LOWER LIMB ARTERIES ASSESSED WITH DOPPLER ANGIOGRAPHY – A PROSPECTIVE COMPARATIVE STUDY WITH MULTI DETECTOR CT ANGIOGRAPHY

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Abstract - This prospective study aims to determine the accuracy of Duplex Ultrasound compared with MDCT angiography in identifying and estimating the degree of obstructive arterial lesions in lower limbs. The study group includes 34 patients with unilateral or bilateral lower limb ischemic disease - who have come to the department of radiology for CT angiography. Result and conclusion: Combination of Duplex Ultrasound with MDCT angiography has better diagnostic accuracy. Duplex Ultrasound is a safe, inexpensive, non-invasive, easily available diagnostic tool with high diagnostic accuracy and is indispensable in the investigation of peripheral arterial disease.

Keywords - Duplex Ultrasound; MDCT angiography; obstructive arterial lesions;

I. INTRODUCTION
Lower limb arterial disease is an important cause of morbidity in middle aged and the elderly. The atheromatous narrowing or occlusion of an artery or arteries of the leg commonly causes it. It may be symptomatic causing intermittent claudication, ischemic rest pain, ulceration, and gangrene. Management strategies differ for patients with lower limb arterial disease. Patients with intermittent claudication are often managed conservatively, while patients with limb threatening ischemia are treated with angioplasty, surgical revascularization or amputation. The choice of intervention is governed by the severity of the disease and may involve combined treatments. Thus patients with limb threatening ischemia require a detailed assessment for a suitable treatment plan to be developed. Intra-arterial contrast angiography is regarded as the reference standard for investigating lower limb arterial disease. Its drawbacks are those associated with arterial puncture, ionizing radiation, and potential nephrotoxicity of iodinated contrast agents. Several alternative imaging techniques are available, including Magnetic Resonance Angiography, Computed Tomography Angiography and Duplex Ultrasoundography. While Computed Tomography Angiography carries risks relating to ionizing radiation, and both contrast enhanced Magnetic Resonance Angiography and Computed Tomography Angiography carry risks associated with the use of contrast agents, Duplex Ultrasoundography is unassociated with any risk. Recent advances in Duplex Ultrasound like better post-processing capability, transducer technology, image resolution, signal strength, and spectral analysis capabilities have improved its ability to visualize and grade abnormalities, thus extending the scope for non-invasive assessment of peripheral arterial disease. Several studies validate contrast material–enhanced Multi Detector CT Angiography as a noninvasive alternative to conventional Digital Subtraction Angiography for imaging the vascular tree. Unfortunately there is a paucity of high quality trials to determine the accuracy of magnetic resonance angiography (MRA), duplex ultrasound and computed tomography angiography (CTA) in the investigation of peripheral arterial disease.

II. AIM OF THE STUDY
This prospective study aims to determine the accuracy of Duplex Ultrasound compared with MDCT angiography in identifying and estimating the degree of obstructive arterial lesions in lower limbs.

PERIPHERAL ARTERIAL DISEASE NATOMY OF LOWER LIMB ARTERIAL SYSTEM
Aorta divides into common iliac arteries at the level of L4. Common iliac bifurcates at the L5-S1 disc into internal and external iliac artery. Internal iliac artery courses anterior and adjacent to the sacroiliac joint. External iliac artery passes obliquely down medial border of psaos & anterior and lateral to external iliac vein and becomes the common femoral artery as it passes below the inguinal ligament. Common femoral artery is approximately 4 cm in length and divides into superficial femoral & profunda femoris arteries. SFA lies between femoral vein & nerve in femoral triangle. At the distal apex of femoral triangle, above the knee, it passes through the opening in adductor magnus to enter popliteal space as popliteal artery. Popliteal artery after providing
genicular arteries at level of knee joint passes deep to soleus, where it transverses through another fibrous tunnel. Popliteal artery then sends paired sural arteries to gastrocnemius & soleus & ends by dividing into anterior tibial artery, Posterior Tibial Artery and Peroneal artery. At the level of ankle – Anterior Tibial Artery becomes Dorsalis Pedis, Posterior Tibial Artery becomes medial and lateral plantar arteries.

PERIPHERAL ARTERIAL DISEASE
Lower limb arterial pathology may be occlusive or non-occlusive (Table 1). The most common condition affecting the arteries of lower extremity is ischemia due to occlusive disease. Occlusive disease may be acute, acute on chronic or chronic.

CLINICAL FEATURES
The clinical effect of occlusive disease varies depending on the location, severity and number of arterial lesions present. Patients may be asymptomatic, symptomatic based on which the disease is commonly divided in the Fontaine stages, introduced by Dr René Fontaine in 1954:

<table>
<thead>
<tr>
<th>Stage</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>asymptomatic</td>
</tr>
<tr>
<td>II</td>
<td>intermittent claudication</td>
</tr>
<tr>
<td>III</td>
<td>rest pain / nocturnal pain</td>
</tr>
<tr>
<td>IV</td>
<td>necrosis / gangrene</td>
</tr>
</tbody>
</table>

**TABLE 1**
CAUSES OF OCCLUSIVE ARTERIAL LESIONS IN LOWER EXTREMITIES ARTERIES POTENTIALLY CAUSING CLAUDICATION

<table>
<thead>
<tr>
<th>Arterial Disease</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atherosclerosis (PAD)</td>
</tr>
<tr>
<td>Arteritis</td>
</tr>
</tbody>
</table>

MANAGEMENT The management of the PAD is decided based on the Fontaine stage:
- **Stage 1**: Medical management - modification of risk factors which also decides cardiovascular risk and prevention of disease progression and major complications.
- **Stage 2**: These patients are not treated with invasive procedure unless claudication distance is very short or the symptoms limit their life style.
- **Stage 3 and 4**: Must be treated by angioplasty / stenting / surgery.

INDICATIONS FOR IMAGING
The purpose of imaging is to assess the anatomical location, morphology and extent of disease in order to determine suitability for intervention.

IMAGING MODALITIES
The options for imaging are Digital Subtraction Angiography (DSA), Duplex Ultrasound, Magnetic Resonance Angiography and Computed Tomography Angiography.

1. DIGITAL SUBTRACTION ARTERIOGRAPHY
DSA is still considered the gold standard against which other techniques are compared. Digital cine-fluoroscopy allows real-time guidance of interventional procedures which are first-line management for critical ischemia, especially in patients who are not fit for a general anesthetist. Modern angiography suites consist of ultra-rapid digital cine-fluoroscopy systems, mounted on C-arms, with digital display facilities and complex post-processing software. The most critical step is the computerized subtraction of the precontrast (mask) image from the post-contrast image, producing a resultant image of contrast-filled vessels only. Digital subtraction techniques reduce the dose of contrast required. Good spatial and temporal resolution, combined with a large field of view, allows bolus chasing from the aorta to the feet. The peripheral arterial tree can be seen and mapped quickly with overlapping runs. Large numbers of collaterals can be anatomically visualized quickly and in one session. More recently, rotational computed angiography (Dyna-CT) has been introduced. This involves a modified...
angiography image intensifier, with a rotating C-arm, so that computed tomography-like slices can be acquired in the interventional suite. Advantages are used to guide endovascular intervention, provides a complete arterial map of the lower limb circulation which is easily interpretable and Pressure gradients can be measured to determine hemodynamic significance. Complications of catheterisation which may occur both within the vessel and at the puncture site. Although it has been estimated that 1.7% of complications may be severe, improvements in catheter and guidewire technology have reduced their incidences significantly. DSA involves ionizing radiation (for both patients and staff). The mask projections are easily distorted by patient movement, although modern software systems compensate for some motion artefacts. It may overestimate the length of occlusions. It may not always demonstrate patent crural vessels. Slow flow can be missed depending on technical parameters (contrast injection rate, projection, or frame rate). Allergic reactions to iodinated contrast occur, with around 0.1% of these being severe. There is a risk of nephrotoxicity from iodinated contrast and this is increased in elderly patients, infants, and those with pre-existing renal impairment.

2. DUPLEX ULTRASOUND
combines both B-mode ultrasound and colour doppler ultrasound to provide both anatomical and hemodynamic (functional) information. Recent advances in gray scale imaging including compounding, speckle reduction techniques gives excellent high resolution images. Advantages are widely available, inexpensive noninvasive, nonionizing and does not require nephrotoxic contrast. Limitation are operator-dependent and independent. Ultrasound is a focal imaging tool, and cannot define co-existent extrinsic pathology completely or provide global imaging of the cardiovascular system. It cannot provide reliable imaging if there are poor acoustic windows (eg, body habitus, bowel gas attenuation, diffuse vascular calcification, or metallic stents) or poor intrinsic echogenicity of the tissues. Duplex scanning is time-consuming and inconvenient post-operatively – when the region of interest is obscured by dressings – and removing these can involve infection risk.

3. MAGNETIC RESONANCE ANGIOGRAPHY
consists of moving-table bolus-chase protocols using gadolinium-enhancement in combination with a phased-array leg angiography coil. It is ideal for problem solving imaging of the below-knee run-off, which is not easily assessed by DU or DSA. “Hybrid” MRA is the combination of a time resolved MRA of the calf and foot followed by a bolus-chase multi station MRA. Time resolved imaging can be 2D or 3D. Hybrid MRA can detect run-off arteries not seen by DSA, which is of supreme importance in planning limb salvage surgery. Advantages are no ionising radiation, no risk of contrast nephropathy when gadolinium is used in recommended doses. Unlike ultrasound and CTA, it is unaffected by arterial calcification. Disadvantages are patient motion artefacts. Overestimates stenosis. Venous contamination can obscure arteries below the knee. Claustrophobia, Metallic implants (such as pacemakers) or foreign bodies may preclude the examination or produce magnetic susceptibility artefacts. Gadolinium-based contrast agents has recently been associated with nephrogenic systemic fibrosis in patients with renal impairment (all cases have been in patients with a glomerular filtration rate of less than 60 ml/min).

4. COMPUTED TOMOGRAPHY ANGIOGRAPHY
The introduction of Multidetector CT scanners has dramatically improved spatial resolution and a moving tabletop enables examination from aorta to feet in a single contrast injection. Volumetric data are then reconstructed at a workstation and normally represented in maximum intensity projection format producing easily interpretable arteriographic images. Advantages includes both luminal and extraluminal pathology can be shown simultaneously, excellent for assessment of aneurysms and acute arterial trauma. A major drawback of CT angiography is the difficulty in assessing arterial luminal stenosis in extensively calcified vessels. In the presence of extensive vessel wall calcifications, especially in small arteries, it is difficult to produce interpretable maximum intensity projection images. Overstaging – false negative stenosis or occlusion can occur because of the “blooming” effect of the calcium in calcified plaques, so that a patent vessel with calcification is mistaken for an occluded vessel on the transverse CT images. There may be different rates of crural vessel opacification, or inadequate opacification distal to an occlusion. CTA should be avoided in the elderly (>84 years), patients with renal failure, diabetes, or heart failure. There is the same risk of an allergic reaction to contrast, nephrotoxicity and exposure to ionizing radiation as for DSA. Typical mean effective dose for CTA study of the periphery (including lower limbs) has been reported as 12–14 mSv per study depending on technical protocol versus 11 mSv for DSA.

III. MATERIALS AND METHODS
STUDY POPULATION -The study group includes 34 patients with unilateral or bilateral lower limb ischemic disease - who have come to the department of radiology for CT angiography.

INCLUSION CRITERIA are any age group, Unilateral or Bilateral lower limb arterial disease and Acute or Chronic lower limb arterial disease.

EXCLUSION CRITERIA are patients with extensive ulcerations and gangrene, immediate unstable post operative patients with sterile dressings in lower limb, patients with contrast reaction, patients who extreme pain in the lower limb due to ischemia and patients with renal failure and contrast hypersensitivity did not undergo CT angiography.

DATA ACQUISITION
DUPLEX ULTRASONOGRAPHY Done with Siemens ACUSON Antares Duplex Ultrasound machine band width frequency transducer with a range of 5-13 MHz for lower limb artery and 3.5 MHz probe for infrarenal aorta and iliac vessels. Patients were kept fasting for at least 6 hours, to improve visualization of the aorto-iliac region. Colour flow assisted B-mode was used to rapidly map the vessel of interest and locate lesions. Pulse Doppler was used to analyze spectral waveform and to measure peak systolic velocity. Gray scale sonography to identify plaque morphological
features and calcification. Following scanner control adjustments were followed, Colour box was not too large as the image frame rate may become too low. The colour pulse repetition frequency was optimized so that the peak systolic velocity is in the upper region of the colour scale. Stenoses will be rapidly identified as areas of aliasing. The colour wall filter was set correctly. Angle of insonation was kept close to 60 degree to the vessel axis.

Duplex ultrasound criteria for assessment of peripheral arterial disease

Patency of vessel was determined by normal triphasic waveform pattern and colour saturation, demonstrated throughout the lumen of the artery. Occlusion was diagnosed, when no colour saturation and no Doppler waveform was seen in the artery. Non occlusive lesions - Arterial lesions were located by change in colour flow pattern, change in vessel diameter and broadening of Doppler spectrum. Grading of the arterial segment with color Doppler was based on the PSV ratio and spectral pattern analysis. A hemodynamically significant stenosis (>50%) was inferred when the waveform changed from triphasic to monophasic, with appearance of spectral broadening and PSV ratio >2. Peak systolic velocity ratio is measured with respect to a point with normal flow pattern in the lumen at least 4 cm proximalys.

Although a number of parameters in the Doppler waveform are affected by stenoses, the peak systolic velocity ratio is the most widely adopted measurement. A peak systolic velocity ratio of greater than two indicates a stenosis of greater than 50%. In order to eliminate interobserver variation, all Doppler studies were done by the same radiologist.

a. **Doppler lower limb artery showing normal** Triphasic Pattern

b. **Hemodynamically insignificant stenosis spectral broadening**

c. **Hemodynamically Significant Stenosis with elevated Psv**

CT ANGIOGRAPHY

CT angiography was done with PHILIPS 64 slice Multi detector CT. Patients were placed in supine position with feet entering the gantry first. Scannogram and plain study are taken. Spiral acquisitions were performed in a single scanning pass from the level of the diaphragm down to the ankles. The average length of scanning for a patient is about 1500mm. Patients were asked to hold their breath during the first part of the scanning pass. After saline check, 100mL volume of iodinated contrast material (320 mg of iodine per milliliter), was administered through a 20-gauge cannula in an antecubital vein at a rate of 4.5mL/sec. through pressure injector followed by saline chase.

The scanning parameters were as follows 120kV, 200 mA (effective), and Section thickness of 2mm.

e. **Scanogram – 120kv , 30 Mas , Length 1459mm**

f. **Planning For Plain, Arterial And Venous Study, Including The Placement Of Locator**
Postprocessing reconstructions were performed by dedicated CT technologists and images are interpreted by experienced radiologists. The images were analysed on the basis of transverse images, MIP & VR images – for stenosis, occlusion, calcification, plaque morphology and collaterals.

**Stenosis was graded as follows**

**Grade 1**- Normal vessel or mild vessel irregularities (<10% luminal narrowing).

**Grade 2**- Moderate arterial stenosis (10%–49% luminal narrowing).

**Grade 3**- Severe arterial stenosis (50%–99% luminal narrowing).

**Grade 4** - Occlusion.

**IV. IMAGE ANALYSIS**

The following vascular segments were analyzed independently for the presence of hemodynamically significant stenosis or occlusion, plaque morphology and collaterals.

- Infra-renal aorta.
- Common iliac artery
- External iliac artery
- Common femoral artery,
- Proximal superficial femoral artery
- Mid superficial femoral artery
- Distal superficial femoral artery
- Origin of deep femoral artery
- Popliteal artery
- Anterior tibial artery
- Posterior tibial artery
- Peroneal artery
- Dorsalis pedis.

Thus, for a patient with unilateral limb involvement, 13 segments were examined and in case of bilateral limb disease, 25 segments were examined.

**V. REPRESENTATIVE CASES AND IMAGES**

CASE: 67 year old male with ulcer in left foot. A. CT angiography shows complete occlusion of left superficial femoral artery at its origin with reformation of its distal third and normal appearing popliteal artery. B. Color Doppler images show normal triphasic waveform pattern and reduced velocity in left CFA, occlusion of proximal SFA, reformed at distal SFA showing monophasic waveform pattern and monophasic waveform pattern in popliteal artery.
PLAQUE MORPHOLOGY

1. Soft plaque causing < 50% narrowing of Right SFA – gray scale USG image and its corresponding CT image

2. Calcified plaque

3. Acute thrombus distending right middle SFA seen better with USG Doppler image.

VI. RESULTS AND ANALYSIS

The study involved 34 patients (32 men, 2 women). Of these patients, 28 were above 40 and 60 years of age. 3 patients had below knee amputation. Though 68 limbs, 835 individual arterial segments were evaluated using each modality but only 807 segments for available for comparison. 25 patients had atherosclerosis, 7 had TAO, while 1 had acute thrombosis due to trauma and 1 had cystic adventitial disease of popliteal artery. 2 had intermittent claudication (Fontaine’s stage II), 7 had rest pain (Fontaine’s stage III), trophic changes, ulcers and gangrene were seen in 25
persons (Fontaine’s stage IV). 18 were chronic smokers, 16 had diabetes and 25 had hypertension.

**Statistical Analysis**

Results were tabulated and analyzed by two way contingency tables and Kappa statistics. Sensitivity, Specificity, Positive Predictive Value and Negative Predictive Value were obtained.

### Aortoiliac Region

#### Infra Renal Aorta

<table>
<thead>
<tr>
<th></th>
<th>Doppler Positive</th>
<th>Doppler Negative</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Doppler Positive</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Doppler Negative</td>
<td>0</td>
<td>26</td>
<td>26</td>
</tr>
</tbody>
</table>

Sensitivity: 100%  
Specificity: 100%

PPV: 100%  
NPV: 100%

Analysis with Kappa statistics

Number of observed agreements: 27 (100.00% of the observations)  
Number of agreements expected by chance: 25.1 (92.67% of the observations)

Kappa = 1.000  
95% confidence interval: From 1.000 to 1.000  
The strength of agreement is perfect.

### External Iliac Artery

<table>
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<tr>
<th></th>
<th>Doppler Positive</th>
<th>Doppler Negative</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Doppler Positive</td>
<td>7</td>
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</tr>
<tr>
<td>Doppler Negative</td>
<td>1</td>
<td>54</td>
<td>55</td>
</tr>
</tbody>
</table>

Sensitivity: 87.5%  
Specificity: 100%

PPV: 100%  
NPV: 98.18%

Analysis with Kappa statistics

Number of observed agreements: 61 (98.39% of the observations)  
Number of agreements expected by chance: 48.6 (78.72% of the observations)

Kappa = 0.524  
95% confidence interval: From 0.777 to 1.072  
The strength of agreement is considered to be ‘very good’.

### Common Iliac Artery

<table>
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<tr>
<th></th>
<th>Doppler Positive</th>
<th>Doppler Negative</th>
<th>Total</th>
</tr>
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<tbody>
<tr>
<td>Doppler Positive</td>
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</tr>
<tr>
<td>Doppler Negative</td>
<td>8</td>
<td>48</td>
<td>56</td>
</tr>
</tbody>
</table>

Sensitivity: 87.5%  
Specificity: 100%

PPV: 100%  
NPV: 97.96%

Analysis with Kappa statistics

### FemoroPopliteal Region

### Common Femoral Artery

<table>
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<tr>
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<th>Doppler Positive</th>
<th>Doppler Negative</th>
<th>Total</th>
</tr>
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<tbody>
<tr>
<td>Doppler Positive</td>
<td>9</td>
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<td>9</td>
</tr>
<tr>
<td>Doppler Negative</td>
<td>0</td>
<td>59</td>
<td>59</td>
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</table>

Sensitivity: 100%  
Specificity: 100%
### PROXIMAL PART OF PROFUNDA FEMORIS

<table>
<thead>
<tr>
<th></th>
<th>Doppler Positive</th>
<th>Doppler Negative</th>
<th>Total</th>
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<tbody>
<tr>
<td>CT Positive</td>
<td>9</td>
<td>0</td>
<td>9</td>
</tr>
<tr>
<td>CT Negative</td>
<td>6</td>
<td>53</td>
<td>59</td>
</tr>
<tr>
<td>Total</td>
<td>15</td>
<td>53</td>
<td>68</td>
</tr>
</tbody>
</table>

Sensitivity: 100%  Specificity: 89.83%

**Analysis with Kappa statistics**

Number of observed agreements: 68 (100.00% of the observations)
Number of agreements expected by chance: 45.4 (77.03% of the observations)
Kappa = 1.000
95% confidence interval: From 1.000 to 1.000
The strength of agreement is perfect.

### MIDDLE SUPERFICIAL FEMORAL ARTERY

<table>
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<tr>
<th></th>
<th>Doppler Positive</th>
<th>Doppler Negative</th>
<th>Total</th>
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<tbody>
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</tr>
<tr>
<td>CT Negative</td>
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<td>39</td>
</tr>
<tr>
<td>Total</td>
<td>29</td>
<td>39</td>
<td>68</td>
</tr>
</tbody>
</table>

Sensitivity: 100%  Specificity: 100%

**Analysis with Kappa statistics**

Number of observed agreements: 68 (100.00% of the observations)
Number of agreements expected by chance: 34.7 (51.08% of the observations)
Kappa = 1.000
95% confidence interval: From 1.000 to 1.000
The strength of agreement is perfect.

### DISTAL SUPERFICIAL FEMORAL ARTERY

<table>
<thead>
<tr>
<th></th>
<th>Doppler Positive</th>
<th>Doppler Negative</th>
<th>Total</th>
</tr>
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<tbody>
<tr>
<td>CT Positive</td>
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<td>2</td>
<td>37</td>
</tr>
<tr>
<td>CT Negative</td>
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<td>25</td>
</tr>
<tr>
<td>Total</td>
<td>35</td>
<td>27</td>
<td>62</td>
</tr>
</tbody>
</table>

Sensitivity: 100%  Specificity: 92.59%

**Analysis with Kappa statistics**

Number of observed agreements: 68 (100.00% of the observations)
Number of agreements expected by chance: 34.7 (51.08% of the observations)
Kappa = 1.000
95% confidence interval: From 1.000 to 1.000
The strength of agreement is perfect.
### POPLITEAL ARTERY

<table>
<thead>
<tr>
<th></th>
<th>CT POSITIVE</th>
<th>CT NEGATIVE</th>
<th>TOTAL</th>
</tr>
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<td>DOPPLER POSITIVE</td>
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<tr>
<td>DOPPLER NEGATIVE</td>
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<td>23</td>
</tr>
<tr>
<td></td>
<td>43</td>
<td>25</td>
<td>68</td>
</tr>
</tbody>
</table>

Sensitivity: 100%       Specificity: 92%

PPV: 95.56%       NPV: 100%

Analysis with Kappa statistics

Kappa: 0.934
95% confidence interval: From 0.844 to 1.024
The strength of agreement is considered to be 'very good'.

### POSTERIOR TIBIAL ARTERY

<table>
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<tr>
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<th>CT POSITIVE</th>
<th>CT NEGATIVE</th>
<th>TOTAL</th>
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<tr>
<td>DOPPLER POSITIVE</td>
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<tr>
<td>DOPPLER NEGATIVE</td>
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<tr>
<td></td>
<td>18</td>
<td>47</td>
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</tbody>
</table>

Sensitivity: 77.77%       Specificity: 87.23%

PPV: 70%       NPV: 91.11%

Analysis with Kappa statistics

Kappa: 0.620
95% confidence interval: From 0.417 to 0.840
The strength of agreement is considered to be 'good'.

### INFRAPOPLITEAL REGION

### ANTERIOR TIBIAL ARTERY

<table>
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<tr>
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<th>CT POSITIVE</th>
<th>CT NEGATIVE</th>
<th>TOTAL</th>
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</thead>
<tbody>
<tr>
<td>DOPPLER POSITIVE</td>
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<td>16</td>
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<tr>
<td>DOPPLER NEGATIVE</td>
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<tr>
<td></td>
<td>12</td>
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<td>65</td>
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</table>

Sensitivity: 75%       Specificity: 86.79%

PPV: 56.25%       NPV: 93.88%

Analysis with Kappa statistics

Kappa: 0.906
95% confidence interval: From 0.848 to 1.024
The strength of agreement is considered to be 'very good'.

### PERONEAL ARTERY

<table>
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<tr>
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<th>CT NEGATIVE</th>
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<td>DOPPLER NEGATIVE</td>
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<td></td>
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Sensitivity: 75%       Specificity: 71%

PPV: 53.57%       NPV: 86.48%

Analysis with Kappa statistics
DORSALIS PEDIS

<table>
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<tr>
<th>CT POSITIVE</th>
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<td>5</td>
</tr>
<tr>
<td>DOPPLER NEGATIVE</td>
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<td>33</td>
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</table>

Sensitivity : 74.07%  Specificity: 86.84%

PPV: 80%  NPV: 82.5%

Analysis with Kappa statistics

| Number of observed agreements: 53 (81.54% of the observations) |
| Number of agreements expected by chance: 33.8 (51.95% of the observations) |

Kappa=0.616
95% confidence interval: From 0.419 to 0.812
The strength of agreement is considered to be "good".

FEMORO POPLITEAL REGION

Total number of segments = 402

<table>
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<th>CT NEGATIVE</th>
<th>TOTAL</th>
</tr>
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<tr>
<td>DOPPLER NEGATIVE</td>
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<td>241</td>
</tr>
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</table>

151 251 402

Sensitivity : 100%  Specificity : 96.01%

PPV: 93.79%  NPV: 100%

Analysis with Kappa statistics

| Number of observed agreements: 392 (97.51% of the observations) |
| Number of agreements expected by chance: 211.0 (52.46% of the observations) |

Kappa=0.948
95% confidence interval: From 0.916 to 0.960
The strength of agreement is considered to be "very good".

AORTO ILIAC REGION

Total number of segments : 170
No of segments obscured by bowel gas: 25
No of segments available for comparison : 145

<table>
<thead>
<tr>
<th>CT POSITIVE</th>
<th>CT NEGATIVE</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOPPLER POSITIVE</td>
<td>14</td>
</tr>
<tr>
<td>DOPPLER NEGATIVE</td>
<td>2</td>
</tr>
</tbody>
</table>

16 | 129 | 145

Sensitivity : 87.5%  Specificity : 100%

INFRAPLITEAR REGION

Total number of segments = 260

<table>
<thead>
<tr>
<th>CT POSITIVE</th>
<th>CT NEGATIVE</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOPPLER POSITIVE</td>
<td>58</td>
<td>31</td>
</tr>
<tr>
<td>DOPPLER NEGATIVE</td>
<td>19</td>
<td>152</td>
</tr>
</tbody>
</table>

186 | 74 | 260

Sensitivity : 75.32%  Specificity : 83.06%

PPV: 65.16%  NPV: 88.88%
Table 3 showing the sensitivity, specificity, PPV and NPV of duplex ultrasound of lower limb arterial system

Table 4 showing agreement between the two modalities analysed with KAPPA STATISTICS –

VII. DISCUSSION

The study involved 34 patients out of whom 3 patients had below knee amputation. Out of 34 patients, infra renal aorta was obscured by bowel gas in 7 patients. Out of those 27 segments assessed, 1 patient had significant stenosis and the rest had normal or hemodynamically insignificant stenosis. CT angiography confirmed the findings. The sensitivity, specificity, positive predictive value and negative predictive value of Doppler was 100% in evaluating infra renal aorta. The strength of agreement was perfect between
Doppler and CT angiography when analysed with kappa statistics. In common iliac arterial segment, out of 68 segments, 12 segments were not evaluated due to bowel gas. Of the evaluated 56 segments, Doppler was able to pick up 7 of the 8 hemodynamically significant stenosis.

It missed significant stenosis in 1 patient who had a calcific plaque. False negativity in this patient could be due to over estimation of stenosis by CT angiography in arteries with calcific plaques. Because of this, the sensitivity of Doppler was reduced to 87.5%. However the strength of agreement was considered to be very good between Doppler and CT angiography when analysed with kappa statistics. In external iliac arterial segment, out of 68 segments, 6 segments were obscured by bowel gas. In the remaining 62 segments, Doppler failed to detect hemodynamically significant stenosis in the same patient as that of common iliac artery, probably due to overestimation of the stenosis caused by calcific plaque by CT angiography. The sensitivity fell to 87.5% and the specificity was 100%. The strength of agreement was considered to be very good between Doppler and CT angiography when analysed with kappa statistics. In the common femoral artery, Doppler was able to detect all the 9 hemodynamically significant stenosis with the resulting sensitivity and specificity of 100%. The strength of agreement was perfect between Doppler and CT angiography when analysed with kappa statistics.

In the proximal and middle superficial femoral artery, Doppler was able to detect all the 26 and 29 hemodynamically significant stenosis respectively with the resulting sensitivity and specificity of 100%. In the distal superficial femoral artery, out of 68 segments, only 62 segments were available for comparison since in 6 patients distal SFA was not visualized – which is a blind spot for sonographers. In the evaluated patients, Doppler did not miss any hemodynamically significant stenosis – instead over estimated 2 segments with hemodynamically insignificant stenosis resulting in false positivity. These patients had long segment disease in the proximal and mid part of SFA which resulted in monophasic flow in the distal SFA which was mistaken for hemodynamically significant stenosis in the distal part. Only the proximal part of Profunda femoris was evaluated in the study as the distal part and its branches were not accessible. Out of 68 segments evaluated, Doppler detected all hemodynamically significant stenosis. It also over estimated 6 segments with hemodynamically insignificant stenosis resulting in false positivity. These segments showed elevated peak systolic velocity due to compensatory increased flow through them to the distal leg when there is occlusion of SFA. As a result the specificity of Doppler in evaluating proximal profunda femoris was only 89.83%, while the sensitivity was 100%. In the popliteal artery, Doppler did not miss any hemodynamically significant stenosis - instead over estimated 2 segments with hemodynamically insignificant stenosis in those patients who had long segment disease in the proximal and mid part of SFA with resultant monophasic flow in the distal SFA which was mistaken for hemodynamically significant stenosis. The sensitivity and specificity of Doppler in evaluating popliteal artery was 100% and 92% respectively. The infra popliteal vessels were evaluated only for the presence or absence of flow with Doppler which was compared to the presence of opacification or non opacification of those vessels with contrast in CT angiography.
Doppler was not able to find flow in 7 anterior tibial arterial segments, 6 posterior tibial arterial segments, 13 peroneal arterial segments and 5 dorsalis pedis which opacified with contrast in CT angiography. These patients had occlusion of femoropopliteal region with reformation of the infrapopliteal vessels at their mid or distal part and it was difficult to find the reformation of these vessels as there were many collateral vessels seen in the leg. Although major arteries are accompanied by venae committant and not the collaterals it was still difficult to trace out the major vessels.

Interestingly, Doppler was able to pick up flow in those infrapopliteal vessels which were not opacified with contrast. In three patients with proximal significant stenosis, there was no opacification in the infrapopliteal vessels with the contrast, but Doppler was able to pick up monophasic flow. This could be because of different rates of crural vessel opacification, or inadequate opacification distal to an occlusion in CT angiography. This implies that when Doppler is used in conjunction with CT angiography, the false positive occlusions of CT angiography could be minimized.

Thus, the sensitivity of Doppler in evaluating aortoiliac segments, femoropopliteal segments and infrapopliteal segments were 87.5%, 100% and 75.32% respectively and specificity in evaluating aortoiliac segments, femoropopliteal segments and infrapopliteal segments were 100%, 96.01% and 83.06% respectively if CT angiography was taken as gold standard. The agreement between the two modalities in the evaluation of aortoiliac region and femoropopliteal region was very good, and of infrapopliteal vessels is only moderate.

### Table 5 showing the results of previous Doppler studies in evaluating lower limb arterial system

<table>
<thead>
<tr>
<th>NO. OF PATIENT</th>
<th>NO. OF SEGMENT</th>
<th>TRUE POSITIVE</th>
<th>FALSE POSITIVE</th>
<th>FALSE NEGATIVE</th>
<th>TRUE</th>
<th>SENSITIVITY</th>
<th>SPECIFICITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALY</td>
<td>90</td>
<td>404</td>
<td>27</td>
<td>34</td>
<td>2643</td>
<td>92.2</td>
<td>99</td>
</tr>
<tr>
<td>BERGAMINI</td>
<td>44</td>
<td>404</td>
<td>13</td>
<td>24</td>
<td>273</td>
<td>79.7</td>
<td>95.5</td>
</tr>
<tr>
<td>HATSUKAMI</td>
<td>29</td>
<td>243</td>
<td>6</td>
<td>12</td>
<td>152</td>
<td>85.8</td>
<td>96.2</td>
</tr>
<tr>
<td>LINKE</td>
<td>25</td>
<td>134</td>
<td>4</td>
<td>2</td>
<td>87</td>
<td>95.3</td>
<td>95.6</td>
</tr>
<tr>
<td>SENSIER</td>
<td>76</td>
<td>469</td>
<td>26</td>
<td>28</td>
<td>201</td>
<td>88.4</td>
<td>88.5</td>
</tr>
<tr>
<td>EL-KAYALI</td>
<td>44</td>
<td>357</td>
<td>15</td>
<td>3</td>
<td>216</td>
<td>97.6</td>
<td>93.5</td>
</tr>
<tr>
<td>LEGEMATE</td>
<td>61</td>
<td>918</td>
<td>30</td>
<td>33</td>
<td>676</td>
<td>84.4</td>
<td>95.8</td>
</tr>
<tr>
<td>THIS STUDY</td>
<td>34</td>
<td>807</td>
<td>41</td>
<td>21</td>
<td>522</td>
<td>91.39</td>
<td>92.71</td>
</tr>
</tbody>
</table>

Interestingly, Doppler was able to pick up flow in those infrapopliteal vessels which were not opacified with contrast. In three patients with proximal significant stenosis, there was no opacification in the infrapopliteal vessels with the contrast, but Doppler was able to pick up monophasic flow. This could be because of different rates of crural vessel opacification, or inadequate opacification distal to an occlusion in CT angiography. This implies that when Doppler is used in conjunction with CT angiography, the false positive occlusions of CT angiography could be minimized.

Thus, the sensitivity of Doppler in evaluating aortoiliac segments, femoropopliteal segments and infrapopliteal segments were 87.5%, 100% and 75.32% respectively and specificity in evaluating aortoiliac segments, femoropopliteal segments and infrapopliteal segments were 100%, 96.01% and 83.06% respectively if CT angiography was taken as gold standard. The agreement between the two modalities in the evaluation of aortoiliac region and femoropopliteal region was very good, and of infrapopliteal vessels is only moderate.

Table 5 showing the results of previous Doppler studies in evaluating lower limb arterial system

Earlier studies evaluating color Doppler imaging have shown varying degrees of sensitivity and specificity. We have observed a similar trend in our result as shown in table 5. This study showed various advantages of Doppler over CT angiography. When extensive calcifications are present in the vessel, the end product of CT angiography is of questionable diagnostic value as it overstates the lesion. Doppler is able to demonstrate this overstaging of MDCT by showing that the calcific plaque which appears to have produced more than 50% stenosis has actually not resulted in hemodynamically significant stenosis. Doppler is able to demonstrate flow in those infrapopliteal vessels where CT shows no opacification with contrast due to proximal significant stenosis. It is also able to demonstrate the nature of plaque—whether calcific or soft plaque. Soft plaques were better demonstrated with ultrasound than with CT. It is able to show the duration of occlusion—as acute thrombus distends the vessels while chronic occlusion narrows the vessel caliber. 1 patient had traumatic injury of right SFA and Doppler showed complete occlusion of the proximal and mid SFA with thrombus with distal monophasic flow. Although the occlusion was demonstrated in CT angiography the distension of the vessel with thrombus was not demonstrable in CT because of its lack of soft tissue resolution. There is no hazard of radiation with Doppler, while the mean effective dose of radiation delivered to a patient in a single study with CT angiography is 12-14 mSv. Since no iodinated contrast is required, it is safely performed in patients with renal failure (these patients were excluded from the study in whom Doppler alone was done to evaluate the lowerlimb arteries).
Doppler could be performed in cases of emergencies like traumatic / iatrogenic injuries to rule out arterial obstruction at any time, while CT angiography is not easily available at all the time and is available only at apex institutions. Doppler is also cost effective when compared to CT angiography.

VIII. CONCLUSION

Duplex Ultrasound provides high-resolution, precise anatomical and physiological information of the peripheral arteries. It is unlikely to misclassify a whole limb as “normal” and thus inappropriately screen out a patient from further investigation. Duplex Ultrasound was found to have a high negative predictive value and could exclude a significant lesion, thus helping to avoid other costly diagnostic modalities in a mildly symptomatic patient. It could determine the nature and extent of arterial disease based on which treatment can be planned, either endovascular or surgical. It may also determine the significance of equivocal lesions identified by MDCT angiography. Combination of Duplex Ultrasound with MDCT angiography has better diagnostic accuracy. Thus, Duplex Ultrasound is a safe, inexpensive, non-invasive, easily available diagnostic tool with high diagnostic accuracy and is indispensable in the investigation of peripheral arterial disease.

ACKNOWLEDGMENT

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REFERENCES


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