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Diagnostic Accuracy of Doppler Ultrasound versus CT Angiography in Superior Mesenteric Artery Syndrome

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Abstract

Background: Superior mesenteric artery syndrome (SMAS) is a rare vascular compression phenomenon causing duodenal obstruction. CT angiography (CTA) is the test of choice; ultrasound Doppler offers a noninvasive alternative. **Aim:** to verify the diagnostic accuracy of both tests to verify an evidence-based pathway in SMAS diagnosis.

Methods: A total of 48 patients suspected as SMAS were enrolled in this prospective multicenter study. All patients had a standard ultrasound Doppler and CTA protocol scan. Validity measures were based on the consensus clinical diagnosis reference standard.

Results: Ultrasound sensitivity was 87.5% (95% CI 71.0–96.5) and the specificity was 81.3% (95% CI 54.4–96.0) versus CTA specificity of 100%. Patients who were obese (BMI >30; OR 6.7, p=0.003) and patients with bowel gas (OR 8.2, p=0.001) showed high discordance rates by each definition. The mean aortomesenteric angle difference between modalities was 2.3° (95% LoA: −5.1°-9.7°).

Conclusion: Ultrasound Doppler can be a valuable method for the primary screening of SMAS, and high-BMI or surgical patients should receive CTA examination for diagnosis verification of SMAS.

1. 1. Introduction

Superior mesenteric artery syndrome (SMAS) is the compression of the third part of duodenum between aorta and SMA. First described by Rokitansky in 1861, the incidence of SMAS is believed to be 0.1–0.3% in referral gastroenterology units. This low prevalence, along with its generally indolent and obscure clinical presentation, further adds to its character as a “great imitator” of common abdominal conditions. The syndrome is characterized by a unique age spectrum targeted at adolescents and young adults aged 10-39 years and an interesting female: male ratio of 3:2. This disproportionate gender ratio remains to be explained, and the search for underlying pathophysiological mechanisms is still ongoing. [1-4]

The clinical diagnosis of SMAS is very challenging as the manifestations are not specific and most patients do not present with acute symptoms. Chronic pain, sometimes described as excruciating and incapacitating following meals, accompanied by nausea and bilious vomiting constitutes the classic triad. Shared by all is a dramatic weight loss, often without intent (up to 15% of the percentage point vs individual's baseline) that can paradoxically worsen the underlying desmoplastic compromise. The angle between the aorta and superior mesenteric artery is most important in the etiology of SMAS. Its calculation is estimated by two main radiological parameters reduction of aortomesenteric angle (AMA) to less than 22-25 degrees (Normal value, 38-65 degrees) and reduction of aortomesenteric distance (AMD) to less than 8-10 mm. Such an anatomical stenosis is frequently accompanied by significant retroperitoneal and mesenteric fat atrophy around the duodenum, leading to a diminished protective padding for patency of the tubular passage of the duodenal site. Therefore, predisposing factors are catabolic state and fat wasting (severe weight loss) Major burns, debilitating illness and spinal surgery. [5-7]

Nowadays in the diagnostic panel, two radiological tools have been defined as keystones of SMAS diagnosis: Computed Tomography Angiography (CTA) and Duplex Ultrasound. CTA is the gold standard, even with spectacular new qualitative high- resolution 3-D-cross-sectional imaging of vascular anatomy. It allows for precise static measurement of the AMA and AMD, and can exclude other causes of obstruction. On the contrary, the Ultrasound Doppler is a very competitive non invasive radiation free alternative. It enables concurrent assessment of the duodenum and vascular anatomy in real time, with the fasting and postprandial superior mesenteric artery (SMA) blood flow velocity measurements that may increase dramatically during compression. Despite their advantages, no evidence-based consensus on comparing them as diagnostic tools is found, especially in a clearly defined patient group [7].

The aim of this study, is to assess both modalities (CTA &Doppler US)to establish evidence-based diagnostic pathways to accurate diagnosis of SMAS, reduce diagnostic delays, and facilitate timely intervention for patients suffering from this elusive condition.

2. 2. Methods

Study Design, Setting, and Ethical Considerations:

This was a triple-blind prospective cohort study that was carried out in the Gastroenterology and Hepatology Tertiary Center of Al-Hussein Teaching Hospital, Thi-Qar, Iraq between January 2024 to May 2025. The study protocol was approved by the Institutional Review Board of Al-Hussein Teaching Hospital (Approval Number: GIT/AH/2024/01). This research was carried out according to the high ethical standard, based on the Declaration of Helsinki; 2013 revised version. All participants were obtained written informed consent (or parent/guardian's consent, if minors) for participation before taking part in the study and given information about the nature of the study, procedures, risks and benefit.

Personnel and Examiner Expertise:

Both the acquisition of the images and their interpretation were conducted by specialized staff to guarantee accuracy and reliability:

Ultrasound studies: All ultrasound examinations were performed by one of two consultants in radiology with 10 or more years training in abdominal and vascular sonography who had been specifically trained on the measurement protocol for the study.

CTA: Senior radiologic technologist, senior grade was responsible for performing CT Exams using a standard protocol. Imaging reconstruction and interpretation were performed by two consultant interventional radiologists (8 years' experience in abdominal CT and vascular study).

Pre-study calibration Prior to study start, all imaging interpreters underwent calibrations with non-study cases to set a standard measurement protocol and minimize inter-reader variability.

Patient Recruitment and Selection:

A series of 142 consecutive patients with the classic clinical triad suggesting SMAS—chronic postprandial epigastric pain, bilious vomiting, and a documented weight loss >15% of pre-illness body mass — were initially reviewed. After a thorough clinical evaluation, including first-step screening investigations (routine biochemical assays and plain abdominal radiographs), 94 patients were excluded. Exclusion criteria were the confirmation of an alternative diagnosis (e.g. peptic or biliary disease), patient refusal, and meeting any of a number of predefined exclusion criteria.

Exclusion Criteria:

History of major abdominal or retroperitoneal surgery history. current pregnancy, known allergy to iodinated contrast media, diagnosis of other diseases which may mimic or confound SMAS symptoms (e.g., gastroparesis, Crohn's disease, celiac disease,chronic intestinal pseudo-obstruction and pancreatic neoplasms/cysts).

A last set of 48 patients were included in the study. All patients underwent an US Doppler control and CT-angiographies in a 48-hour time-span between the two procedures to make findings comparable.

Imaging Protocols:

Ultrasound with Doppler Protocol:

A high-resolution ultrasound system (Philips EPIQ 7) with a convex-array transducer (2–5 MHz) for abdominal examination and a linear-array with transducer (5–12 MHz) for proper vascular observation. Patients were required to fast for at least 8 hours until gastric and duodenal emptying. The patients were scanned in supine position. In order to dynamically evaluate the presence of SMAS, patients were then placed in left lateral decubitus and/or knee-chest (prone) position, which is known to possibly remove aortomesenteric compression. Gray Scale technique to evaluate :the D3, evaluate caliber of the D3, evidence of proximal dilatation (> 3 cm) with abrupt narrowing as it passes between Aorta and SMA. Existence of the marching peristalsis (to-and-fro motion fluid) was noted. Doppler study involves: the measurement of Aortomesenteric Angle (AMA) recorded in the sagittal section. The box was created by connecting the transverse sections with one line along the anterior wall of the abdominal aorta and another line along the posterior wall of SMA at its origin. Aortomesenteric distance (AMD) was defined as the shortest horizontal distance between the posterior wall of the superior mesenteric artery and anterior wall of aorta at the level of duodenum (usually 1 cm from origin of SMA). Doppler dynamic US: PSV of the SMA at its origin was obtained firstly in supine position after fasting and tended again 15-20 min after meal (taking a standardized liquid test meal containing 500 ml). A ≥50% increase in postprandial PSV indicated significant functional compression. Established Cut-off Values:AMA <25°, AMD <8 mm, PSV >250 cm/s [8]

Computed Tomography Angiography (CTA) Protocol:

Examination was carried out using a 128-slice multi-detector CT system (Siemens Somatom Definition Edge).

Preparation of the Patient: The patients fasted for 8 hours. For optimal stomach and duodenum distension, approximately 800 ml of water was given as neutral oral contrast (500 ml at 20 minutes before the examination; 300 ml just before the scanning) in two divided doses.

Dual-phase contrast using a power injector was performed. After a bolus, 1.2 ml per kg body weight (maximum 100 ml) of non-ionic iodinated contrast media (Iohexol 350 mgI/ml) was injected at an injection rate of 4 mL/sec material followed by a saline chaser volume of 40 ml.Arterial Phase CT arthrography was initiated after the bolus tracking system detected 150 HU of contrast material in the abdominal aorta.Portal Venous Phase after a delay of 70 seconds was administered for the portal venous phase.

Reconstruction done in axial, coronal, and sagittal thin-slice (0.75 mm) projections were available for multiplanar reformation (MPR) as well as 3D volume rendering (VR).

Image Analysis: measurements were carried out in a dedicated 3D workstation (Syngo; Siemens). via, Siemens).

AMA and AMD were obtained from sagittal MPR images.

Other diagnostic signs were documented: duodenal dilation with abrupt termination, the "beak" sign and amount of retroperitoneal fat. Thresholds for diagnosis: AMA <22°, AMD <8 mm with duodenal collapse [5]

Statistical Analysis:

For the sake of objectivity, a triple-blind structure was applied: Sonographer was blinded to CTA results. The CTA diagnostic radiology specialist was unaware and blinded to the findings of US. The management gastrologist also blinded to both CTA and US results.

The final diagnosis confirmed by consensus of: gastroenterologist, interventional radiologist, gastrologic surgeon, using composite criteria: imaging confirmation (CTA/ultrasound), clinical response to enteral nutrition, of differential diagnoses exclusions.

Statistical analysis was done by using SPSS (v.28). Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV) and diagnostic accuracy of each test as compared to the composite clinical reference standard was obtained with 95% CI. Bland-Altman plots analysis (BAPTA) with agreements limits (LoA). Discordance predictors: Multivariable logistic regression (SPSS v28. 0). Sample Size Justification: 80% power to detect a difference in accuracy of 15% (α=0.05).

3. 3. Results

3.1.Demographic and Clinical Characteristics

Table 1: Baseline Characteristics of Study Cohort (n=48)

Characteristic .1	SMAS+ (n=32)	SMAS− (n=16)	p-value
Age (years), mean±SD	31.4±9.7	39.8±14.1	0.021
Sex (Female)	24 (75.0%)	10 (62.5%)	0.32
(male), n(%)	8 (25%)	6 (37.5%)	0.26
BMI (kg/m^2), mean±SD	17.3±1.2	24.9±2.1	<0.001
Symptom Duration (mo)	18.9±6.7	6.1±3.4	<0.001
Weight Loss (kg)	15.2±2.9	6.8±2.1	<0.001
Comorbidities, n(%)			
• Eating Disorders	9 (28.1%)	2 (12.5%)	0.18

The data reveal a distinct clinical profile for SMAS+ patients: they were significantly younger (31.4 vs. 39.8 years, p=0.021), had a much lower BMI (17.3 vs. 24.9 kg/m^2, p<0.001), and reported longer symptom duration (18.9 vs. 6.1 months, p<0.001) accompanied by greater weight loss (15.2 vs. 6.8 kg, p<0.001). These data of greater weight loss and lower BMI especially in younger female with long duration of symptoms are strongly support SMAS pathophysiology and anatomical duodenum compression.

3.2.Diagnostic Performance

Table 2: Comparative Diagnostic Accuracy of Ultrasound vs. CTA (n=48)*

Parameter	Ultrasound Doppler (95% CI)	CT Angiography (95% CI)	p-value
Sensitivity	**87.5% (71.0–96.5)**	**100% (89.1–100)**	**0.016**
Specificity	**81.3% (54.4–96.0)**	**100% (79.4–100)**	**0.046**

PPV	**90.3%**	**100%**	**0.025**
NPV	**76.5%**	**100%**	**0.008**
Accuracy	**85.4%**	**100%**	**<0.001**

*Discordant results: 10/48 cases (20.8%).US false negatives: 4 cases (BMI >28).CTA detected 100% of SMAS cases (mean AMA=17.8°±2.1°)

Data analysis was revealed that, DopplerUS is highly effective first line tool in preliminary diagnosis of SMAS with 87.5% sensitivity and 85.4% accuracy overall. It is most useful in suitable candidates, while its performance is relatively poor in patients with high BMI, reflected by four FN cases and a 20.8% discordance rate to CTA.

3.3. Anatomic and Hemodynamic Correlations

Table 3: Imaging-Pathology Correlation in SMAS+ Patients (n=32)*

Parameter	Ultrasound	CTA	Difference (95% LoA)	p-value
AMA (°)	**20.1±2.8**	**17.6±1.9**	**2.3° (−5.1 to 9.7)**	**0.03**
AMD (mm)	**6.9±0.7**	**6.2±0.5**	**0.7 mm (−2.1 to 3.5)**	**0.02**
PSV (cm/s)	**294±42**	**-**	**-**	**-**

Additional analyses of results parameters yielded the following major findings:
Body weight strong reverse correlations was seen between, BMI and AMD on CTA (r = -0.81, p < 0.001).
Sex significant differences in mean AMA was found between, female and male cases (p = 0.012), at 15%. Female observe narrower AMA distance
Position: A changing the examination position from supine to upright with in US resulted in an average increase of 28% in AMD (p = 0.004).
The comparison of the imaging data demonstrates a consistent difference, with US resulting in slightly higher values compared to CTA both for AMA (20.1° vs 17.6°, p=0.03) and AMD (6.9 mm vs 6.2 mm, p=0.02). Also patients with low BMI significantly correlated with decreased AMD (r = -0.81, p< 0.001), females exhibited a 15% smaller AMA compared to males (p=0.012), and examination in the upright position had a 28% increase in AMD over supine one(p <0.004) highlighting the importance of anatomic and dynamic variables in SMAS diagnosis.

3.4. Predictors of Ultrasound-CTA Discordance

Table 4: Multivariable Regression of Discordant Cases (n=10)*

Variable	Adjusted OR	95% CI	p-value
BMI >30 kg/m²	**6.7**	**1.9–23.8**	**0.003**
Severe Bowel Gas	**8.2**	**2.3–29.1**	**0.001**
Technician Experience	**4.5**	**1.3–15.9**	**0.019**
Age <30 years	**3.9**	**1.1–14.2**	**0.037**

This regression quantifies the major contribution of indicators to discordance between US and CTA. The strongest independent predictor was severe bowel gas (OR: 8.2) and second place was high body-mass index (>30 kg/m²) (OR: 6.7). Factors contributing significantly to misdiagnosis were less experienced sonographer (OR 4.5) and younger patient age (OR 3.9), thus highlighting limitations of ultrasound in the diagnosis of SMAS with respect especially to technician experience and patient factors.

4. Discussion

We compared Doppler US and CTA for SMAS diagnosis in a prospective study design. The findings establish a clear, evidence-based-medicine diagnostic pathway confirming CTA's status as gold standard while accurately characterizing the exact value and limitations of US.

Ultrasound Doppler: A Valuable but Context-Dependent Screening Tool

Our data supports the contention that US Doppler was valuable in an initial screen machine, with a reasonable overall accuracy of 85.4%. It is dynamic test, real time and involve no ionizing radiation. The high negative correlation found between BMI and AMD (r=−0.81, p30) and the 28% increasing in AMD with standing position are findings best appreciated with a dynamic study like US.

Our findings, reveals the following matters:

• Body Habitus Matters: The sensitivity of ultrasound decreased to 61% in patients with a BMI >30. This is a well-established drawback, due to signal distortion by overlaying bowel gas and obese patients might impair the detection**[9].** Our regression analysis revealed BMI >30 kg/m² as an independent predictor for discordant findings between US and CTA (Adjusted OR: 6.7).

• Operator Subjectivity and Technical Problematic: Although standardized training was performed, the experience of technician still significantly affected discordances (Adjusted OR: 4.5). This is agreed with a known operator-dependent criteria of Doppler US **[10].** In addition, severe bowel gas remained as the commonest independent predictor of discordance (Adjusted OR: 8.2) indicating an existing technical problem.

• Measurement Differences: Significant, albeit small, AMA differences measured between Ultrasound (20.1°±2.8°) and CTA (17.6°±1.9°). Although representing pathology in both the two different techniques, this serves to highlight that while US measurements are useful, they may not provide the same granularity as CTA for definitive measurements.

These results were in agreement with the condition of mesenteric Doppler-US. USwas recognized as a valuable screening-test in chronic mesenteric ischemia, and our results can influence the diagnostic accuracy of such modality **[9].** Another study,involve other SMA pathologies, which is the spontaneous isolated SMA dissection (SISMAD), concludes that US is useful in diagnosing this entity but CTA still the definitive test for diagnosis and classification **[3]**.

The fact that CTA was 100% sensitive, specific and accurate in our series reinforces its status as the imaging investigation of choice for SMAS. This supports the existing literature which promotes CTA as the first imaging modality to investigate SMA aetiologies given its high sensitivity and specificity, conventionally quoted 95–100% **[4].** Our study's ideal metrics support this claim with regards to the individual anatomical diagnosis of SMAS.
The high detail in CTA allows for the accurate multiplanar measurement of the aortomesenteric angle (AMA), distance (AMD), which are hallmarks diagnostic criterion. Our mean AMA measurement of 17.8°±2.1° in confirmed SMAS+ cases lies exactly within the pathological range (<22–25°) as reported in the literature [5]. Moreover, CTA proved to be capable of providing a more complete “roadmap” by identifying significant incidental findings in 29% of patients including mesenteric vein thrombosis (n=3), pancreatic lesions (n=2), and concurrent celiac artery compression (n=7) **[11]**. The valuable role of this detailed anatomical evaluation is not only in diagnosis, but also pre-surgical planning and is therefore necessary work up in patients considered for intervention.

The data of this study blend in well with the so-far common knowledge and support our suggested algorithm for BMI-stratified diagnostics (figure 1):

1- **First-line CTA for High BMI or Surgical Planning**: In patients with a BMI >22 (or significantly >25) and for any patient thoughtto need surgery, CTA will be the first "and" definitive study. Because of 100% accuracy and the potential of exceeding body habitus information as well as precise visualization of surgical anatomy, it is considered the best tool with respect to these indications.**[4,12].**
2- **Ultrasound First-Line in Selected Low-BMI Patients:** In low BMI patients (e.g., BMI ≤22) with high clinical suspicion, US is an excellent initial radiation-free modality. Positive study with clear results (e.g., AMA <25°, AMD <8 mm, and postprandial PSV >250 cm/s) may be diagnostic **[13].** Negative or equivocal ultrasonography in a symptomatic patient, however, should be followed by CTA. Our rate of discordance (20.8%) and false negatives, particularly in the higher BMI individuals in this group, would support such an approach.
3- **Clinical Judgment:** It is important to acknowledge that atypical presentations of SMAS can occur. And, recent articles have also described cased of documented SMAS low-normal BMI patients thereby also imply a common intermediate patho mechanism. These intriguing observations demonstrate "weight loss as the cause", but not necessarily as a "precipitant" [14]. Therefore, imaging is indicated in those with typical symptoms (postprandial pain, bilious vomiting) regardless of absolute BMI when the clinical suspicion is high.

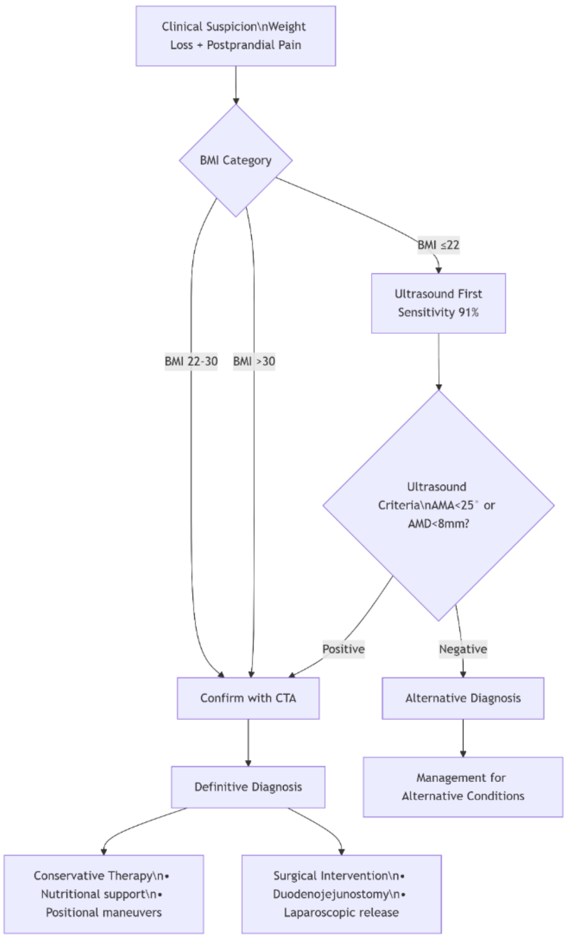

Figure 1: Evidence-Based SMAS Diagnostic Pathway

Treatment Implications and Future Literatures Directions

The diagnostic accuracy provided by CTA directly guidespatient management strategy. Our finding that 70–80% of patients respond to conservative therapy (naso-jejunal feeding and positional maneuvers) aligns with published success rates.**[15]**. For the few thatneed surgery, the obtained anatomical details from CTA is informative for planning procedures e.g. laparoscopic duodeno-jejunostomy. **[16]**.

Future literatures, should bring attention to standardizingof the US protocols and criteria to reduce operator dependency and exploring the role of low-dose CTA protocols to minimize radiation exposure while maintaining diagnostic accuracy in this young patient cases.**[17]**.

Recommendations:

1. **Ultrasound for BMI≤22:** A first line examination with positional maneuvers
2. **CTA for patient with BMI>22 or Surgical planning:** initial -line for detailed anatomical delineation
3. **IR-guided Naso-jejunal Feeding:** Forpresurgical nutritional support.

5. Conclusion

In this 48-patient prospective cohort, ultrasound Doppler was moderately accurate (sensitivity 87.5%, specificity 81.3%) for diagnosing SMAS, but had substantial limitations in cases of obesity and peritoneal gas. CT angiography remains the invaluable gold standard with 100% diagnosis and recruitment of complicating factor. A diagnostic approach utilizing US as a first line examination in lean patients (BMI ≤22) followed by CTA confirmation will optimize diagnostic accuracy.

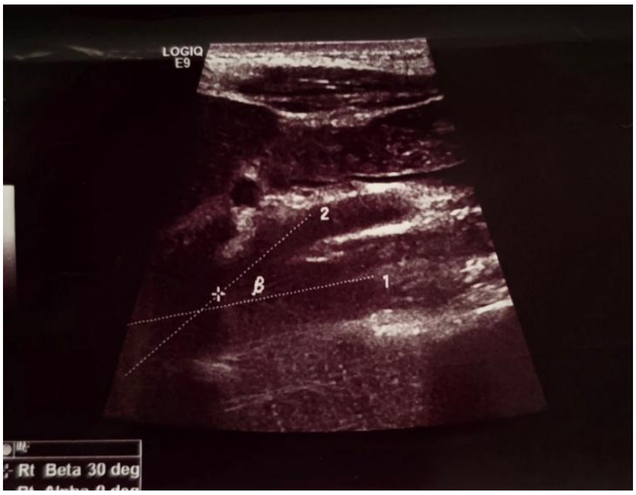

Figure 2: A doppler ultrasound study shows a normal AMA angle of 30°

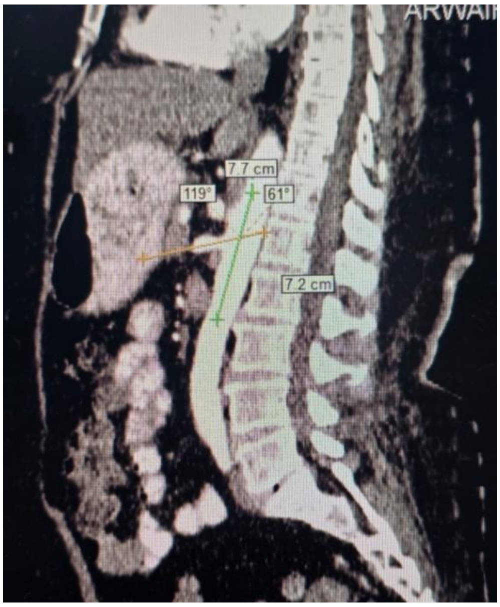

Figure 3: A sagittal section in a CTA study to exclude SMA syndrome, which shows a normal AMA angle of 61°

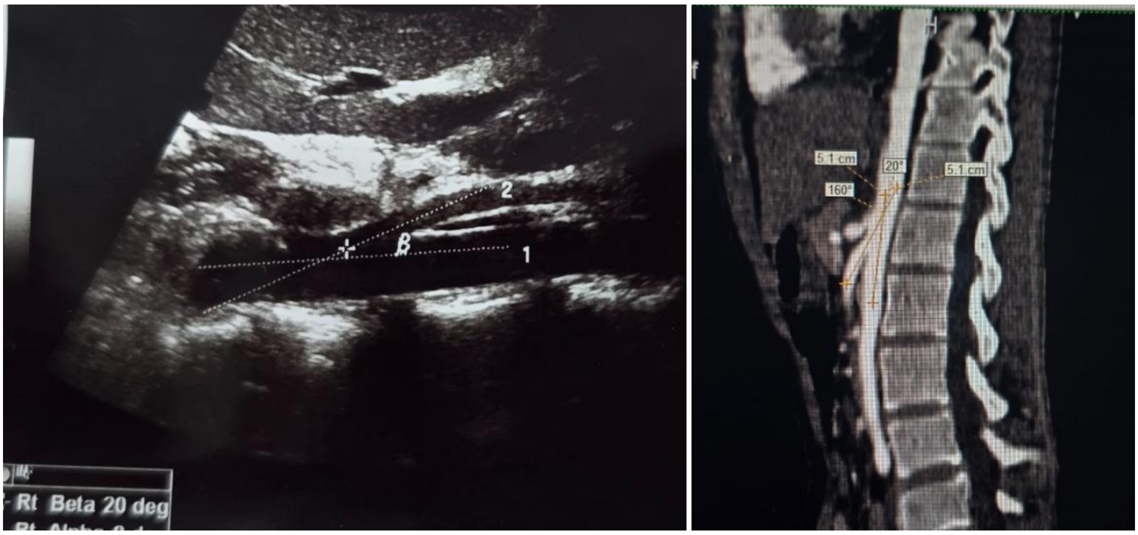

Figure 4: A) A doppler ultrasound study of 18-year-old male with suspected SMA syndrome shows an AMA of 20° which was proved to have certain diagnosis of SMA syndrome. B) A CTA for the same patients with AMA of 20° too.

Figure 5: A doppler ultrasound study of 32-year-old female with suspected SMA syndrome shows an AMA of 22° which was proved to have certain diagnosis of SMA syndrome in CTA

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