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Review Article

The Anatomy of the Median Arcuate Ligament–Celiac Trunk Relationship across Body Position, Age and Imaging Modalities: Surgical and Diagnostic Implications for Median Arcuate Ligament Syndrome (MALS)

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Abstract:

Median arcuate ligament syndrome (MALS) is an uncommon and debated clinical entity caused by extrinsic compression of the celiac artery (CA) by the median arcuate ligament (MAL) or diaphragmatic crura. Radiologic signs of celiac artery compression are relatively common in asymptomatic individuals, and the challenge for clinicians is to distinguish physiologic or positional compression from clinically meaningful, symptomatic vascular or neurogenic compromise. This review examines: i) the anatomy and embryology of the MAL-CA relationship, ii) cadaveric and population imaging data on anatomic variants and age/sex/body-habitus influences, iii) the effect of respiratory phase and body position on the degree of compression and imaging appearance, iv) the strengths and limitations of ultrasound (US), computed tomography angiography (CTA), magnetic resonance angiography (MRA), and digital subtraction angiography (DSA) including dynamic/positional protocols, and v) surgical and endovascular management implications. Practical recommendations for diagnostic imaging protocols and operative planning are proposed. Persistent knowledge gaps are identified and a research agenda suggested to improve diagnostic specificity and surgical outcomes.

Keywords: Median arcuate ligament, Imaging modalities, Median arcuate ligament syndrome

Introduction

Median arcuate ligament syndrome (MALS), also called Dunbar syndrome or celiac artery compression syndrome, arises when fibrous diaphragmatic fibers (the MAL and/or crura) compress the proximal celiac trunk. Typical symptoms include postprandial epigastric pain, early satiety, nausea, and weight loss overlap with many gastrointestinal disorders, complicating diagnosis. Imaging often demonstrates a characteristic "hook" or "J-shaped" indentation of the proximal celiac artery; however, similar imaging features are found in many asymptomatic individuals. Accurate diagnosis therefore depends on integrating anatomy, dynamic physiology (respiration and position), and correlations of imaging with clinical and hemodynamic data. This review focuses specifically on the anatomic relationship between median arcuate ligament and celiac artery across respiration, body position, age and sex, synthesizes available cadaveric and imaging evidence, reviews imaging protocols that accentuate or attenuate compression, and discusses implications for surgical release and other therapies.

Anatomy and Embryology; the median arcuate ligament and the celiac trunk

The median arcuate ligament (MAL) represents a fibrous arch formed by the left and right diaphragmatic crura crossing anterior to the aorta at the level of the diaphragm. The celiac trunk ordinarily arises from the anterior aorta at the T12-L1 level and courses anteriorly and slightly inferiorly to supply the foregut. Anatomical variation is common: the level of origin of the celiac trunk, its angle of departure, and relation to the MAL vary between individuals. Embryologically, variable descent of the dorsal aorta, variable growth of the diaphragm, and branching pattern variation contribute to these anatomical differences, which can predispose to relative proximity or overlap between MAL and the celiac origin and therefore to extrinsic compression in certain positions or respiratory phases. [1-4]

Prevalence of Radiologic Compression versus Symptomatic Disease

Large imaging and cadaveric series report that radiographic signs of celiac compression are detected in a notable minority of asymptomatic individuals (estimates vary; typically 3-25% depending on criteria and imaging technique). By contrast, symptomatic MALS remains rare. This discordance highlights that compression on static imaging alone is insufficient to diagnose the syndrome without compatible clinical features and hemodynamic evidence. [5-9]

Anatomical Variants Relevant to MAL-CA Relationship

Important anatomic features that influence risk of compression include:

- Level of celiac trunk origin (higher origin increases chance of overlap with MAL). [3,10]
- Celiac trunk takeoff angle: a more acute superior/upward angulation predisposes to the classic "hook" deformity when the MAL overlies the proximal CA.[3]
- Length and thickness of the MAL/crural fibers and their attachments; some studies show variable thickness and even muscular fibers within the band. [11,12]
- Presence of accessory or replaced hepatic/left gastric arteries altering local hemodynamics and surgical planning.[13]
- Cadaveric series and CT morphometric studies have sought to quantify these relationships; some report female predominance for shorter MAL-CA distances and more frequent MAL overlap, potentially aligning with the higher prevalence of symptomatic MALS in young women reported clinically. [3,14,15]

Effect of Respiration and body Position on Compression

The celiac trunk and diaphragm move dynamically with respiration. During inspiration, descent of the diaphragm and the aortic-visceral relationships generally relieve compression-CA moves inferiorly and straightens while expiration tends to increase MAL-induced indentation producing peak stenosis. Several imaging and hemodynamic studies demonstrate significantly higher peak systolic velocities (PSV) and more pronounced luminal narrowing during expiration than inspiration. Upright positioning may further relieve compression depending on individual geometry; some researchers recommend imaging in both supine and upright positions to correlate symptoms that occur with standing or postural changes. [6,16-19] Thus, imaging in a single respiratory phase risks both over- and under-diagnosis.

Imaging modalities; Protocols, Findings and Limitations

Ultrasound (Doppler and dynamic US)

Color duplex ultrasound (CDU) is a good option as it provides real-time hemodynamic data without radiation or contrast. Typical findings for MALS include increased PSV in the celiac artery during expiration with normalization on inspiration. Several groups have proposed EPSV cutoff values and dynamic protocols that combine B-mode hook-sign visualization with Doppler PSV changes. Limitations include operator dependency, patient body habitus, and limited visualization in some patients.[10,11-15]

Computed Tomography Angiography (CTA)

CTA with sagittal and coronal reconstructions remains the most commonly used cross-sectional imaging modality to detect the classic "hook" or focal indentation at the proximal CA. Importantly, acquiring arterial phase images during deep expiration accentuates the finding so protocoling for expiratory arterial-phase CTA (or dual-phase with both inspiration and expiration) improves sensitivity. CTA also allows assessment of post-stenotic dilatation, collateral circulation, and alternative pathology such as atherosclerosis. [8,16]

Magnetic Resonance Angiography (MRA)

MRA can depict CA narrowing and flow dynamics with phase-contrast or contrast-enhanced sequences. It offers radiation-free imaging, but fewer centers use dynamic MRA protocols for respiration. MRA can be complementary when CTA is contraindicated (contrast allergy/renal dysfunction) or when repeated imaging is required.[18]

Digital Subtraction Angiography (DSA)

Conventional angiography remains the gold standard for luminal assessment and for dynamic evaluation. DSA performed during inspiration and expiration demonstrates the characteristic narrowing and post-stenotic dilation and allows correlation with pressure gradients and immediate endovascular maneuvers if needed. However, DSA is invasive and reserved for cases where intervention or equivocal noninvasive imaging requires clarification.[19,8]

New and Niche Imaging Approaches: Upright/weight-bearing CT and Dynamic CT Protocols

Upright CT scanners and dynamic CT protocols that image in different respiratory phases and positions can demonstrate changes not seen with standard supine inspiratory imaging. Several contemporary case series and small cohort studies emphasize the incremental diagnostic value of expiratory and upright imaging to reveal functionally significant compression.[16,20]

Hemodynamic Assessment and Diagnostic Thresholds

Hemodynamic criteria (e.g., PSV on duplex ultrasound, trans-stenotic pressure gradients on catheter angiography) provide functional evidence for clinically significant stenosis. PSV values and threshold cutoffs vary across studies; dynamic increases in PSV with expiration are informative, but no universally accepted single PSV cutoff exists. When anatomic compression is accompanied by physiologic evidence (significant PSV rise or pressure gradient), and the clinical picture is compatible, the probability of symptomatic MALS increases. [10,21,22,23]

Clinical Correlation

Most individuals with radiographic celiac compression remain asymptomatic. Factors associated with symptom development may include:

- Degree and duration of compression and resulting ischemia,
- Neuropathic irritation of the celiac plexus by MAL fibers,
- Patient sex (female predominance reported), and
- Coexisting connective tissue disorders (anecdotal associations). However, evidence is inconsistent and often limited by small series and heterogeneous diagnostic criteria. [5,14,3]

Surgical and Endovascular Management; Anatomical Considerations

Surgical MAL release (open, laparoscopic or robotic) is the mainstay of definitive therapy for symptomatic MALS when conservative measures fail and objective evidence supports compression. Key anatomic considerations:

- Complete circumferential release of the MAL and crural fibers crossing the anterior aorta is essential; incomplete release risks persistent symptoms.
- Visualization of the celiac plexus and neurolysis may be performed simultaneously, addressing a putative neuropathic pain component.
- Preoperative imaging (CTA/MRA with expiratory views, duplex with PSV changes) and intraoperative planning must account for variants: high CA origin, replaced hepatic artery, or close proximity to other visceral branches.
- Endovascular stenting is generally reserved for residual fixed stenosis after release or for patients unsuitable for surgical decompression; stent failure may occur if extrinsic compression is not adequately relieved.[6,8,24]

Minimally invasive approaches (laparoscopic and robotic release) show favorable perioperative outcomes in many contemporary series, but patient selection profoundly affects symptomatic relief rates. Published series show variable rates of sustained symptom improvement; studies with strict selection criteria (clinically compatible symptoms, objective hemodynamic evidence, and exclusion of other GI causes) achieve higher success.[6,22]

Diagnostic Algorithm and Practical Imaging Recommendations

Based on the literature synthesis, an important diagnostic pathway:

1. **Clinical suspicion**: compatible postprandial epigastric pain, weight loss, and exclusion of common GI causes.
2. **Noninvasive dynamic testing**: duplex US with inspiratory/expiratory PSV measurements; look for marked expiratory increase and normalization with inspiration.
3. **Anatomic cross-sectional imaging**: CTA with sagittal reconstructions arterial-phase imaging performed in deep expiration (or both inspiration and expiration if feasible). Consider upright CT if symptoms are position-related. MRA as an alternative if CTA contraindicated.
4. **Confirmatory invasive testing**: DSA with respiratory-phase angiograms and pressure measurements when noninvasive data are equivocal or when planning endovascular intervention.
5. **Multidisciplinary review**: gastroenterology, vascular surgery, interventional radiology, and pain management to confirm appropriateness for surgical MAL release. This pathway aims to reduce false positives arising from static imaging alone and to ensure that only carefully selected patients proceed to surgical intervention. [8,10,20]

Outcomes and Predictors of Success after Release

Factors associated with better outcomes include:

- Clear preoperative hemodynamic evidence of expiration-exacerbated compression,
- Typical symptom profile and prolonged duration of symptoms attributable to CA compression,
- Lack of major alternative GI pathology. Incomplete release, unrecognized alternative pain generators, or longstanding visceral neuropathy can lead to persistent symptoms. Reported symptomatic improvement rates are variable across series (partial to full relief in many but not all patients).[20]

Controversies and Knowledge Gaps

- **Overdiagnosis risk**: high prevalence of radiographic compression but low symptomatic disease rate demands better specificity for imaging criteria.
- **Standardized dynamic thresholds**: lack of universally accepted PSV cutoffs or CTA grading systems limits comparability.
- **Role of neuropathic mechanisms**: the relative contribution of celiac plexus irritation versus ischemia is incompletely understood.
- **Effect of age, sex, and body habitus**: while some studies suggest sex differences and age-independent morphology, data are inconsistent and often small-scale. Larger, population-based morphometric studies are needed.
- **Position-dependent imaging standardization**: formal protocols for inspiratory vs expiratory vs upright imaging are not universally adopted. Prospective studies correlating imaging changes with symptoms and surgical outcomes are required.[3,5,14,16]

Conclusion

MALS represents the intersection of anatomy, physiology and clinical judgment. Knowledge of the variable anatomic relationship between the MAL and the celiac trunk and how respiration and body position dynamically alter that relationship is important for accurate diagnosis and for identifying patients who may benefit from surgical release. To improve diagnostic specificity and patient outcomes, standardized dynamic imaging protocols, objective hemodynamic thresholds, and prospective outcome-linked studies are urgently needed.

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