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Validity of linear endoscopic ultrasound in rectal lesions evaluation

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Abstract

Rectal examination involves both linear and radial endoscopic ultrasound (EUS) probes, each serving specific regions. Radial probes are suitable for the anal canal, while linear probes better assess the rectal and pararectal areas. Endosonographers may switch probes for interventions like biopsies. Linear probes offer enhanced tumor visualization but may pose challenges in evaluating pelvic anatomy. Various imaging methods, including CT, MRI, and EUS, are employed for rectal lesion assessment, often combined in pre-treatment evaluations. The rectum, crucial for water absorption and defecation, is anatomically divided into intraperitoneal, retroperitoneal, and extraperitoneal segments. Rectal masses, classified as mural, intra-luminal, or extra-rectal, exhibit diverse origins. Diagnostic strategies involve anoscopy, sigmoidoscopy, and barium enema, with surgical interventions recommended for asymptomatic retrorectal tumors. Colorectal carcinomas follow an adenoma-carcinoma sequence, influenced by genetic factors and inflammatory bowel diseases. Rectal cancer workup includes laboratory studies and imaging, with staging employing both Dukes Classification and the TNM system. Multidisciplinary management involves surgery, medical oncology, and radiation oncology, considering neoadjuvant therapy and excision techniques. Linear EUS, with evolving equipment and techniques, plays a crucial role in diagnosing and staging rectal lesions, aiding in treatment decisions and post-radiation therapy assessments.

Keywords: Linear Endoscope, Ultrasound, Rectal Lesions, Evaluation, Management

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1. Introduction

The rectum is examined using linear and radial EUS probes, each suited for different regions and procedures. Radial probes are ideal for the anal canal, while linear probes better evaluate the rectal and pararectal areas [1]. Some endosonographers use radial probes for initial exams and switch to linear for interventions like biopsies or drainage. Linear probes are also useful for placing stents in short benign strictures and offer better visualization of tumors and deeper layers, although assessing pelvic anatomy and the sphincter complex might be difficult with them [2].Various imaging methods like CT, MRI, and EUS assess rectal lesions [3]. EUS and MRI are often used together in pre-treatment evaluations [4]. Radial EUS, comparable to CT and MRI, is preferred for gastrointestinal wall staging, but linear-array EUS is increasingly used for diagnosing pancreato-biliary and luminal diseases, despite a lack of data on its accuracy for rectal lesions [5-7].

2. Anatomy and Function of the Rectum

The rectum, the terminal portion of the large intestine connecting the sigmoid colon to the anal canal, is approximately 12 to 16 cm long and can be divided into three segments: upper intraperitoneal, middle retroperitoneal, and lower extraperitoneal [8]. It is vital for water and electrolyte absorption, playing a crucial role in the defecation process.

2.1. Gross Anatomy: Key Features

Macroscopically, the rectum exhibits two flexures—sacral and perineal—resulting from the sacrum's concave form and the encirclement by the levator ani muscle. Three rectal folds, superior, middle, and inferior, and the rectal ampulla, a defecation reservoir, are key features [9].

2.2. Vascular and Lymphatic Systems

The rectum is supplied by the superior, middle, and inferior rectal arteries. Venous drainage is through superior, middle, and inferior rectal veins, with clinical significance in portal hypertension cases. Lymph vessels follow veins, contributing to metastasis patterns [11 ,10]

2.3 Microscopic Structure

Microscopically, the rectum shares the typical large intestine structure, including mucosa, submucosa, muscularis, and serosa/adventitia. Notable features include the anal transitional zone with stratified squamous non-keratinized epithelium and a thickened submucosa at transverse folds. The muscularis comprises inner circular and outer longitudinal musculature, hosting Auerbach's plexus [12].

3. Analysis of Rectal Functions

The rectum serves as the final site for electrolyte absorption and the decomposition of indigestible food by anaerobic bacteria. Water absorption thickens stool, mixed with mucus. Functionally, the rectum is integral to continence, registering stool presence in the ampulla through stretch receptors, prompting the urge to defecate. Defecation initiation or delay involves the coordination of levator ani and sphincter muscles [13].

4. Classification and Origins of Rectal Masses

Rectal masses exhibit diverse origins, classified as intra-luminal, mural, or palpable externally while arising from outside the rectum.

4.1. Mural Rectal Masses

Mural rectal masses originate within the rectal wall and include various conditions such as rectal carcinoma, polyps, hypertrophied anal papilla, diverticula phlegmon, and amebic granuloma. Additionally, direct extensions from prostate or cervical malignancies contribute to this category [14].

4.2. Intra-luminal Masses

Intra-luminal rectal masses involve sources protruding into the rectum, encompassing conditions like sigmoid colon carcinoma (with prolapse into the pouch of Douglas), foreign bodies, and feces. Understanding the complexity of these origins is crucial for accurate diagnosis and management [15].

4.3. Extra-rectal Influences

Extra-rectal causes contribute to the spectrum of rectal masses, involving entities like endometriosis, pelvic abscess or sarcoma, metastatic deposits in the pelvis (Blumer’s shelf), uterine or ovarian malignancy, and direct extensions from prostate or cervical malignancies. Recognition of these diverse origins is vital for a comprehensive approach to rectal mass evaluation and treatment [16].

4.4. Benign Rectal Tumors

4.4.1. Rectal Hemangioma

Rectal hemangiomas, rare benign vascular tumors, predominantly occur in the small bowel and colon. While usually solitary, they can be multiple, especially in cases of Klippel–Trenaunay–Weber syndrome [17].

4.4.2. Lipoma

Colonic lipomas, the most common benign nonepithelial GI tumors, primarily locate in the submucosal layer. Rectal lipomas, with their characteristic fat presence, pose no diagnostic challenge. MRI features include high signal intensity on T1-weighted and T2-weighted images, with signal loss on fat-suppression sequences [18].

4.4.3. Developmental Cysts

The most prevalent retrorectal cystic tumors, developmental cysts, often occur in middle-aged women. Classifications include epidermoid, dermoid, enteric (including tailgut and rectal duplication cysts), and neurenteric cysts [19].

4.4.4. Neurogenic Tumors

Constituting 5–15% of presacral tumors, neurogenic tumors, arising from peripheral nerves, feature schwannomas and neurofibromas as predominant entities [20].

4.4.5. Abscesses and Diagnostic Challenges

Anorectal region complications, common in inflammatory conditions like Crohn's disease, can lead to perianal or perirectal abscesses. Clinical diagnosis is usual, but atypical presentations may necessitate imaging, particularly for recurrent abscesses revealing potential complex fistulae or loculated cavities [21].

4.4.6. Osseous Tumors Benign and Malignant

Comprising about 10% of retrorectal lesions, primary osseous tumors, arising from sacral cartilage, fibrous, and bone marrow tissues, include notable entities like giant cell tumors (GCTs) and chordomas [22].

4.4.7 Anterior Sacral Meningocele:

A relatively rare congenital abnormality, anterior sacral meningoceles involve herniation of the dural sac into the presacral space through a sacral defect, containing cerebrospinal fluid and neural elements [23].

4.4.8. Endometriosis and Deep Infiltrating Lesions

Affecting women of childbearing age, endometriosis involves the presence of endometrioid glands and stroma outside the uterus. Deep infiltrating endometriosis (DIE) penetrates the retroperitoneal space or pelvic organ walls to a depth of 5 mm or greater [24].

4.5. Diagnostic Strategies for Rectal Conditions

Proctologists rely on anoscopy, sigmoidoscopy, and barium enema for diagnosing perirectal conditions. Routine biopsy or polyp excision is performed, and if one polyp is found, further examination through barium enema or colonoscopy is recommended to identify additional polyps [25].

4.6. Surgical Interventions for Rectal Tumors

Resection of asymptomatic retrorectal tumors is advised due to potential complications. Imaging, particularly MRI, aids in preoperative planning, distinguishing solid from cystic tumors. Biopsy is discouraged due to infection risks. Surgical approaches vary based on tumor size and location, with combined abdominal and perineal methods for larger tumors [26-29] .

4.7. Pathophysiology of Colorectal Carcinomas

Colorectal carcinomas, mostly adenocarcinomas, follow the adenoma-carcinoma sequence. Adenomas

precede adenocarcinomas, with APC gene mutations initiating uncontrolled cell replication. Other pathways involve DNA mismatch repair gene mutations and inflammatory bowel disease. Hyperplastic polyps may have malignant potential. Histologically, adenomas are tubular, tubulovillous, or villous [30].

4.8. Etiological Factors in Colorectal Cancers

Most colorectal cancers are sporadic, occurring after age 50. Some exhibit familial clustering without an identified syndrome. Familial adenomatous polyposis (FAP) and Lynch syndrome contribute to hereditary cases. Risk factors include personal or family history of colorectal cancer, adenomatous polyps, and rectal involvement in inflammatory bowel disease [31].

4.9. Genetic Disorders Linked to Rectal Cancers

4.9.1 Familial Adenomatous Polyposis (FAP)

FAP is an autosomal dominant syndrome caused by a defect in the APC gene, leading to over 100 adenomatous polyps and extra-intestinal manifestations. Colorectal cancer risk is nearly 100% if untreated by age 40, with approximately 20% due to spontaneous mutation [32].

4.9.2 Hereditary Nonpolyposis Colorectal Cancer (HNPCC)

HNPCC, or Lynch syndrome, results from defective mismatch repair genes. Patients face a higher risk of malignant transformation in their polyps and other cancers. Revised Amsterdam criteria guide at-risk patient selection. The National Comprehensive Cancer Network (NCCN) provides testing strategies, including universal screening for colorectal cancer patients using microsatellite instability or immunohistochemistry [33-35].

4.10. Inflammatory Bowel Disease and Rectal Cancer

In patients with inflammatory bowel disease, the malignant pathway differs from adenoma-carcinoma sequences. Ulcerative colitis (UC) increases colorectal cancer risk, with an incidence of approximately 1% per year after 10 years, rising to 30% with dysplasia. Crohn's disease elevates colorectal cancer incidence 4-20 times that of the general population, particularly in strictures and de-functionalized segments. Surveillance recommendations align with UC for Crohn colitis patients [36, 37].

4.11. Comprehensive Rectal Cancer Workup

Rectal cancer diagnosis necessitates a thorough workup, including laboratory studies and imaging. Routine laboratory studies, as recommended by **Kotzev et al.** [38], encompass a complete blood count, serum chemistries (including liver and kidney function tests), and carcinoembryonic antigen (CEA) tests. An additional cancer antigen (CA) 19-9 assay can aid in disease monitoring. Notably, screening CBC may unveil hypochromic, microcytic anemia indicative of iron deficiency. Liver function tests, often part of preoperative workup, might appear normal even with liver metastases. All individuals with iron deficiency anemia require gastrointestinal evaluation. CEA testing is essential for rectal cancer patients, serving as a baseline pre-surgery and a postoperative follow-up marker. Elevated postoperative CEA levels suggest potential recurrence, while a level exceeding 100 ng/mL indicates metastatic disease, warranting a thorough investigation. Diagnostics, including fecal immunochemical tests (FITs), have shown high accuracy in detecting colorectal cancer [39].

4.11.1 Screening and Histological Insights

The purpose of screening is to intercept adenoma-carcinoma sequence progression. Ramezani et al. [40] note that early detection increases the likelihood of managing existing cancers at an early stage. Histopathologic features like poor differentiation, lymphovascular invasion, and elevated preoperative CEA levels correlate with increased recurrence rates and poorer survival [41].

4.11.2 Staging of Rectal Cancer

Rectal cancer staging employs both Dukes Classification and the Tumor, Node, Metastasis (TNM) system. Originally introduced by Cuthbert Dukes in 1932, Dukes Classification divides tumors into three stages based on rectal wall involvement and lymph node metastases [42]. TNM, established in 1954, provides a universal staging system relying on clinical and pathologic data. TNM correlates well with 5-year survival rates, disregarding certain prognostic factors like histologic grade or invasion [43]. The 5-year survival rate varies across stages, ranging from over 90% for Stage I to 5-7% for Stage IV.

4.12 Multidisciplinary Management of Rectal Cancer

Rectal cancer treatment necessitates a multidisciplinary strategy involving surgery, medical oncology, and radiation oncology [44]. Optimal treatment planning involves complex decisions, considering surgery intent, functional outcomes, and organ preservation. Factors like surgeon training, volume, and neoadjuvant therapy influence sphincter preservation. Abdominoperineal resection comes with drawbacks, including permanent colostomy and increased morbidity.

4.12.1 Neoadjuvant Therapy and Excision Techniques

Neoadjuvant therapies like long-course radiation or total neoadjuvant therapy (TNT) followed by surgery are standard for locally advanced rectal cancer [45]. Local excision, though associated with rapid recovery and lower morbidity, is challenged by recurrence rates, especially in T2 lesions. Factors influencing local excision candidacy include lesion characteristics and patient-related factors [46].

4.12.2. Specialized Surgical Methods

Endocavitary radiation, using high-dose, low-voltage radiation, offers an alternative method. [47] report an 83% overall survival rate with a 30% local recurrence rate. Transanal Endoscopic Microsurgery (TEM), though having a steep learning curve, is considered for early-stage rectal cancers.

Table 1: Comparison of AJCC Definition of TNM Staging System to Dukes Classification.

Rectal Cancer Stages	TNM Staging	Duke Staging	5-Year Survival
Stage I	T_{1-2} N_0 M_0	A	>90%
Stage II	T_3 N_0 M_0	B	60%-85%
	T_4 N_0 M_0		60%-85%
Stage III	T_{1-2} N_1 M_0	C	55%-60%
	T_{3-4} N_1 M_0		35%-42%
	T_{1-4} N_2 M_0		25%-27%
Stage IV	T_{1-4} N_{0-2} M_1		5%-7%

Figure 1: The electronic radial echoendoscope (Olympus Corporation, Tokyo, Japan).

Figure 2: The radial echoendoscope scans at an axis perpendicular to the endoscope shaft.

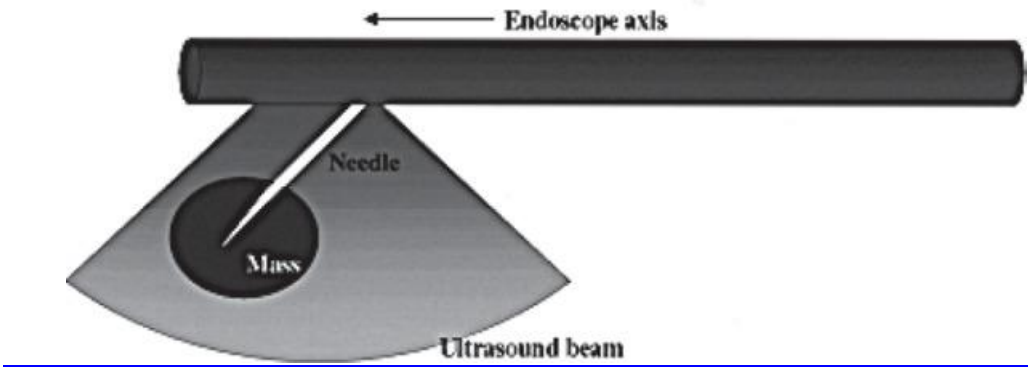

Figure 3: The linear echoendoscope scans in a plane parallel to the endoscope shaft (Instruments inserted through the accessory channel are visualised as they pass through the ultrasound beam).

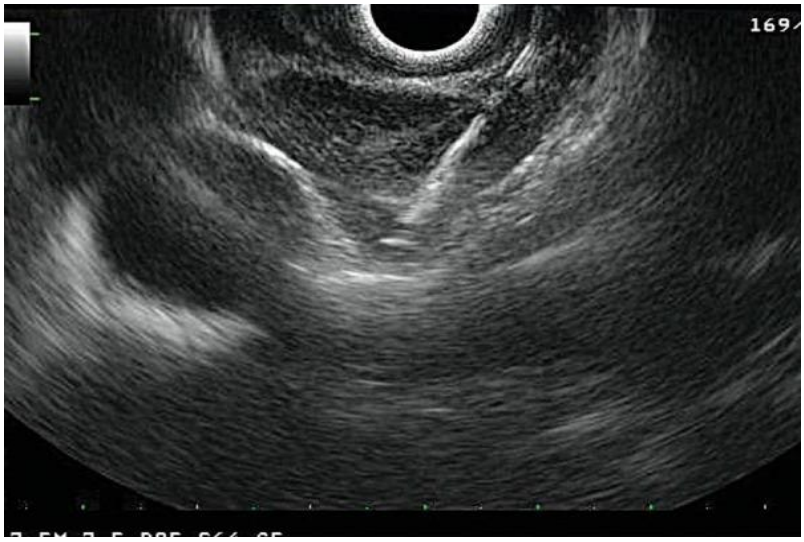

Figure 4: Fine needle aspiration of a mediastinal lymph node.

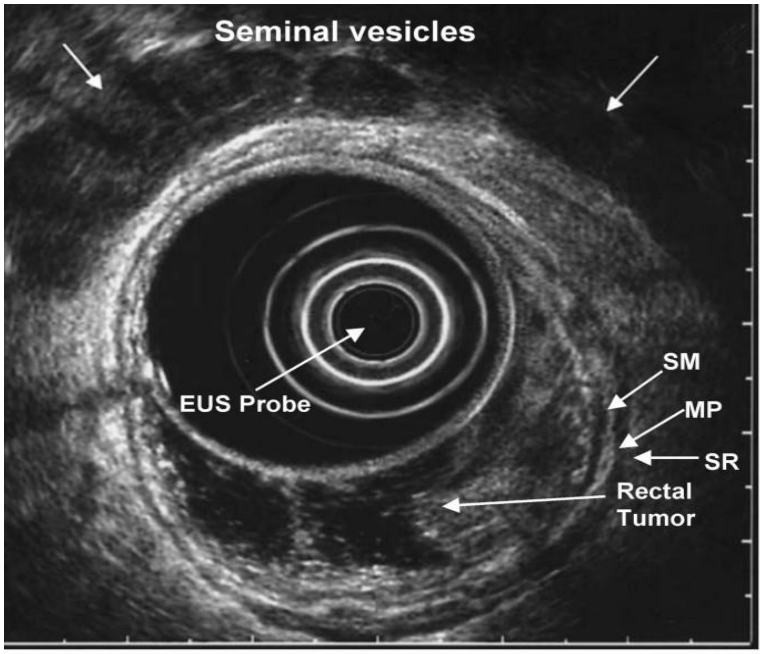

Figure 5: EUS image of T1 rectal cancer confined to mucosa and superficial submucosa. SM=submucosa, MP=muscularis propria, SR=serosa.

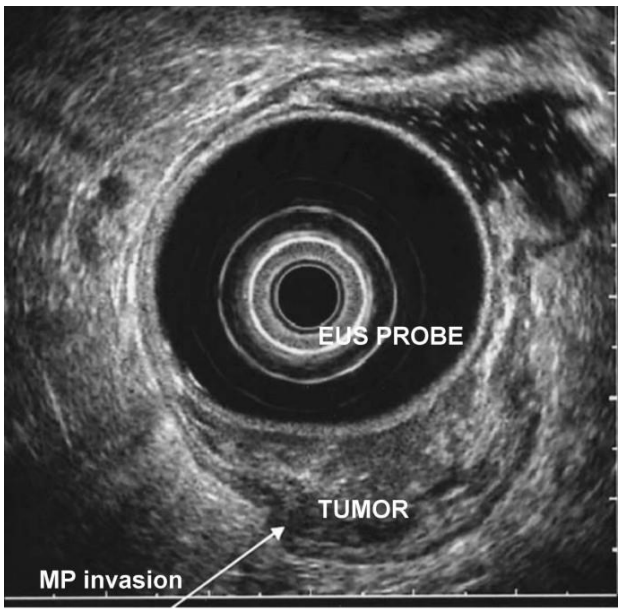

Figure 6: EUS image of T2 rectal cancer invading the muscularis propria.

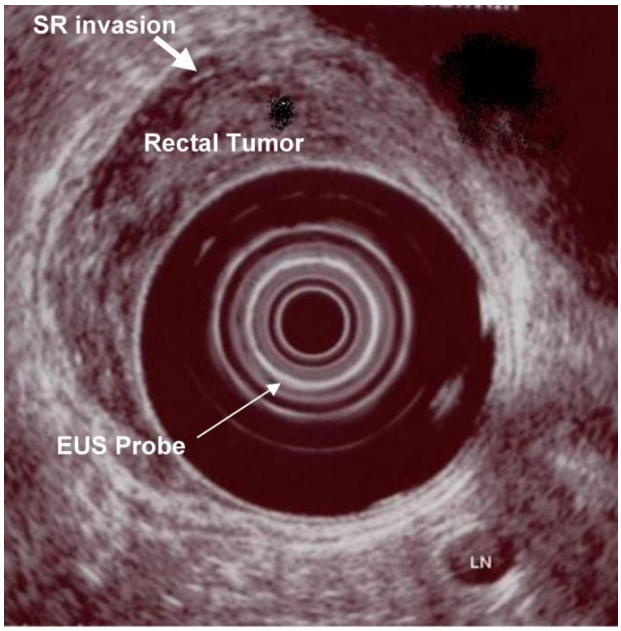

Figure 7: EUS image of T4 rectal cancer with a metastasis to a perirectal lymph node (L).

4.12.3. Sphincter-Preserving Techniques

Various sphincter-sparing procedures, including Low Anterior Resection (LAR) and Colo-Anal Anastomosis (CAA), balance the need for cancer removal and preservation of sphincter function. Laparoscopic techniques offer advantages in recovery and pain management [48]. LAR is suitable for lesions in the middle and upper third of the rectum. CAA is performed for distal rectal cancers, providing an alternative to a permanent colostomy.

4.12.4. Advancements in Laparoscopic Resections

Minimally invasive techniques, like laparoscopic rectal resections, are increasingly accepted. While offering faster recovery, it requires skilled surgeons [49]. For lower-third rectal cancers, Abdominal Perineal Resection (APR) may be necessary, especially when negative margin resection results in sphincter function loss.

4.12.5. Role of Adjuvant Therapy

Radical resection alone leads to high recurrence rates, necessitating adjuvant therapies. The role of adjuvant radiation, with or without chemotherapy, in reducing recurrence risk is well-established. Tumor stage, grade, and lymphovascular invasion guide adjuvant therapy decisions [50].

4.12.6. Importance of Long-Term Monitoring

Post-treatment surveillance is critical for rectal cancer survivors. Guidelines recommend regular sigmoidoscopy, endorectal ultrasound, CEA assays, and

periodic CT scans [51, 52]. Surveillance aims to detect local or distant recurrence early, enabling timely intervention.

5. Linear Endoscopic Ultrasound (EUS) in Rectal Lesion Evaluation

The linear echoendoscope, primarily designed for fine needle aspiration (FNA) and imaging of lesions within the gastrointestinal (GI) tract, has witnessed significant advancements over the last two decades. The increased utilization of linear EUS procedures has paralleled the establishment of dedicated training programs, resulting in an expansion of manufacturers. Currently, three prominent manufacturers of linear echoendoscopes are Olympus, Pentax, and Fujinon [53].

5.1. Evolution of EUS Equipment and Techniques

Echoendoscopes come in radial or curvilinear array systems, with mechanical or electronic formats. The electronic echoendoscope, favored for its durability due to the absence of moving parts, resembles a modified gastroscope, featuring optical video views and ultrasound capability [54]. Radial echoendoscopes, dating back to the late 1980s, use a rotating ultrasound transducer for cross-sectional imaging, while electronic radial echoendoscopes offer Doppler capabilities [55].

5.2. Fine Needle Aspiration: Enhancing Diagnostic Precision

Distinguishing itself from radial counterparts, the linear echoendoscope's scanning plane aligns with the scope shaft, enabling FNA procedures. FNA needles, ranging from 25G to 19G, play a crucial role in EUS applications. Larger needles, essential for therapeutic procedures, may increase trauma but are necessary for passing guidewires. The linear echoendoscope allows the needle to be visible in its entirety during FNA, ensuring precision in targeted lesion sampling [56]. FNA needles vary in size (25G to 19G) and design, with considerations for sample quality and the nature of the lesion. Trucut biopsy needles, particularly the 19G variant, offer the ability to obtain core specimens, potentially enhancing accuracy for submucosal lesions and lymphomas [57, 58].

5.3. Standardization of EUS Procedures

EUS procedures follow standard endoscopic examination protocols, often performed on an outpatient basis with intravenous sedation. The echoendoscope is advanced through the mouth to the target region, with water instillation or a water-filled balloon aiding acoustic coupling for optimal imaging quality [59].

5.4. Anatomical Assessment and Lesion Identification via EUS

For extraluminal lesions, anatomical "stations" guide the assessment. Upper retroperitoneum, lower retroperitoneum, and structures within the posterior mediastinum are visualized through the gastric, duodenal, and esophageal walls, respectively [60].

5.5. Real-Time Guidance in EUS-FNA

EUS-FNA of mass lesions outside the gut wall often involves the combined use of radial and linear echoendoscopes. Colour Doppler aids in identifying blood flow, ensuring safe needle passage. Real-time ultrasound guidance allows for precise needle maneuvering during FNA, with the extracted contents subjected to various diagnostic analyses [60].

5.6. Understanding the Risks: EUS Complications

While the passage of echoendoscopes through the oropharynx demands careful navigation due to their oblique viewing and longer, more rigid tips, the incidence of perforation during this process does not surpass that of standard endoscopy. Complications in EUS are more prevalent in therapeutic applications, particularly during EUS-FNA, with an overall complication rate ranging from 1-2%. These complications include infection, hemorrhage, pancreatitis, and duodenal perforation, emphasizing the importance of cautious procedural management [61].

5.7. The Diagnostic and Staging Role of EUS

EUS has established itself in various applications, including diagnostic/staging procedures for malignancy, assessment of submucosal abnormalities, evaluation of mediastinal lymphadenopathy, and pancreatico-biliary diseases. Comparatively, EUS-FNA stands out favorably against percutaneous biopsy techniques, especially for smaller lesions [62].

5.8. Malignancy Staging and Impact of EUS

EUS plays a pivotal role in staging luminal gastrointestinal malignancies based on the TNM classification. Its accuracy, particularly in locoregional T and N staging, approaches 85%. EUS's unique ability to depict the five histologic layers of the gut wall provides detailed insights, aiding accurate T staging. The impact of EUS-FNA is transformative, often altering the management of patients with gastrointestinal, pancreatic, and pulmonary malignancies, leading to more informed decisions and, in some cases, avoiding unnecessary surgeries [63].

5.8.1. Technique and Utility of Linear EUS in Rectal Cancer

In the context of rectal cancer, linear EUS, typically following forward viewing endoscopy and radial EUS, is employed for lesion evaluation and FNA. The linear echoendoscope's role in the rectum involves gentle insertion, withdrawal, and torque maneuvers for visualizing adjacent structures and target lesions. While literature regarding the sole use of linear array scopes for primary staging of rectal cancer is limited, experiences suggest its adequacy for imaging and FNA in cases requiring intervention [53].

5.8.2. Comprehensive Imaging in Rectal EUS

Rectal EUS techniques involve both radial and linear echoendoscopes. Linear devices, specifically designed for interventional EUS-FNA, produce sector-shaped images in a plane parallel to the endoscope's insertion tube. Patients undergoing rectal EUS preparation typically receive oral lavage. Imaging involves filling the echoendoscope ultrasound balloon with water, assessing the depth of invasion, presence of lymph nodes, and invasion into perirectal fat or adjacent organs. Fine needle aspiration (FNA) may be employed for sampling suspicious lesions, such as perirectal or iliac lymphadenopathy, contributing to a comprehensive diagnostic approach [53, 64].

5.8.3. Accuracy of Staging with EUS

Rectal cancer prognosis hinges on local, nodal, and distant tumor status, classified through the Tumor-Node-Metastasis (TNM) staging system. Utilizing EUS for T staging demonstrates superior accuracy ranging from 80–95%, surpassing CT (65–75%) and MR imaging (75–85%). However, under-staging of T3 tumors is a limitation due to its resolution constraints, particularly for tumors lower in the rectum. Over-staging of T2 tumors can occur due to inflammation around the tumor, which appears sonographically similar to malignant tissue. Additional factors impacting accuracy include the level of the tumor, operator experience, circumferential rectal tumors causing stenosis, and the influence of preoperative radiotherapy [23, 65].

5.9. Nodal Involvement: Challenges in EUS Assessment

Evaluating metastatic nodal involvement by EUS yields an accuracy of approximately 70–75%, surpassing CT (55–65%) and MR imaging (60–70%). Challenges arise from the difficulty of detecting tumor within a lymph node. EUS reveals characteristics such as a hypoechoic appearance, round shape, and nodal diameter of 1 cm or greater, indicating malignant involvement. However, EUS-guided FNA does not significantly enhance preoperative staging accuracy. Lymph nodes larger than 0.5 cm have a 50–70% likelihood of being metastatic, while those smaller than 4 mm have less than a 20% probability [66].

5.10. EUS in Management Decision-Making

Rectal EUS plays a pivotal role in determining tumor penetration into the bowel wall, guiding decisions on preoperative neoadjuvant therapy. In cases of rectal carcinoma, EUS outperforms CT in accuracy for determining T stage. Aggressive EUS usage may risk over-staging; however, its positive predictive value for identifying T3/T4 disease is 100%. Rectal EUS aids in detecting advanced T stage disease, guiding preoperative treatment decisions. Despite its effectiveness, EUS may understage a proportion of patients, but the rate is lower compared to CT scans. Cost-effectiveness analyses suggest that abdominal CT plus EUS is the most cost-effective approach for nonmetastatic proximal rectal cancer [67, 68].

5.11. Correlation of EUS Staging with Treatment Protocols

The correlation of EUS staging with the histopathological staging dictates the recommended therapy for rectal cancer. Different stages (UT1, UT2, UT3, UT4) are associated with specific interventions, including excision, preoperative chemoradiotherapy followed by resection, or resection with postoperative chemotherapy. This correlation emphasizes the clinical relevance of accurate staging through EUS in determining the optimal treatment approach for rectal cancer [68].

5.12. Post-Radiation Therapy: EUS in Staging and Limitations

The accuracy of EUS for staging rectal cancer after radiation therapy decreases significantly due to post-radiation changes such as edema, inflammation, necrosis, and fibrosis. Studies suggest a 50% accuracy for T-stage after radiation, accompanied by a 40% over-staging rate. Lymph node staging accuracy is also compromised. Consequently, restaging tumors after neoadjuvant therapy is challenging, emphasizing the importance of clinical correlation in guiding operative and postoperative management modalities [69].

5.13. EUS in Detection of Rectal Cancer Recurrence

EUS demonstrates superiority over CT scans in detecting local recurrence in rectal cancer. Its sensitivity for detecting recurrence, even in asymptomatic patients, is higher (100%) compared to CT (82–85%), digital rectal examination, and CEA levels. Despite limitations in distinguishing mucosal inflammation from recurrence, EUS sensitivity makes it a valuable screening tool, particularly in the first 2 years after surgical treatment of rectal cancer [70, 71].

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