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CT Imaging as a Single Modality for Clinical Staging of Gastric Cancer in Limited Resource Centers: A Retrospective Pilot Study

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ABSTRACT

Background: Gastric cancer disproportionately impacts populations in resource-limited settings. Within a safety-net network, we assessed the utility of computed tomography (CT) as a single staging modality.

Methods: We utilized a clinical database of gastric cancer patients treated within the Los Angeles County safety-net hospital system from 2016 to 2023 in conjunction with retrospective imaging review by certified radiologists. We assessed agreement between clinical and pathological staging for patients who underwent curative gastrectomy using the Kappa coefficient.

Results: Of 107 patients with available CT imaging, 43.9% ($n = 47$) were staged with CT as a single modality. Most tumors displayed infiltrating (75%) or diffuse (28%) morphology, 41% displayed adequate gastric distention and regional lymphadenopathy was common (68%). Twenty-nine patients underwent curative gastrectomy. Overall agreement was minimal ($\kappa = 0.29$, 95% CI [0.071−0.51], $p = 0.022$), weak for T3/T4 tumors ($\kappa = 0.50$, 95% CI [0.17−0.82], $p < 0.01$), and weak for Hispanic/Latino patients ($\kappa = 0.47$, 95% CI [0.19−0.76], $p < 0.01$).

Conclusions: There was minimal agreement between clinical and pathologic staging when assessing clinical stage by CT imaging alone, suggesting that CT is not adequate as a single modality staging tool. While every effort should be made to obtain multimodal staging, larger studies are warranted to improve CT imaging protocols for staging in resource-limited settings.

1 | Introduction

Gastric cancer remains a significant global health challenge, with a disproportionate burden on populations in limited resource settings [1–3]. Accurate clinical staging is therefore critical for guiding treatment regimens and optimizing patient outcomes. Practice guidelines generally recommend the use of multiple imaging modalities to obtain clinical staging, including computed tomography (CT), endoscopic ultrasound (EUS), diagnostic laparoscopy (DL), magnetic resonance imaging (MRI), and/or positron emission tomography (PET) [4–7]. However, in resource-limited hospital settings, the accessibility and timeliness of these advanced imaging modalities pose a major barrier to patient care [8].

Consensus is currently lacking whether a single imaging modality is adequate for gastric cancer staging [9]. EUS has been shown to be superior in determining the depth of tumor invasion [4, 10], while single portal-venous phase CT has demonstrated superiority in the evaluation of metastatic disease, with the exception for peritoneal metastasis [4]. CT is low cost, requires minimal time and is widely available at most centers, rendering it feasible as a single-modality clinical staging tool in resource-limited settings. However, traditional CT algorithms may lack the sensitivity and specificity required for accurate gastric cancer staging [11]. Creating a standardized CT protocol and interpretation checklist for clinical staging may bridge this gap, thereby providing a pragmatic solution in resource-limited settings. The lack of worldwide consensus for clinical staging further emphasizes the need for standardization [8]. There is agreement that adequate gastric distention is critical to improving delineation between normal gastric mucosa and tumor tissue to establish depth of tumor invasion, which is a key prognostic factor that drives management decisions [12, 13].

Primary aims of this pilot study included (1) assessing the agreement between clinical and pathologic T staging for patients who received curative surgery, (2) comparing whether gastric distention on CT imaging improves agreement, and (3) comparing whether ethnicity changes agreement. Secondary aims included (1) development of an interpretation checklist for reporting CT-based gastric cancer characteristics when using CT as the sole staging modality, (2) describe tumor characteristics of included patients, and (3) assess frequency of imaging modalities utilized for clinical staging. We hypothesized that while routine CT imaging may not reliably predict pathologic T staging, this may be improved when adequate gastric distention is present.

2 | Materials & Methods

2.1 | Patient Cohort

We utilized a retrospectively generated patient database of gastric cancer treated in Los Angeles County [14]. As the second largest municipal healthcare system in the United States, the Los Angeles County Department of Public Health Services (LA DHS) serves as a safety-net hospital system for nearly 750 000 patients annually who are historically marginalized and face barriers to receiving healthcare [15].

Patient data was reviewed with a waiver of informed consent, as approved by UCLA's Institutional Review Board (IRB) protocol #1551114-5 and was conducted in accordance with the Declaration of Helsinki. We randomly selected patients with CT imaging available at time of diagnosis for inclusion. An *a priori* power analysis was not performed for this study. All clinicopathologic data was previously collected. Frequency data of the various imaging modalities performed for clinical staging was also collected.

2.2 | Retrospective Imaging Review

Images were reviewed on a Fujifilm PACS workstation (Fujifilm, Tokyo, Japan) for TNM staging per the AJCC 8th edition staging system [16]. CT scans were independently reviewed by three board-certified radiologists (K.M., S.V., P.D.). Observers were not blinded to the diagnosis of gastric cancer but were blinded to clinicopathologic data and initial radiologic findings. Each CT scan was reviewed by at least two observers, and differences in assessment were resolved with consensus discussion. All observers completed a questionnaire detailing the imaging appearance of the tumor, lymph nodes, and the presence of metastatic disease (Supporting Information S1: Table 1).

Tumors were defined as "proximal" if they were non-esophageal tumors with the epicenter located within the gastric cardia and "distal" if the tumor epicenter was distal to the gastric cardia (Figure 1). Tumor morphology was described based upon Borrmann's classification, with "polypoid tumors" defined by the presence of an intraluminal convex mass, "infiltrating tumors" defined by the presence of a diffuse thickening without a discrete mass, and "ulcerating tumors" defined by the presence of a crater-like hole within the intraluminal aspect of the mass (Figure 2) [17]. "Perforation" was defined as the presence of a gastric wall discontinuity or the presence of pneumoperitoneum. Only cases in which perforation was minimal/contained and did not require emergent surgical intervention were included in this study. Gastric distention was defined as "adequate" when the stomach was $\geq 50\%$ distended by estimated volume and "poor" when $< 50\%$ distended (Figure 3).

T stage was defined as follows: Tx = tumor was not visible on CT, T1/T2 = absence of peri-gastric fat stranding, T3/T4a = presence of fat stranding (indicating extra-gastric extension/transmural involvement), and T4b = invasion of adjacent organs or obliteration of fat plane between adjacent organs and the target lesion (Figure 4). Nodal staging was defined as follows: lymphadenopathy was defined by lymph nodes with short-axis $\geq 6-8$ mm and a rounded/necrotic morphology, with regional versus distant lymphadenopathy defined by the AJCC 8th edition staging system (Figure 5) [18]. Metastatic disease was defined as evidence of distal lymphadenopathy and/or distal organ metastasis. Ascites was considered to be suspicious for peritoneal carcinomatosis, unless an alternative etiology was suspected.

2.3 | Statistical Methods

Standard descriptive statistics were used for categorical and continuous data. Chi-square or Fisher's Exact test were performed to evaluate categorical variables. Agreement between radiologic and pathologic tumor staging were presented as Cohen's Kappa coefficients with 95% confidence interval (CI). Kappa coefficients were interpreted using

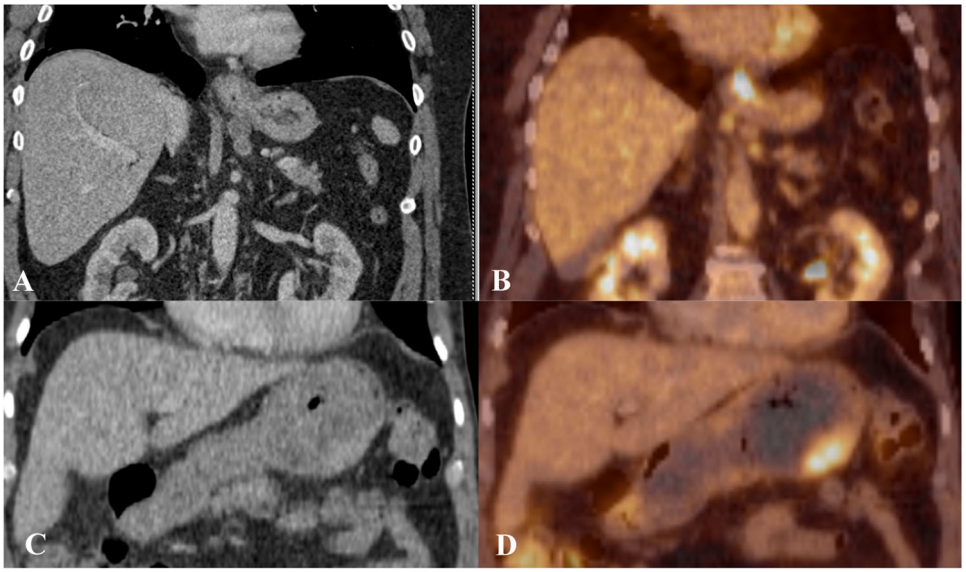

FIGURE 1 | Radiographic tumor location of gastric cancer. Representative CT images of gastric cancer located in the cardia (A) versus greater curvature (C). Corresponding PET images are provided for improved visualization of the tumor location (B, D).

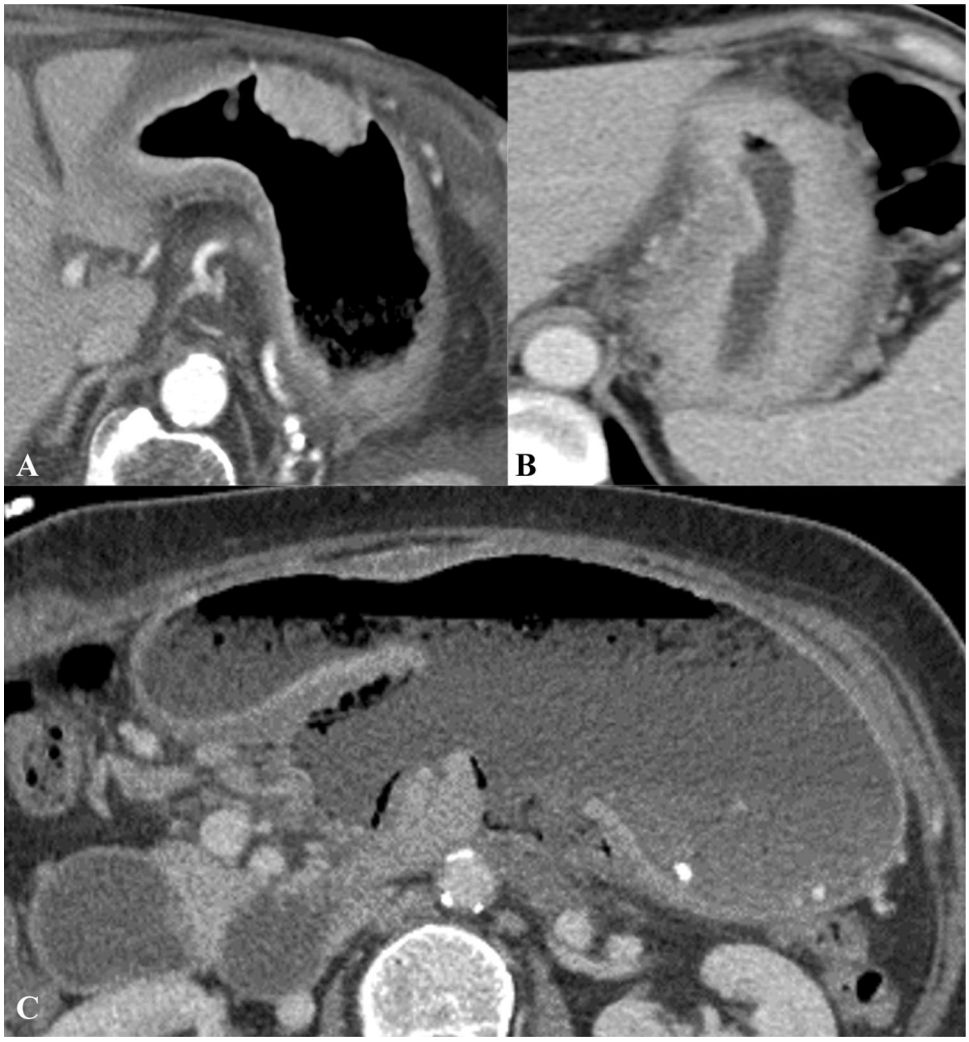

FIGURE 2 | Radiographic tumor morphology of gastric cancer. Representative CT images of gastric cancer demonstrating the following morphologies: (A) polypoid, (B) infiltrating, and (C) ulcerated with perforation.

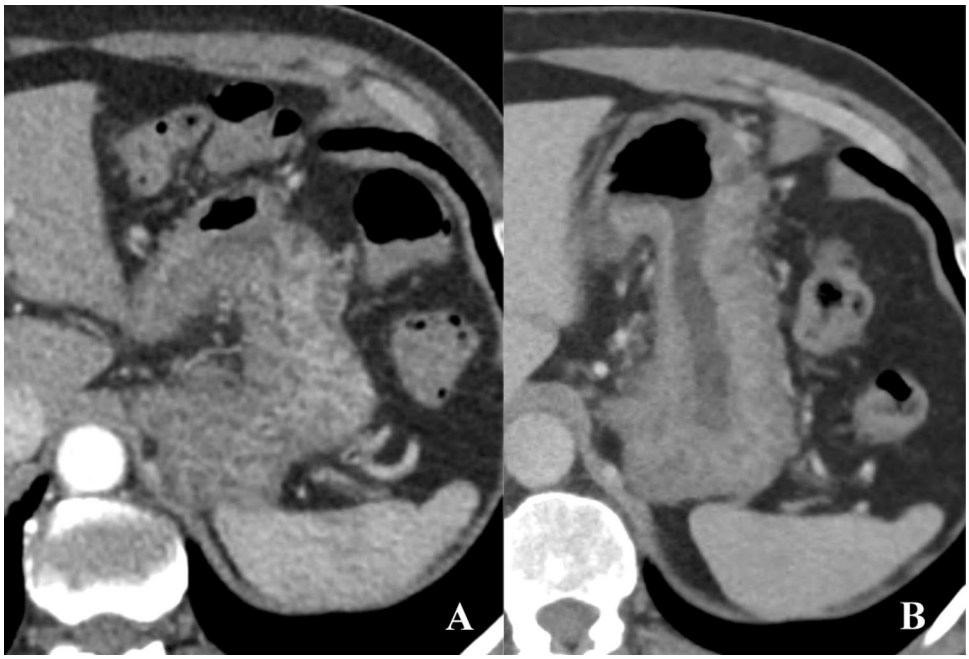

FIGURE 3 | Radiographic gastric distention for gastric cancer. Representative CT images of gastric cancer comparing stomach distention. (A) An infiltrative tumor with poor visualization due to inadequate gastric distention; and (B) notable improved visualization of the underlying tumor with adequate gastric distention.

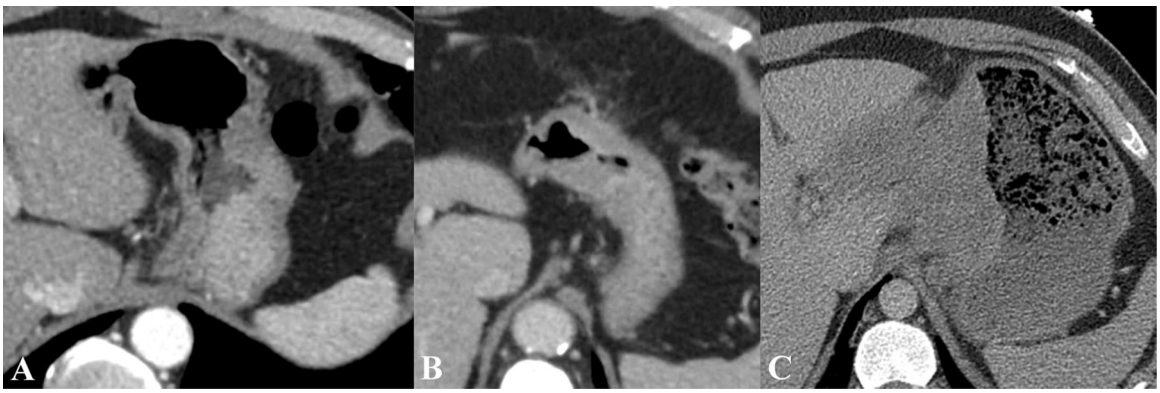

FIGURE 4 | Radiographic T staging in gastric cancer. Representative CT images of the various tumor stages of gastric cancer: (A) T1/T2, (B) T3/T4a, and (C) T4b.

McHugh's definitions: $\kappa = 0–0.20$: no agreement; 0.21–0.39: minimal agreement; 0.40–0.59: weak agreement; 0.60–0.79: moderate agreement; 0.80–0.90: strong agreement; above 0.90: almost perfect agreement [17]. $p < 0.05$ were considered significant. The following statistical software was used to perform analyses in this study: SAS (v.9.4; SAS Institute, Cary, NC).

3 | Results

3.1 | Patient Characteristics and Frequency of Imaging Modality

In total, 107 patients with available CT imaging were included in the present study (Table 1). The majority of patients were male ($n = 69$, 64.5%) and identified as Hispanic/Latino ($n = 82$, 76.6%). The average age at diagnosis was 56.6 years, and most patients denied a history of tobacco or alcohol use ($n = 74$, 69.2% and $n = 66$, 62.6%, respectively). The most common T, N, and M stages were T3/T4a ($n = 46$, 43%), N1 ($n = 41$, 38.3%), and M1 ($n = 61$, 57%), respectively. Of those with M0 disease, $n = 29$ (27.1%) patients underwent curative surgery and had available surgical pathology results for inclusion in the analysis of agreement between clinical and pathologic staging.

Our assessment of imaging modalities performed for clinical staging demonstrated that 43.9% ($n = 47$) of patients were staged with CT as a single modality (Table 2). Additionally, 56.1% ($n = 60$) of patients received adjunctive imaging modalities including PET/CT 32.7% ($n = 35$), EUS 17.8% ($n = 19$), DL 9.45% ($n = 10$), MRI 3.74% ($n = 4$), and paracentesis 7.48% ($n = 8$).

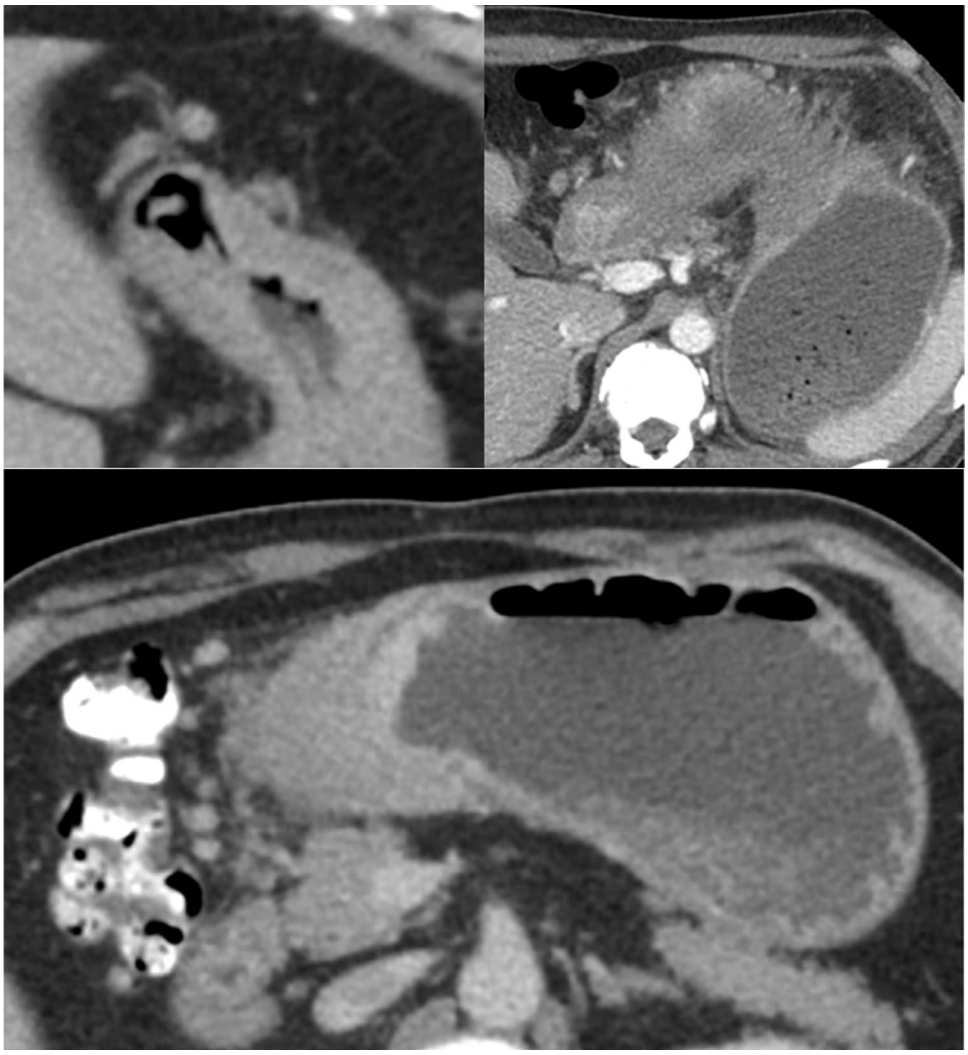

FIGURE 5 | Radiographic lymphadenopathy in gastric cancer. Representative CT images of gastric cancer with regional lymphadenopathy.

3.2 | Agreement Between Clinical and Pathologic Staging

Of the 46 patients with M0 disease, 29 had available surgical pathology results and were included in the analysis of agreement between clinical and pathologic staging (Table 3). Clinical staging was determined by retrospective CT imaging review in this analysis. Overall, there was minimal agreement between clinical and pathologic staging ($n = 29$, $\kappa = 0.29$, 95% CI [0.071−0.51], $p = 0.022$) (Supporting Information S1: Figure 1). Agreement was also minimal when stratified by T1a/T1b/T2 tumors ($n = 31$, $\kappa = 0.30$, 95% CI [0.010−0.59], $p = 0.025$) (Supporting Information S1: Figure 2) and improved but weak for T3a/T4a tumors ($n = 50$, $\kappa = 0.50$, 95% CI [0.17−0.82], $p < 0.01$) (Supporting Information S1: Figure 3).

Regarding tumor location, agreement was minimal for distal tumors ($n = 26$, $\kappa = 0.32$, 95% CI [0.084−0.54], $p < 0.01$) (Supporting Information S1: Figure 4). There was no agreement between clinical CT and pathologic staging for proximal tumors, though this was not statistically significant ($n = 3$, $\kappa = 0.14$, 95% CI [−0.12–0.40], $p = 0.39$) (Supporting Information S1: Figure 5). Regarding gastric distention, agreement remained minimal, though this was not statistically significant ($n = 9$, $\kappa = 0.32$, 95% CI [−0.12−0.72], $p = 0.18$) (Supporting Information S1: Figures 6–7). There was improved but still weak agreement for patients who identified as Hispanic/Latino ($n = 19$, $\kappa = 0.47$, 95% CI [0.19–0.76], $p < 0.01$) (Supporting Information S1: Figure 8) and no agreement for non-Hispanic/Latino patients ($n = 10$, $\kappa = -0.17$, 95% CI [−0.37−0.035], $p = 0.20$) (Supporting Information S1: Figure 9), though the latter was not statistically significant.

3.3 | Development of a CT Interpretation Checklist for Reporting Gastric Cancer Clinical Staging

A CT interpretation checklist was developed using our retrospective image review experience (Table 4). The "Quality of Evaluation" component describes gastric distention, whether all layers of the gastric wall are visualized, the presence of limitations and the overall quality of the study. Limitations described include cachexia, anasarca, and imaging artifact. The "Primary Tumor" component is used to provide descriptions of the primary tumor. This includes size

TABLE 1 | Clinicopathologic characteristics of study population.

Characteristic	*N*	%
Gender		
Male	69	64.5
Female	38	35.5
Ethnicity		
Hispanic/Latino	82	76.6
Non-Hispanic/Latino	25	23.4
Tumor location		
Proximal	17	15.9
Distal	90	84.1
Histologic subtype		
Diffuse	30	28.0
Intestinal	18	16.8
Mixed	5	4.67
Unknown	54	50.5
Histological features		
Linitis plastica	9	8.41
Signet ring	56	52.3
Evidence of *Helicobacter pylori*		
Positive	19	17.8
Negative	33	30.8
Unknown	57	53.3
Carcinoma grading		
G1	3	2.80
G2	8	7.48
G3	88	82.2
Unknown	8	7.48
Microsatellite instability status		
High	2	0.42
Stable	46	95.8
HER2 status		
Positive	16	20.0
Negative	64	80.0
PD-L1 status		
Positive	33	75.0
Negative	11	25.0

Note: Summary of clinicopathologic characteristics of patients diagnosed with gastric cancer.
Abbreviations: HER2, human epidermal growth factor receptor 2; PD-L1, programmed death-ligand 1.

TABLE 2 | Imaging modality frequency.

	Total frequency *N* (%)	As single modality *N* (%)
Imaging modality		
CT	107 (100)	47 (43.9)
PET	35 (32.7)	—
EUS	19 (17.8)	—
DL	10 (9.45)	—
MRI	4 (3.74)	—
DP	8 (7.48)	—

Note: Frequency of various imaging modalities used to clinically stage patients with gastric cancer. "Total Frequency" represents the frequency of the imaging modality performed among all patients included in the current study. "As Single Modality" represents the frequency of the specified image modality performed as a single modality, in which no other imaging modalities were used.
Abbreviations: CT, computed tomography; DL, diagnostic laparoscopy; DP, diagnostic paracentesis; EUS, endoscopic ultrasound; MRI, magnetic resonance imaging; PET/CT, positron emission tomography/computed tomography.

measurement, morphology (polypoid, diffuse), location of the tumor epicenter, presence of ulceration, peri-gastric fat stranding, direct invasion to adjacent organs, and the presence of perforation or obstruction. The clinical T-stage is determined based on the following criteria: T1/T2, absence of fat stranding; T3/T4a, presence of fat stranding; T4b, presence of organ invasion. The "Regional Lymph Nodes" component estimates the number of abnormal regional lymph nodes. Clinical N-stage is determined based on this finding. The "Metastasis" component describes the distal spread of the tumor, including non-regional or distant lymphadenopathy, malignant ascites, and organ involvement. Clinical M-stage is determined based on this finding.

3.4 | Tumor Characteristics by CT Imaging

Tumor imaging characteristics based on retrospective image review are summarized in Table 5. Most tumors ($n = 90$, 84.1%) were identifiable on a retrospective review of imaging (Figures 6 and 7). Gastric distention was poor for most cases ($n = 63$, 58.9%). Morphologically, tumors were described as "infiltrating" ($n = 70$, 65.4%), "infiltrating and polypoid" ($n = 10$, 9.35%), or "polypoid" ($n = 9$, 8.41%). Few tumors were described as "ulcerated" ($n = 2$, 1.87%), "infiltrating and ulcerated" ($n = 1$, 0.94%), or "unable to be specified" ($n = 15$, 14%). Tumor location was predominately "distal" ($n = 90$, 84.1%). Regional nodal disease was identified in the majority of patients ($n = 74$, 69.2%), whereas distant nodal disease was identified in fewer patients ($n = 33$, 30.8%). Malignant ascites was identified in 37.4% ($n = 40$) of patients. Few patients demonstrated evidence of perforation ($n = 4$, 3.7%). Distal organ involvement was present in 31.8% ($n = 34$) of patients; most commonly involving the liver ($n = 10$) or bone ($n = 8$).

Given that the burden of gastric cancer has recently increased for Hispanic/Latino patients, we compared tumor characteristics between Hispanic/Latino and non-Hispanic/Latino patients to guide clinical staging practices. Hispanic/Latino patients predominately had infiltrating morphology (73.2%, $n = 60$) compared to non-Hispanic/Latino patients (40.0%, $n = 10$), $p = 0.0147$. Non-Hispanic/Latino patients demonstrated a higher frequency of polypoid morphology (20.0%, $n = 5$) compared to Hispanic/Latino patients (4.88%, $n = 4$). Clinical TNM staging were similar between ethnicity groups.

TABLE 3 | Agreement between clinical and pathologic T stage.

	N	Kappa (95% CI)	Cohen's interpretation	*p* value
Overall	29	0.29 (0.07−0.51)	Minimal	< 0.01
T1a/T1b/T2	31	0.30 (0.01−0.59)	Minimal	0.025
T3a/T4a	50	0.50 (0.17−0.82)	Weak	< 0.01
Adequate distension	9	0.31 (−0.11−0.72)	Minimal	0.18
Poor distension	20	0.25 (−0.0011−0.51)	Minimal	0.017
Distal location	26	0.31 (0.084−0.54)	Minimal	< 0.01
Proximal location	3	0.14 (−0.12−0.40)	None	0.39
Hispanic/Latino	19	0.47 (0.19−0.76)	Weak	< 0.01
Not Hispanic/Latino	10	−0.17 (−0.37−0.035)	None	0.20

Note: Agreement analysis comparing clinical T staging to pathologic T staging for patients with gastric cancer who underwent curative gastrectomy. Clinical staging based on retrospective CT imaging review.

4 | Discussion

In this pilot study, we retrospectively reviewed CT imaging of 107 patients with gastric cancer treated within a safety-net hospital system to assess the utility of CT as a single imaging modality for clinical staging. For patients who underwent surgery, we found overall minimal agreement between clinical and pathological T-staging. This agreement improved for T3/T4a tumors and for Hispanic/Latino patients but remained weak. The presence of gastric distention did not improve agreement. Hispanic/Latino patients displayed predominately infiltrative tumor morphology whereas non-Hispanic/Latino patients had higher rates of polypoid morphology. These findings were used to develop an interpretation checklist for reporting gastric cancer characteristics to guide clinical staging.

Complete surgical resection with negative margins remains the gold standard of gastric cancer care with curative intent [19]. For patients with locally advanced disease, neoadjuvant chemotherapy is now the standard of care in the United States and has been shown to increase the likelihood of successful R0 resection, disease-free survival, and overall survival [8, 9, 20, 21]. Given the progress in available therapeutic options for specified stages of disease, selection of the proper imaging modality to accurately clinically stage and develop an initial treatment strategy is critical [4, 5, 17]. Under-staging disease may lead to inappropriate attempts to treat with endoscopic mucosal resection or a lack of treatment with neoadjuvant therapy, while overstaging disease may result in treatment with toxic chemotherapy agents upfront with little benefit or an overly invasive surgical approach [8, 9].

Each imaging modality for gastric cancer has distinct advantages and disadvantages. Routine CT, for example, is widely accessible and requires a short examination time, but has limited ability to differentiate between layers of the gastric wall [4, 8, 22]. Multi-detector row CT gastrography may improve accuracy for T-staging but is not available at most centers and increases healthcare costs [23]. EUS offers improved differentiation of the layers of the gastric wall but can be highly operator-dependent and is an invasive procedure [4, 7, 8, 20]. MRI, which has historically displayed a limited role in gastric cancer staging, provides excellent soft tissue contrast resolution and accurate differentiation of the soft tissue layers of the gastric wall [4, 8, 24, 25]. However, MRI is often cost prohibitive, requires longer acquisition times, and is susceptible to image degradation from peristaltic and respiratory motion [4, 8, 24, 25].

A recent systematic review found both EUS and CT to have a wide range of reported accuracies for individual T and N staging [4]. Reported ranges of sensitivity for detecting T1 disease were 64%−92% and 13%−94% for EUS and CT, respectively [4]. A retrospective cohort study of patients diagnosed with gastric cancer undergoing preoperative clinical staging with EUS and CT followed by gastrectomy with curative intent found that routine CT had relatively poor accuracy in differentiating locally advanced from early disease (early disease defined as stage 0-IA per AJCC 7th edition criteria) [11]. Furthermore, the authors of the study reported that CT demonstrated an accuracy of 4.0% and 56% for T and N stage, respectively [11]. In contrast, EUS displayed an accuracy of 41.0% and 42.9% for T and N stage [11].

We wish to highlight several lessons gained from our experience with retrospective CT review within a safety-net majority Hispanic/Latino patient population. Tumors in this cohort commonly presented as diffuse, infiltrative disease which was often obscured by gastric under-distention. Also, the gastric wall layers were not well distinguished on most routine CT examinations unlike the multiphasic CT gastrography examinations described in dedicated staging studies [26, 27]. We did note that routine CT performed well in identifying metastatic disease, correctly identified in all 61 cases. There was also wide variability in gastric distention. Advanced tumors may not preclude the ability to adequately distend the stomach, limiting evaluation. The presence of food contents in the stomach also concealed small lesions. Physiologic contraction of the pyloric channel also occasionally imitated distal lesions and obscured the extent of infiltration. Distant lymph nodes in various anatomic locations (e.g., peri-pancreatic) were sometimes erroneously considered to be regional lymph nodes, which led to under-staging of nodal disease. Hispanic/Latino patients had higher rates of infiltrative disease compared to non-Hispanic/Latino patients. Radiologists should be aware of these findings when reviewing images for clinical staging of gastric cancer.

TABLE 4 | Radiologist checklist for CT-based clinical staging of gastric cancer.

Section	Variable	Response
□ Quality of evaluation	A. Gastric distention > 50%	1. Yes 2. No
	B. Visualization of three layers of gastric wall	1. Yes 2. No
	C. Limitations	1. Cachexia 2. Anasarca 3. Imaging artifact 4. Other 5. None
	D. Overall quality	1. Good (yes to A and B) 2. No limitations (no to A, B, C) 3. Limited (no to A and B, and yes to C)
□ Primary tumor	E. Size/morphology	1. Polypoid (provide size measurement) 2. Diffuse (nonmeasurable)
	F. Tumor epicenter/extent	1. Proximal (Gastroesophageal junction/cardia) 2. Distal (Tumors distal to cardia)
	G. Ulceration	1. Yes 2. No
	H. Peri-gastric tumor-related fat-stranding	1. Yes 2. No (describe extent)
	I. Direct invasion of adjacent organ (no separating fat-plane)	1. Yes 2. No (describe extent)
	J. Estimated T-stage	1. T1/T2 (no fat stranding) 2. T3/T4 (fat stranding) 3. T4b (organ invasion)
	K. Complications	1. Perforation 2. Obstruction 3. Bleeding
□ Regional lymph nodes (LN)	L. Regional LAD	1. Yes: estimate number of abnormal LNs 2. No
	M. N-stage based on CT	1. N0 (no abnormal LN) 2. N1 (1−2 abnormal LN) 3. N2 (3−6 abnormal LN) 4. N3 (> 6 abnormal LN)
□ Metastasis	N. Distal LAD (non-regional)	1. Yes 2. No
	O. Peritoneum involvement (ascites and/or nodularity)	1. Yes 2. No
	P. Organ involvement	1. Yes 2. No (describe organs involved)
	Q. M-stage based on CT	1. M0 2. M1

Note: CT imaging checklist for radiologist use when reviewing CT images of gastric cancer to improve standardization of data reporting.
Abbreviation: LAD, lymphadenopathy.

There are several limitations of our study that should be considered. We recognize this is an exploratory pilot study and that the findings are underpowered. While our data set represents a retrospectively generated patient database of gastric cancer treated across multiple hospitals within the Los Angeles County safety-net hospital system, it does not comprehensively represent all patients diagnosed with gastric cancer. The retrospective review of imaging is inherently subjective and may be

TABLE 5 | Gastric cancer imaging characteristics by retrospective review.

Characteristic	All patients *N* (%)	Hispanic/Latino patients (*N*, %)	Non-Hispanic/Latino patients (*N*, %)	*p* value
On retrospective review, was the cancer identifiable on diagnostic imaging study?				0.0584
Yes	90 (84.1)	72 (87.8)	18 (72.0)	
No	17 (15.9)	10 (12.2)	7 (28.0)	
Cardia involved on radiology review				0.0682
Yes	23 (21.5)	18 (22.0)	5 (20.0)	
No	69 (64.5)	56 (68.3)	13 (52.0)	
Not specified	15 (14.0)	8 (9.76)	7 (28.0)	
Tumor morphology				0.0147
Infiltrating	70 (65.4)	60 (73.2)	10 (40.0)	
Infiltrating, polypoid	10 (9.35)	7 (8.54)	3 (12.0)	
Infiltrating, ulcerated	1 (0.935)	1 (1.22)	0 (0.00)	
Polypoid	9 (8.41)	4 (4.88)	5 (20.0)	
Ulcerated	2 (1.87)	2 (2.44)	0 (0.00)	
Not specified	15 (14.0)	8 (9.76)	7 (28.0)	
Perforation				0.937
Yes	4 (3.74)	3 (3.66)	1 (4.00)	
No	103 (96.3)	79 (96.3)	24 (96.0)	
Radiologic T stage				0.382
T1/T2	32 (29.9)	25 (30.5)	7 (28.0)	
T2/T3	1 (0.935)	0 (0.00)	1 (4.00)	
T3/T4a	46 (43.0)	34 (41.5)	12 (48.0)	
T4b	14 (13.1)	11 (13.4)	3 (12.0)	
Tx	14 (13.1)	12 (14.6)	2 (8.00)	
Any LAD[a]				0.0975
Yes	78 (72.9)	63 (76.8)	15 (60.0)	
No	29 (27.1)	19 (23.2)	10 (40.0)	
Regional LAD				0.104
Yes	74 (69.2)	60 (73.2)	14 (56.0)	
No	33 (30.8)	22 (26.8)	11 (44.0)	
Distal LAD				0.180
Yes	33 (30.8)	28 (34.2)	5 (20.0)	
No	74 (69.2)	54 (65.9)	20 (80.0)	
Malignant ascites				0.114
Yes	40 (37.4)	34 (41.5)	6 (24.0)	
No	67 (62.6)	48 (58.5)	19 (76.0)	
Distal organ involvement[b]				0.978
Yes	34 (31.8)	26 (31.7)	8 (32.0)	
No	73 (68.2)	56 (68.3)	17 (68.0)	
Radiological M stage				0.299
M0	46 (43.0)	33 (40.2)	13 (52.0)	
M1[c]	61 (57.0)	49 (59.8)	12 (48.0)	

Note: Gastric cancer imaging characteristics by retrospective imaging review. Frequencies are displayed based on column totals.
Abbreviation: LAD, lymphadenopathy.
[a]Defined as lymph nodes with 6–8 mm short axis, rounded/necrotic morphology. Inclusive of both regional and distant nodal disease.
[b]Indicates distal organ involvement, which includes distant LAD, ascites/carcinomatosis, and/or distal organ metastases
[c]Indicates metastatic disease other than peritoneum/lymph node involvement.

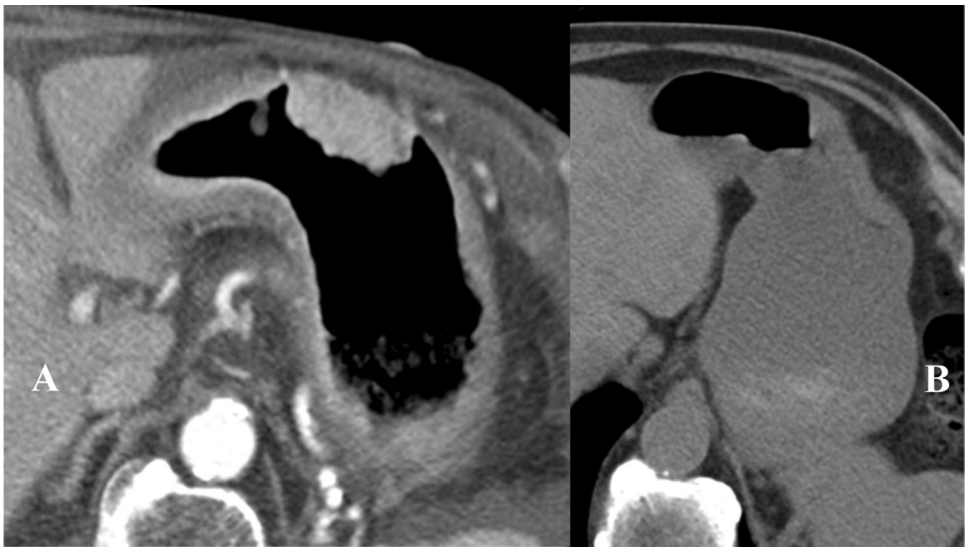

FIGURE 6 | Radiographic contrast enhancement of gastric cancer. Representative CT images of gastric cancer displaying (A) adequate distention of the stomach resulting in optimal visualization of the tumor with contrast enhancement and (B) well-distended stomach but without contrast, resulting in poor visualization of the underlying tumor.

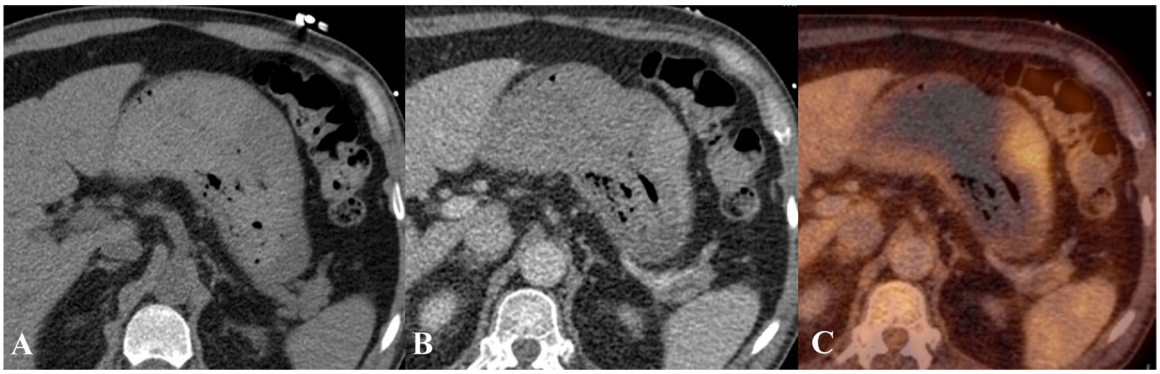

FIGURE 7 | Radiographic tumor visualization in gastric cancer. Representative CT images from a single patient demonstrating (A) a well-distended stomach but with residual food contents and without contrast, resulting in poor visualization of the tumor; (B) improvement in tumor visualization with addition of intravenous contrast; and (C) further improvement in tumor visualization with the addition of positron emission tomography (PET).

subject to error. We attempted to mitigate this by involving three board-certified radiologists who were blinded to the patient's clinical data. Additionally, the majority of patients included in this study had locally advanced or metastatic disease, such that performing descriptive interpretation of these tumors was challenging. As a result, few patients underwent curative surgery, limiting our agreement analyses as noted above. The three-layered appearance of the gastric wall was not well visualized on most CT scans in this study, significantly limited the ability to determine T-staging.

5 | Conclusion

The results of our pilot study have demonstrated that CT may not be adequate as a single imaging modality for gastric cancer staging. Every effort should therefore be made to follow a multimodal imaging strategy for clinical staging. Further study is warranted to overcome current barriers of clinical staging in resource-limited centers, improve patient outcomes, optimize resource utilization, and enhance quality of care.

Author Contributions

Conception and design: Mariam R. Thomas, Karoly Viragh, Shawdi Manouchehr-Pour, Priyanka Dube, Kyle D. Klingbeil, and Brian E. Kadera. Development of methodology: Mariam R. Thomas, Karoly Viragh, Shawdi Manouchehr-Pour, Priyanka Dube, Kyle D. Klingbeil, and Brian E. Kadera. Acquisition of data: Kyle D. Klingbeil, Dustin L. Dillon, Kirollos Bechay, Shawdi Manouchehr-Pour, Mariam R. Thomas, and Karoly Viragh. Analysis and Interpretation of data: Kyle D. Klingbeil and Isabel K. Eng. Writing, review, and/or revision of manuscript: Kyle D. Klingbeil, Isabel K. Eng, Priyanka Dube, Dustin L. Dillon, Kirollos Bechay, Shawdi Manouchehr-Pour, Roshan Bastani, Karoly Viragh, Mariam R. Thomas, and Brian E. Kadera. Administrative, technical, or material support: Mariam R. Thomas. Study supervision: Mariam R. Thomas and Brian E. Kadera.

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Ethics Statement

All patient data was retrospectively reviewed with a waiver of informed consent, as approved by UCLA's Institutional Review Board (IRB) protocol #1551114-5.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

All data required to assess the conclusions of our study are available upon reasonable request to the principal investigator.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.