuals and is characterized by a relapsing and remitting course. Imaging plays an important role in the initial diagnosis and follow-up of patients with suspected and confirmed CD because of its ability to provide information about disease activity, interrogate areas inaccessible to endoscopy, and identify extraenteric manifestations and disease complications such as fistulae and abscess formation.[1] The chronic relapsing nature of the disease necessitates multiple imaging procedures during the disease course.[2] Computed tomography (CT) enterography is considered a standard diagnostic investigation of choice in patients with CD with nearly 8-fold increase in utility between 2003 and 2007, as reported by Jaffe et al.[3] CT enterography offers several advantages over other imaging modalities such as rapid acquisition time, widespread availability at all hours of the day, extensive radiologist experience, and ability to detect intraluminal and extraluminal disease manifestations.[4–6]

Notwithstanding its benefits, numerous CT studies during the lifetime of a patient with CD, particularly those in whom Crohn's is diagnosed at an early age, carry potential risks from deleterious effects of ionizing radiation exposure.[7–11] These concerns about radiation exposure from CT studies have led to increased performance of alternative imaging techniques such as MR enterography which provides similar accuracy for evaluating CD without ionizing radiation exposure.[4,12–14] However, MR enterography (MRE) has limitations related to availability (especially after hours and in patients not able to undergo magnetic resonance imaging [MRI]), diagnostic image quality, and increased cost relative to CT enterography.[6] Paralleling the interest in exploring MR capabilities in CD, there have been significant efforts to reduce CT radiation exposure through protocol modifications which have led to substantial reduction in CT radiation exposure.[15–23] The American College of Radiology (ACR) Appropriateness Criteria suggest the use of CT enterography as the initial

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diagnostic test for adult patients with suspected CD. CT enterography is preferred because it is less bowel and respiratory motion dependent and therefore particularly useful in acutely ill patients. For children and young adults who are not acutely ill, MR enterography is preferred.[6] These factors have influenced the cross-sectional imaging patterns of patients with CD particularly in the last decade; however, there are few data on the utilization of CT and MRI in the patients with CD over the last decade. The objective of this study was to assess the utilization trends of CT and MRI in patients with CD and assess the impact of dose reduction techniques on CT radiation exposure over a 10-year period.

MATERIALS AND METHODS

Patient Cohort and Study Design

This study was Institutional Review board approved and Health Insurance Portability and Accountability Act compliant and requirement for informed consent was waived by our hospital's Institutional Review Board.

In this study, we included all patients who underwent CT/MRI for initial diagnosis and follow-up of CD at our institution between January 2006 and December 2015. The patient cohort for this study was identified by searching our radiology database using render software, which acquires radiologic image data from the diagnostic Picture archiving and communication system (PACS) workstations (AGFA Impax; AGFA Technical Imaging Systems, Ridgefield Park, NJ). The resultant patient cohort was then reviewed to identify those patients with a confirmed diagnosis of CD. We excluded all patients who had other diagnoses such as infectious enteritis, ischemic bowel disease, and diverticulitis or indeterminate enteritis. In this patient cohort, we then excluded interventional CT procedures such as biopsy and abscess drainages. After the exclusion, the final patient cohort consisted of 5120 imaging studies performed in 2156 patients.

Patient Cohort

The final patient cohort in this retrospective study included 2156 patients between 2006 and 2015. The average age in this patient cohort was 34.8 ± 17.71 years (range: 3–91 yr) with 1067 males (mean age: 33.9 ± 17.5 yr) and 1089 females (mean age: 35.7 ± 17.8 yr). A total of 5120 imaging examinations (CT + MRI) were performed between 2006 and 2015 for initial diagnosis and management of CD.

Imaging

Our institution is a quaternary care hospital and the Multidetector CT (MDCT) scanners at our institution are multivendor with a wide gamut of technologies including 16-slice, 64 slice, 128-slice, and dual energy scanners. In addition, over the last 10 years, there has been substantial progress in MDCT technology, and we have had a large turnover of CT scanner technology. Similarly, our MR scanner number has also increased during the 10-year period and includes both 1.5 and 3-tesla magnets. Various radiation reduction strategies have been adopted by our institution during last 10-year period. These techniques include automatic tube current (mA) modulations, low peak voltage (kVp) technique and body weight optimized parameters (kVp/mA), higher noise index (raising noise index from 12 to 18), iterative reconstruction technique (Adaptive Statistical Iterative Reconstruction Technique [ASIR]; Sinogram Affirmed Iterative Reconstruction [SAFIRE]), and automated kV modulation (CARE kV) technique.[21,24–30]

Data Collection and Outcome Measures

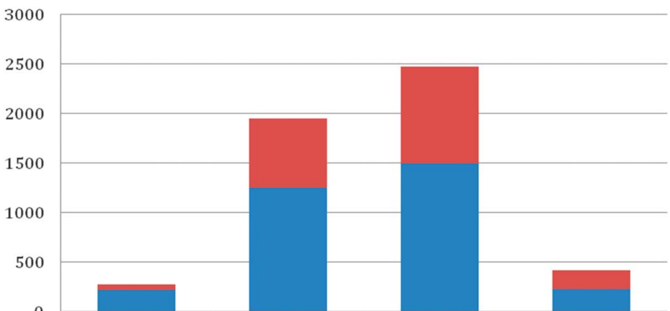
The electronic medical records of the patient cohort were then reviewed by an independent reviewer to document patient demographics, laboratory tests, endoscopic details, clinical diagnosis, and scan indications for CT and MR studies. Indications for ordering the examinations were decided and recorded based on the clinical details and outcome of imaging and classified into 4 broad categories based on the classification given in ACR appropriateness criteria.[6] The 4 categories included (1) initial diagnosis, (2) follow-up (flare up such as fever or increasing abdominal pain or leukocytosis and disease activity), (3) assessment of complications (bowel obstruction or stricture, abscess or fistula formation, and perforation), and (4) response to treatment. Complication assessment was further subcategorized in to abscess, fistula, stricture, acute bowel obstruction, and perforation. The patient cohort was also classified into 3 age group categories—$<$17 years, 17 to 40 years, and $>$40 years—to study their imaging utilization because of varying clinical profiles and disease severity in different age groups.[31–33]

The total CT and MRI examinations performed in this patient cohort for the 10-year period was calculated along with the volume of CT and MR scans over the 10-year period (2006–2015). The annual imaging volume (CT + MR combined, CT alone and MR alone) and change in the annual scan volumes was estimated to identify the trends in CT and MR performance over the 10-year period. The numbers of CT and MRI studies performed for each patient age group and for each individual patient were also calculated. The trends in CT and MR performance over the 10-year period for each age group were calculated. The annual number of patients referred for cross-sectional imaging (CT + MR) was also calculated. Using this number as denominator, average examinations per patient per year were calculated for total cross-sectional imaging studies (CT + MR) and also for CT and MRI examinations separately. The overall and annual CT and MR examinations performed for each of the 4 categories of indications was estimated along with the trend in the CT and MR volume for each indication. Because MRI is considered superior to CT for perianal diseases, we also subcategorized MR scans into the perianal versus intra-abdominal indications.

CT Radiation Exposure

To estimate CT radiation exposure, the CT volume dose index ($CTDI_{vol}$; in milligray or mGy) and the dose-length product (DLP; in milligray-centimeter or mGy-cm) were extracted from radiation dose reports and recorded for each patient. The effective radiation exposure (ED) in milliSeivert (mSv) was calculated using the following formula: $ED \sim k \times DLP$.

In this formula, k constant for abdominal/pelvic CT was considered as 0.015 ($mSv \cdot mGy^{-1} \cdot cm^{-1}$), based on published



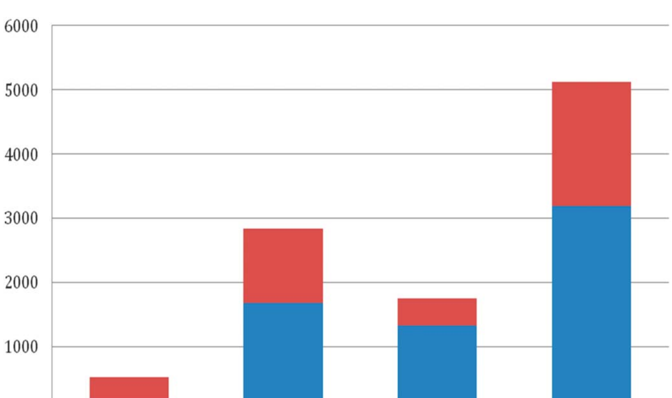
	Initial diagnosis	Follow Up	Complications	Response to treatment
MRI	59	699	979	187
CT	219	1250	1496	231

FIGURE 1. Imaging utilization in patients with CD over a 10-year period based on indication for scanning. The bar diagram highlights the most common indication for choice of cross-sectional imaging studies was for detection of complications and follow-up evaluation.

reports from the International Commission of Radiologic Protection.[34] Average annual radiation exposure per CT was obtained by calculating the mean for all CT examinations performed in that year.

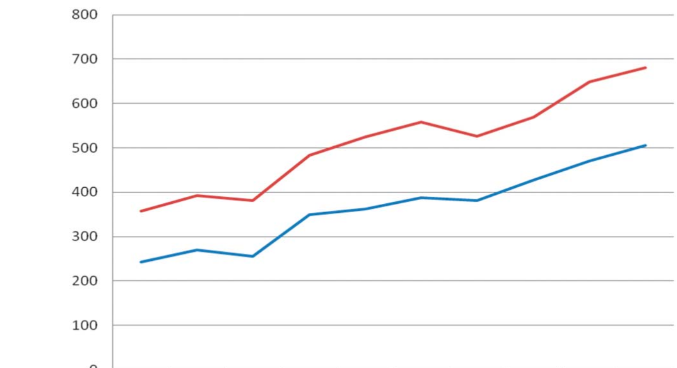
Statistical Analysis

Data compilation and analysis were performed using Microsoft Excel 2007 software (Microsoft Corporation, Redmond, WA). Group statistics were presented as mean ± SD, numbers, and percentages. Linear Regression was used to assess the utilization trends of each modality, different indications, and age groups. The *P* values less than 0.05 were considered as statistically significant. Linear regression coefficients were used for depiction of the strength of correlation.



	<17	17-40	>40	total
MR	341	1165	418	1924
CT	186	1677	1333	3196

FIGURE 2. Imaging utilization in patients with CD in different age groups over a 10-year period. MR utilization exceeds the use of CT in <17 years age group, whereas CT use was more for 17 to 40 and >40 years age groups.



	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
PATIENT	243	270	255	349	362	387	381	427	471	506
CT+MRI	358	393	381	483	524	558	526	570	649	681

FIGURE 3. Annual trends in imaging utilization. Trend line showing annual trends in number of patients (blue line) referred for cross-sectional imaging and total number of examinations (CT+MRI; red line) performed.

RESULTS

Imaging Utilization

Between 2006 and 2015, a total of 3196 CTs were performed in 1590 patients (mean age: 37.5 ± 17.8 yr; 782 males/808 females). The average number of CTs performed per patient was 2.01 (range 1–21). In patients undergoing CTs, 59.6% (n = 947) had only 1 scan, 40.4% (n = 643) had ≥2 scans, 7.9% (n = 126) had ≥ 5 scans, and 0.8% (n = 13) had >10 scans during this 10-year period. In patients who had ≥2 CT exams, the average number of scans per patient was 3.49. A total of 1924 MRIs were performed in 1142 patients (mean age: 31.1 ± 16.1 years; 545 males/597 females). The average number of MR scans performed per patient was 1.68 (range 1–10). In the patients undergoing MRIs, 63.4% (n = 724) had only 1 scan, 36.6% (n = 418) had ≥2 scans, and 4.1% (n = 47) had ≥ 5 scans during this 10-year period. In patients undergoing ≥2 MR examinations, the average number of scans per patient during the 10-year period was 2.87. Of the cohort of 2156 patients, 26% of patients (n = 576) had both CT and MRI studies during this period.

Indication-based Imaging Utilization

In this cohort, the most common indication for cross-sectional imaging studies (CT/MRI) was for the evaluation of complications accounting for 48% (n = 2475/5120), follow-up imaging accounting for 38% (n = 1949/5120), and response assessment in 8% (n = 418/5120). CT/MRI for initial diagnosis of CD was performed only in 5% of scans (n = 278/5120) (Fig. 1). Among patients undergoing CTs, the most common indication was for evaluation of complications in 47% (n = 1496/3196), follow-up imaging in 39% (n = 1250/3196), response assessment in 7% (n = 231/3196), and initial diagnosis in 7% (n = 219/3196). Among patients undergoing MRIs, similar indication-based utilization was observed. MRIs performed for evaluation of disease complications accounted for 51% (n = 979/1924), follow-up imaging for 36% (n = 699/1924), response assessment

TABLE 1. Imaging Utilization Trends Over 10 Years

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	*P*
Total imaging (CT + MR)[a]											
Total examinations	358	393	381	483	524	558	523	570	649	681	<0.001
Total patients	243	270	255	349	362	387	381	427	471	506	<0.001
Examinations for initial diagnosis	38	28	20	23	22	18	29	30	31	39	0.51
Examinations for follow-up	117	157	124	172	190	209	198	242	269	271	<0.001
Examinations for complications	178	182	210	249	273	293	247	250	281	312	0.0017
Examinations for response to treatment	25	26	27	39	39	38	49	48	68	59	<0.001
CT											
Total examinations	321	348	307	330	283	281	285	336	365	340	0.63
Patients for CT examinations	224	250	221	254	208	209	212	253	253	253	0.45
Examinations for initial diagnosis	38	28	17	21	16	10	22	20	24	23	0.28
Examinations for follow-up	113	151	116	126	96	118	109	145	146	130	0.52
Examinations for complications	147	148	155	151	147	138	130	147	164	169	0.39
Examinations for response to treatment	23	21	19	32	24	15	24	24	31	18	0.88
MRI											
Total examinations	37	45	74	153	241	277	238	234	284	341	<0.001
Patients for MR examinations	32	39	64	137	211	231	213	211	260	302	<0.001
Examinations for initial diagnosis	0	0	3	2	6	8	7	10	7	16	<0.001
Examinations for follow-up	4	6	8	46	94	91	89	97	123	141	<0.001
Complications	31	34	55	98	126	155	117	103	117	143	0.005
Examinations for response to treatment	2	5	8	7	15	23	25	24	37	41	<0.001

[a]CT + MR implies total cross-sectional examinations performed for CD including CT and MRI (sum-total of CT and MRI).

for 10% (n = 187/1924), and initial diagnosis for 3% (n = 59/1924).

Age-based Imaging Utilization

In this study, CT/MR scans for evaluation of CD were most frequently performed in the 17 to 40 years age group accounting for 56% (n = 2842, 1677 CT + 1165 MRI), followed by patients >40 years (34%, n = 1751, 1333 CT + 418 MR) and patients <17 years (10%, n = 527, 186 CT + 341 MR). In the pediatric age group (<17 yr), the utilization of MRI far exceeded CT (CT: n = 186 versus MR: n = 341) (Fig. 2).

Ten-year Imaging Utilization Trend

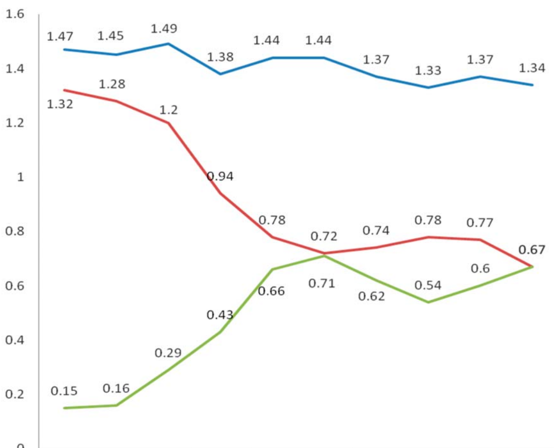
The annual CT/MR utilization for the evaluation of patients with CD increased to 1.9-fold during this period (2006: n = 358, 2015: n = 681, $P < 0.001$, r = 0.96) (Fig. 3 and Table 1). Total number of patients referred for cross-sectional imaging per year also showed an increasing trend (2006: n = 243, 2015: n = 506, 108% increase; $P < 0.001$, r = 0.97). The mean annual change in CT/MR utilization was an increase of 7.7% (−3.05% to 26.7%). The average number of examinations (CT + MR) per patient annually showed a significant decreasing trend (examinations/patient/yr; 2006 = 1.47, 2015: n = 1.34, $P = 0.002$, r = 0.83) (Fig. 4).

The rising overall annual cross-sectional imaging utilization during the 10-year period was predominantly because of a substantial (9.2-fold) increase in the annual MR scan volume (2006: n = 37, 2015: n = 341, $P < 0.001$, r = 0.93) (Table 1). The growing MR utilization (2006: n = 37, 2015: n = 341, $P < 0.001$) was mainly because of a greater number of patients undergoing MR scans annually (2006: n = 32, 2015: n = 302, $P < 0.001$, r = 0.94). The average number of MR examinations per patient annually showed a significant increasing trend (examinations/patient/yr; 2006 = 0.15, 2015: n = 0.67, $P = 0.003$, r = 0.82).

During this 10-year period, there was no significant change in the number of CTs performed annually (2006: n = 321, 2015: n = 340, 5% increase, $P = 0.6$, r = 0.18) (Table 1). The average number of CT examinations per patient annually showed a significant decreasing trend (examinations/patient/yr; 2006 = 1.32, 2015: n = 0.67, $P < 0.001$, r = 0.89) (Fig. 4).

Trends in Indication-based Imaging Utilization

The annual volume of CT/MRIs performed for evaluation of complications showed an increase of 108% (2006: n = 178, 2015: n = 372, $P = 0.001$, r = 0.85) and in patients undergoing follow-up showed an increase of 131% (2006: n = 117, 2015: n = 271, $P < 0.001$, r = 0.96) (Fig. 5 and Table 1). There was also a strong increasing trend for imaging utilization for the evaluation of therapeutic response (2006: n = 25, 2015: n = 59, $P < 0.001$, r = 0.93) with 136% growth. There was no significant change in



	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
CT+MR/PATIENT	1.47	1.45	1.49	1.38	1.44	1.44	1.37	1.33	1.37	1.34
CT/PATIENT	1.32	1.28	1.2	0.94	0.78	0.72	0.74	0.78	0.77	0.67
MR/PATIENT	0.15	0.16	0.29	0.43	0.66	0.71	0.62	0.54	0.6	0.67

FIGURE 4. Average examinations per patient per year (blue line) and average CT examinations per patient per year (red line) show a decreasing trend, whereas average MR examinations per patient per year (green line) showed an increasing trend.

the number of scans performed for initial diagnosis (2006: n = 38, 2015: n = 39, $P = 0.51$).

The main contribution to the increase in MR scans were studies performed for the evaluation of complications (3.6-fold growth, 2006: n = 31, 2015: n = 143, $P = 0.005$, r = 0.80) and follow-up imaging (34-fold growth, 2006: n = 4, 2015: n = 141, $P < 0.001$, r = 0.95) (Fig. 5 and Table 1). There is also a strong increasing trend for evaluation of therapeutic response (2006: n = 2, 2015: n = 41, $P < 0.001$, r = 0.97). There was small but significant increase in number of scans performed for initial diagnosis (2006: n = 0, 2015: n = 16, $P < 0.001$, r = 0.91).

Subcategorization of imaging indications for the assessment of complications showed significant increasing trend in MR utilization for evaluation of fistula, stricture, and acute bowel obstruction (Table 2). The MR utilization for the detection of abscess also demonstrated a rising trend although it was not statistically significant. In patients with suspected perforation, there was no change in the MR utilization. The utilization of CT has remained unchanged for all the different subcategories except for evaluation of fistulae (Table 2). On comparison between CT and MRI, the utilization of MR has exceeded CT utilization for assessment of fistula and small bowel stricture. However, for indications such as acute obstruction, perforation, and abscess, despite the rising utilization of MRI, the CT volume for these indications remains proportionately higher (Table 2).

Trends in Age-based Imaging Utilization

The trends in MR imaging utilization were similar to the overall imaging utilization across the different age groups (Table 3). The strength of increasing trend was higher in <17 years (15-fold growth, 2006: n = 5, 2015: n = 82, $P < 0.001$, r = 0.95) and 17 to 40 years (7-fold growth, 2006: n = 24, 2015: n = 200, $P < 0.001$, r = 0.92) age groups compared with >40 years (2006: n = 8, 2015: n = 59, $P = 0.003$, r = 0.81) age group. In 2015, the MRIs performed in the 17 to 40 years group account for majority of the MR scan volume (58.6%; 200/341) (Table 3). In 2015, MR was more frequently performed compared with CT in patients <40 years (76% and 53% of total imaging in <17 yr and 17–40 yr age groups, respectively), whereas in 2006, MR was less frequently performed (<17 yr 24% of total imaging and 17–40 yr, 12% of total imaging) (Table 3). By contrast, CT remains the predominant modality for evaluation of CD in patients >40 (70%) (Table 3). Imaging utilization for CT did not show significant change over the 10-year period in different age groups (Fig. 5 and Table 1).

Radiation Exposure Trends

Radiation dose reports for review were available for 2888 scans (n = 1492 patients) in this cohort. The mean CT dose index [$CTDI_{vol}$], DLP, and effective dose for the CTs in the study were 10.09 ± 5.7 mGy, 552.1 ± 368.2 mGy-cm, and 8.2 ± 5.5 mSv, respectively (Table 4). There was a 59.4% reduction in the $CTDI_{vol}$ and 61.1% reduction in DLP and effective dose per examination

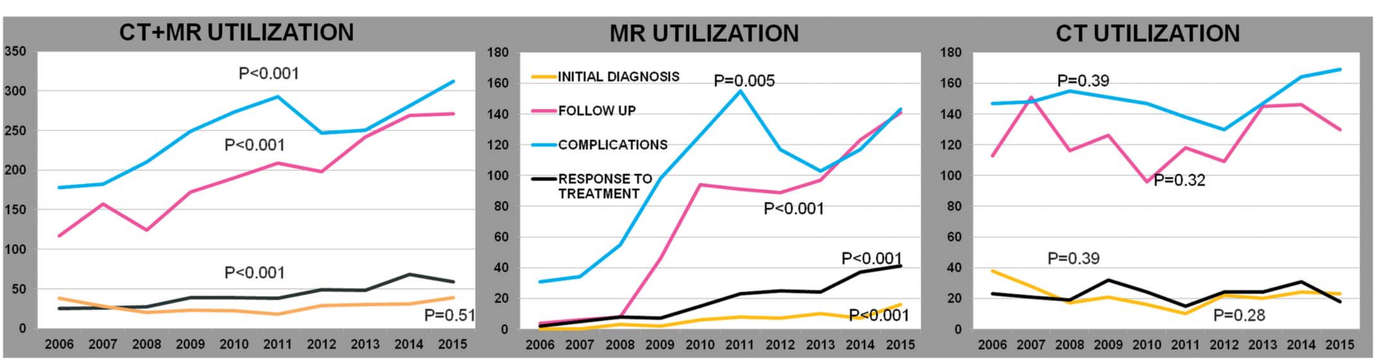


FIGURE 5. Line diagrams show annual trends in CT/MR utilization, (A) annual trends in total (CT + MR) utilization showed a significant increase in volume for all indications except for initial diagnosis. B, Line diagram of CT trend shows no significant change in the annual CT utilization. C, Line diagram for MR utilization showed a significant increase in volume for all indications. Yellow line, initial diagnosis; pink line, follow-up imaging; blue line, complication assessment; black line, response assessment.

TABLE 2. Imaging Performed for the Assessment of Complications During 2006–2015

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	*P*
CT											
Abscess	61	62	58	63	58	56	52	54	59	65	0.6
Fistula	10	19	19	12	19	16	18	14	27	27	0.04
Stricture	18	17	29	27	11	19	11	21	19	18	0.56
Acute bowel obstruction	52	43	47	44	54	43	43	53	53	56	0.19
Perforation	6	7	2	5	5	2	6	5	6	3	0.58
MRI											
Abscess	10	10	18	29	27	32	24	19	20	27	0.11
Fistula	20	17	32	42	57	56	48	49	57	65	<0.001
Stricture	1	5	5	24	32	46	25	25	30	39	0.009
Acute bowel obstruction	0	1	0	3	10	21	20	9	10	12	0.03
Perforation	0	1	0	0	0	0	0	1	0	0	0.8

between 2006 and 2015 (2006: $CTDI_{vol}$ 16.9 ± 7.1 mGy, DLP 988.1 ± 555.5 mGy-cm and 2015: $CTDI_{vol}$ 6.87 ± 4.62 mGy, DLP 384.3 ± 283 mGy-cm, $P < 0.001$ for all parameters, $r = 0.96$ for $CTDI_{vol}$ and 0.95 for DLP and ED) (Table 4). The average annual reduction in radiation exposure was 9.72% (range: 0.5%–20.3%; Table 4).

DISCUSSION

Patient with CD are at a potentially increased risk of CT radiation exposure, as these patients often require multiple imaging studies in their lifetime given the chronic relapsing nature of the disease. In addition, the advances in MR technology and growing experience with fast MR techniques including MR enterography has led to this imaging modality being increasingly used for evaluation of CD.[2,11,35,36] The introduction of newer molecular-targeted biologic agents such tumor necrosis factor- alpha inhibitors has increased the demand for novel imaging techniques for optimal response assessment and determination of disease activity.[37] Emerging MRI techniques, such as diffusion-weighted imaging, ultrasmall superparamagnetic iron oxide– enhanced MRI, and Positron emission tomography -magnetic resonance imaging (PET-MRI), have potential for detecting occult disease activity, evaluating early treatment response, treatment resistance, and differentiating inflammatory from fibrotic strictures.[37] The concerns of radiation risk from CT and newer MR technologies have potentially impacted the ordering practices of imaging studies in patients with CD; however, there are limited data on its impact on utilization. In our single-institutional study investigating the utilization of cross-sectional imaging in patients with CD, we found a nearly 2-fold increase in CT + MRIs performed over the last decade. This substantial increase was both because of rising number of scans performed and growing number of patients undergoing CT/MRI. Rise in the number of patients with CD undergoing cross-sectional imaging studies could be due to several factors including new patients being scanned, increasing reliance of referring providers on imaging to follow-up patients on or off therapy, or use of imaging to monitor response to therapy. Possible expansion of CD practice at the referring provider end would also be a potential factor. Increased use of cross-sectional imaging may also be attributed to a decreased performance of fluoroscopic examinations in recent years.[3] Additional possible reasons for increased utilization are economic (more patients can afford), educational (referring providers realize utility), change in patient demographics, and growing awareness (sicker patients are being referred to institutions such as ours with dedicated IBD clinic).

The rising trend in utilization of imaging in CD was predominantly secondary to a 9-fold growth in MR scan volume while the annual CT numbers remained stagnant. The considerable expansion of MRIs performed annually is also reflected in the rising trend of number of MRI performed per patient per year while the number of CTs being performed per patient every year showed a declining trend. These findings has 2-fold implications, first that referring providers are ordering MRIs more and more for follow-up of patients with CD and second radiologists are increasingly comfortable performing and interpreting MRIs. Increased performance of MR examinations might also be a result of increase in the number of MR scanners at our hospital during this period. Our study shows that despite greater (more number of scans and patients) overall cross-sectional imaging utilization, the average number of examinations per patient per year is decreasing as the growth in the number of patients undergoing imaging studies is more than increase in number of scans resulting in a larger denominator. The most reasonable explanation appears to be an increasing performance of imaging for disease surveillance (stable disease and mild symptoms) (Fig. 5 and Table 1). Adding more such patients (requiring less frequent imaging) to the imaging cohort might have resulted in a decreasing trend in average scans per patient per year.

When we delved into the various indications for mounting utilization of MRI, we found that the growth in MR volume was

TABLE 3. Imaging Utilization Trends in Different Age Groups

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	*P*
Total imaging CT + MRI[a]											
Total	358	393	381	483	524	558	523	570	649	681	<0.001
<17	21	29	26	51	46	52	48	71	75	108	<0.001
17–40	195	221	228	275	295	315	290	295	350	378	<0.001
>40	142	143	127	157	183	191	185	204	224	195	<0.001
CT											
Total	321	348	307	330	283	281	285	336	365	340	0.63
<17	16	24	13	24	12	12	15	25	19	26	0.43
17–40	171	188	177	187	148	149	139	155	185	178	0.53
>40	134	136	117	119	123	120	131	156	161	136	0.14
Total MRI (including perianal)											
Total	37	45	74	153	241	277	238	234	284	341	<0.001
<17	5	5	13	27	34	40	33	46	56	82	<0.001
17–40	24	33	51	88	147	166	151	140	165	200	<0.001
>40	8	7	10	38	60	71	54	48	63	59	0.003
MRI for perianal disease[b]											
<17	3	2	4	10	9	11	5	7	5	7	
17–40	13	17	31	32	39	30	21	17	34	18	
>40	5	4	6	11	12	17	11	12	8	4	

[a]CT + MR implies total cross-sectional examinations performed for CD including CT and MRI (sum-total of CT and MRI).
[b]It is important to note that the proportional contribution of MRIs performed for perianal indications to the total MRI volume showed a decreasing trend for all different age groups.

mostly because of increasing number of studies performed to evaluate for CD complications and in follow-up of asymptomatic patients. MRIs for monitoring response to therapy also showed a growing trend signifying greater than ever reliance of referring providers on imaging to manage patients with CD. Assessment of CD activity is challenging and symptoms of CD often do not correlate with objective measures of disease activity such as biochemical markers and colonoscopy findings.[38,39] Other clinical and laboratory measures to assess the disease activity e.g., Crohn's Disease Activity Index (CDAI) and inflammatory markers such as C-reactive protein and erythrocyte sedimentation rate provide more quantitative assessment, but lack specificity because of their susceptibility to unrelated inflammation.[37] Endoscopic evaluation is considered the gold standard for CD activity and treatment response assessment. However, current endoscopic criteria for disease activity also have significant limitations including interuser variation and lack of established cutoff values to define response/remission.[40,41] Recent evidence also suggests that although endoscopic assessment is frequently used for evaluating CD activity in clinical trials, it is not typically performed in routine clinical practice because of its invasiveness. Being noninvasive, imaging provides an excellent alternative to endoscopy for evaluation of disease activity and therapeutic response. MRE can detect therapeutic resistance before clinical exacerbation of symptoms and can guide dose escalation or combination therapy to achieve/maintain clinical remission. MRE may also help in minimizing unnecessary financial cost and long-term toxicities of biological agents in patients with resistance to treatment.[42] Our study did not show any significant change in cross-sectional imaging utilization for initial diagnosis. It might be a result of the fact that our institution is a quaternary care referral hospital, which means that most of these have a confirmed diagnosis of CD at the time of referral.

TABLE 4. Radiation Dose Trends over a 10-Year Period

Year	$CTDI_{vol}$, mGy	ED, mSv	DLP, mGy-cm	Annual Reduction Percentage in Mean DLP (ED)
2006	16.93 ± 7.1	14.82 ± 8.33	988.12 ± 555.5	
2007	15.08 ± 6.1	12.33 ± 6.16	822.49 ± 411	−16.76
2008	13.06 ± 6.2	10.44 ± 5.72	696.23 ± 381.7	−15.35
2009	11.81 ± 5.9	9.74 ± 6.25	649.74 ± 416.7	−6.67
2010	10.99 ± 4.44	8.72 ± 4.11	581.6 ± 274.3	−10.48
2011	8.49 ± 3.6	6.95 ± 3.57	463.43 ± 238	−20.31
2012	8.16 ± 3.9	6.76 ± 4.27	451.25 ± 284.9	−2.62
2013	7.73 ± 3.5	6.07 ± 3.05	404.79 ± 203.5	−10.29
2014	6.88 ± 3.2	5.79 ± 3.29	386.55 ± 219.5	−4.5
2015	6.87 ± 4.6	5.76 ± 4.2	384.35 ± 283	−0.57

The increased utilization of MR in the identification of complications noted in our study is surprising, considering the challenges faced while performing MR in an acute setting. The many limitations of performing MR in an acute setting or emergency department include equipment availability, limited after hours technical support, lack of round-the-clock availability of experienced technologists, and busy in-house and emergency neuroimaging work flow. As the patients presenting with CD complications are sicker, generation of diagnostic quality MR examinations is also challenging because of poor patient compliance with oral contrast and breath holding. Another significant impediment to the utilization of MR in emergency radiology (ER) setting includes reluctance of insurance companies to authorize use of MRI in CD, although this problem might vary depending on practice setting and geographic location. Despite the increasing trend in utilization of MR for evaluation of CD complications, CT use remained higher than MR for the evaluation of more emergent complications such as perforation, acute obstruction, and abscess.

Age-based categorization is often performed because of the difference in the clinical manifestations across various age categories. The pediatric forms of CD often have more extensive disease involvement including affection of upper gastrointestinal tract and location of disease can change over time more often than in adults.[31–33] CD with elderly onset more often involves the colon and are less often progressing and disabling.[43] Our results show that MRI constituted a huge portion of imaging volume in patients with CD $<$17 years age. The use of MRI also showed significant growth in the 17 to 40 age group and in fact exceeded the use of CT in recent years. It implies that MR enterography is progressively becoming the imaging modality of choice for pediatric and younger adult population.[11,23,31] Interestingly, despite an increasing trend in MR utilization in patients $>$40 years, CT was still the predominant imaging modality until 2015. This variable trend in the different age groups could be because perceived CT radiation hazards are much more relevant in younger population, and therefore, the use of CT is still persisting in the older patient population.[2,44,45]

Despite the plateau in the CT volume over a 10-year period, we found that the mean annual CT radiation exposure showed a 59% reduction from 2006 to 2015. This substantial decline must have been a result of radiation reduction strategies adopted by our institution including automatic tube current modulations, low kVp technique, body weight optimized parameters (kVp/mA), CARE kV technique, higher noise index (raising noise index from 12 to 18), and use of iterative reconstruction techniques.[21,24–30] Detailed discussion of these techniques is out of the scope of this article, and these strategies from our group have been previously reported.[21,24–30] The stability in the number of CTs performed every year signifies the continued importance of CT in the evaluation of patients with CD particularly in the emergency settings and for indications such as diagnosis of bowel leak. The radiation exposure reduction initiatives results are encouraging, given the continued utility of CT in managing patients with CD. In addition to radiation exposure reduction strategies, our institution has also implemented information technology (IT) solutions which alert referring providers during ordering of CT examinations about patients with a history of multiple CTs to enable cautious and prudent ordering of CTs.

In a study performed on pediatric inflammatory bowel disease, Domina et al[2] reported a 53% increase in the yearly number of diagnostic examinations performed. This study reported that the utilization of CT in pediatric patients with IBD increased per patient from 2001 to 2006 by 163% but decreased 42% from 2006 to 2010. The utilization of MRI showed significantly increased use (0.00 versus 0.58 ± 1.01, $P < 0.0001$). In comparison, our study showed a 1.9-fold growth in yearly performance of cross-sectional imaging over a 10-year period in patients with CD. But it is important to note that the study performed by Domino et al took fluoroscopic examinations and endoscopic procedures into consideration in addition to cross-sectional imaging and the investigators included ulcerative colitis as well in addition to CD in a pediatric population in a different period (between 2001 and 2010).

Our study has several limitations. First, the findings in this study reflect single-institutional data in a quaternary care hospital. The true imaging utilization in patients with CD might be potentially underrepresented if the patients undergo imaging scans at other hospitals or imaging centers. However, this is unlikely, as our institution has a dedicated IBD service with close patient follow-up and therefore our data reflect the actual CT/MRI utilization in these patients. Second, our study investigated the utilization of abdominal CT/MRI performed for evaluation of patients with CD. The study did not include non–cross-sectional imaging studies (ultrasound/fluoroscopy) and CT/MRI performed in other body parts (e.g., CT chest). Third, radiation dose data were not available for all CT examinations. Fourth, our study did not include patients undergoing CT/MRIs for suspected CD who were subsequently found not to have CD.

CONCLUSIONS

Our study shows a nearly 2-fold rise in the cross-sectional imaging utilization in patients with CD between 2006 and 2015 with a substantial contribution to this growth from increase in MR scan volume. The CT volume has remained stable over the last 10 years and continuing efforts at radiation exposure reduction has resulted in a 59% reduction in mean annual CT radiation exposure. The MR utilization has exceeded CT utilization in younger population ($<$40 yr); however, CT is still the dominant imaging modality for older patient population. As a matter of conjecture, it seems reasonable to assume that the potential utilization of MRI in patients with CD will continue to rise, whereas CT will remain an important test in the interrogation of patients with acute CD manifestations.

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