A Guideline Protocol for the Assessment of Aortic Stenosis, Including Recommendations for Echocardiography in Relation to Transcatheter Aortic Valve Implantation

From the British Society of Echocardiography Education Committee

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1. Introduction

1.1 The BSE Education Committee has recently published a minimum dataset for a standard adult transthoracic echocardiogram, available on-line at www.bsecho.org. This document specifically states that the minimum dataset is usually only sufficient when the echocardiographic study is entirely normal. The aim of the Education Committee is to publish a series of appendices to cover specific pathologies to support this minimum dataset.

1.2 The intended benefits of such supplementary recommendations are to:

- Support cardiologists and echocardiographers to develop local protocols and quality control programs for adult transthoracic study;
- Promote quality by defining a set of descriptive terms and measurements, in conjunction with a systematic approach to performing and reporting a study in specific disease-states;
- Facilitate the accurate comparison of serial echocardiograms performed in patients at the same or different sites.

1.3. This document gives recommendations for the image and analysis dataset required in patients being assessed for aortic stenosis. Echocardiography has become the standard method for evaluating aortic stenosis severity. Other methods such as cardiac catheterisation are not routine except where the data is non-diagnostic or discrepant with clinical data.

Although the standard method for evaluation of aortic stenosis, there are a number of situations in which data from echocardiography may at first appear inconsistent. If dealt with in a structured fashion, many of these inconsistencies may be reconciled and important information gained to assist patient management. A structured approach is outlined in Appendix 1.

Management of aortic stenosis has been altered by the availability of transcatheter aortic implantation as an alternative treatment for those at high risk or excluded from conventional surgery. Given the central role of echocardiography before, during and after implantation of these devices, there is a further Appendix (2) relating specifically to assessment for transcatheter aortic valve implantation.

1.4. The views and measurements are supplementary to those outlined in the minimum dataset and are given assuming a full study will be performed in all patients.

1.5 When the condition or acoustic windows of the patient prevent the acquisition of one or more components of the supplementary Dataset, or when measurements result in misleading information (e.g. off-axis measurements) this should be stated.

1.6 This document is a guideline for echocardiography in the assessment of aortic stenosis and will be up-dated in accordance with changes directed by publications or changes in practice.
<table>
<thead>
<tr>
<th>VIEW</th>
<th>Modality</th>
<th>Measurement</th>
<th>Explanatory note</th>
<th>Image</th>
</tr>
</thead>
<tbody>
<tr>
<td>PLAX</td>
<td>2D</td>
<td>Cusps viewed</td>
<td>NCC/RCC</td>
<td><img src="image1.jpg" alt="Bicuspid AV with asymmetric closure line" /></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cusp anatomy</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Appearance</td>
<td>Systolic doming/asymmetric closure line (?bicuspid). Commissure fusion (?rheumatic).</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>Mobility</td>
<td>Degree of restriction grade as: mild = restricted motion at basal 1/3 adjacent to hinge only, moderate = base + body (middle third), severe = base + body + free edge (distal 1/3)</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>Thickening</td>
<td>Mild/moderate/severe</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Calcification</td>
<td>Describe severity: mild/mod/severe mild = small isolated spots; moderate = multiple larger spots; severe = heavily calcified, extensive thickening and calcification of all cusps.2 Location and extent: - AV cusps- free edge, body, base (point of insertion). - LVOT, annulus, aortic wall, aortic root, ascending aorta.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Measurements</td>
<td>As per min dataset, performed at similar level as LVOT PW Doppler velocity trace obtained from either 5CV or 3CV, see below. [Zoom mode, mid systole, min 3 beats (5 if AF) measure inner edge to inner edge]</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>LVOT</td>
<td>Zoom mode; Measure from cusp hinge points (at point of cusp insertion into wall), ignoring all calcification. Measure maximum dimension where seen best in cardiac cycle (see notes 3)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Annulus</td>
<td>Try to obtain symmetrical aortic root sinuses with ascending aorta not foreshortened. Measure maximum diameter where seen best in cardiac cycle. Inner edge-inner edge (blood tissue interface).</td>
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<tr>
<td></td>
<td></td>
<td>Aortic Root</td>
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<td></td>
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<tr>
<td></td>
<td></td>
<td>Ascending aorta</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| PSAX, AV level | Colour Doppler | (AV level, above, below) AR jet | Ensure turbulent flow as expected at valve level. If below ?LVOT obstruction  
(See regurgitation quantification guidelines) |
<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>2D</td>
<td>Cusps viewed</td>
<td>NCC/RCC/LCC</td>
<td>Cusp anatomy Mobility/thickening/calcification (as above)</td>
</tr>
</tbody>
</table>
|               | Number of cusps | Bicuspid (elliptical systolic orifice with 2 commissures) 4  
If possible, state which leaflets are not separated. |
|               | Calcification | Distribution Note: location and extent (as above) |
|               | AV level | AV cusps- free edge, body, insertion |
|               | LVOT | Sweep above and below AV -Protrusion of calcification into outflow tract below level of annulus.  
-Aortic wall, extension into lumen, size. |
|               | Aortic Root | 2D planimetry Not recommended as routine measure, since 'effective' rather than 'anatomic' orifice is primary predictor of outcome.  
-Acceptable alternative when Doppler estimation is unreliable (e.g coexisting LVOT obstruction)  
-If performed must ensure minimum orifice identified, i.e. usually at the tips. 3D will assist in optimising this measurement |
|               | Ascending aorta | As above |

<table>
<thead>
<tr>
<th>A5CV</th>
<th>Colour Doppler</th>
<th>Turbulent flow (AV level, above, below) AR jet</th>
<th>general observation</th>
</tr>
</thead>
<tbody>
<tr>
<td>2D</td>
<td>Cusp anatomy Mobility/thickening/calcification</td>
<td>Sample volume positioned just at level of AV annulus and moved carefully into the LVOT if necessary, until laminar flow curve obtained i.e. smooth velocity curve with narrow band, well defined peak. (Typically 0.5-1.0cm from AV annulus in calcific AS; AV annulus level in bicuspid AS). Trace around outer signal</td>
<td></td>
</tr>
</tbody>
</table>

No turbulent flow seen below or above the AV level

tricuspid AV

Bicuspid AV with elliptical orifice
<table>
<thead>
<tr>
<th>CW</th>
<th>AV Vmax/VTI</th>
<th>Maximum velocity obtained should be reported. Trace around outer signal. Repeat in multiple acoustic windows in order to document maximum velocity (see below). Shape of signal useful in ΔΔ -severe stenosis: rounded shape, peak in mid systole -mild stenosis: triangular, peak in early systole Measurements: Max AV velocity Mean AV gradient AVA (Continuity equation) Additional useful measurements: VTI ratio or velocity ratio (dimensionless index)5Severe &lt; 0.25</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colour Doppler</td>
<td>Turbulent flow (AV level, above, below) AR jet</td>
<td>As above</td>
</tr>
</tbody>
</table>

Aortic stenosis with no LVOT obstruction; no turbulent flow in outflow tract

Turbulent flow seen within outflow tract; LVOT obstruction.

<table>
<thead>
<tr>
<th>A3CV</th>
<th>2D</th>
<th>Cusps viewed</th>
<th>NCC/RCC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Doppler</td>
<td>Cusp anatomy Mobility/appearance/calcification</td>
<td>} general Observation</td>
<td></td>
</tr>
<tr>
<td>Colour Doppler</td>
<td>Turbulent flow (AV level, above, below) AR jet</td>
<td>as above</td>
<td></td>
</tr>
<tr>
<td>General considerations</td>
<td>AS severity</td>
<td>Max velocity, mean gradient, AVA (report window where maximum velocity obtained). When AV parameters are discordant see appendix 1</td>
<td></td>
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<tr>
<td>------------------------</td>
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<tr>
<td></td>
<td>AS aetiology</td>
<td>Where possible comment on most likely cause (e.g. rheumatic, degenerative, congenital/bicuspid)</td>
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<tr>
<td></td>
<td>AR severity</td>
<td>See regurgitation quantification guidelines (consider effects on velocity measurements)</td>
<td></td>
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<tr>
<td></td>
<td>Aortic dimensions</td>
<td>Dilatation associated with AVD/bicuspid. May indicate need for early surgery. Also exclude aortic coarctation.</td>
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<tr>
<td></td>
<td>LVEF</td>
<td>See chamber quantification guidelines</td>
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<td></td>
<td>LV hypertrophy</td>
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<td></td>
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<tr>
<td></td>
<td>LA size</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>RV size and function</td>
<td>Affects operative risk</td>
<td></td>
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<tr>
<td></td>
<td>TR</td>
<td>Severity</td>
<td></td>
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<tr>
<td></td>
<td>PAP</td>
<td>Affects operative risk and prognosis</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Other valve disease</td>
<td>?Mitral valve surgery in addition MR, functional versus degenerative disease</td>
<td></td>
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<tr>
<td></td>
<td>BP recorded</td>
<td>Index values as appropriate</td>
<td></td>
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<tr>
<td></td>
<td>BSA recorded</td>
<td></td>
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<tr>
<td>Possible TOE indications</td>
<td>Indeterminate AS severity</td>
<td>poor imaging</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>AV annulus sizing/TAVI assessment (see appendix 2)</td>
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</tr>
</tbody>
</table>

**AV in short axis**

**Hunt for maximum AV velocity**

See PSAX section

Document in report which window maximum velocity obtained
Appendix 1: DISCREPANCIES IN PARAMETERS OF AORTIC STENOSIS SEVERITY

Discrepancies in aortic valve (AV) parameters may occur in up to 25% of cases. The evidence base is not complete. However, the BSE Education committee would like to provide guidance in this clinical scenario. The following is a possible approach to imaging such cases.

Emphasis is placed on assessment of AV anatomy and cusp mobility. Colour flow imaging can help judge approximate orifice size. TOE may be indicated if doubt remains.

Discrepancies in these parameters can be broadly divided into three categories. Before proceeding, ensure you are satisfied the measurements are accurate. Run through the checklist below. Then make some additional calculations where relevant and decide which category the discrepancies in AV parameters belong (1-3).

Therefore:

A. Checklist: ensure measurements correct

- LVOT diameter: compare with previous, is LVOT measurement accurate? Does resolution allow accurate measurement? Sigmoid septum causing LVOT to be non-circular? Remember small error is LVOT diameter result in moderate AS becoming severe on calculations e.g. diameter 2.1 = AVA 1.1cm²; 1.9 = AVA 0.9cm²; while diameter 1.8 = AVA 0.8cm².
- LVOT PW Doppler: has the sample volume been placed at correct level and correct distance from AV, where laminar flow is obtained?
- AV CW Doppler: is AV CW Doppler profile consistent? Ensure not mitral regurgitation signal!!
- Dimensionless index (DI) or velocity ratio: severe <0.25. Although a useful additional measure, by removing the potential inaccuracies of LVOT measurement, remember that it ignores inaccuracies due to abnormal LVOT anatomy e.g. isolated basal hypertrophy. Hence, its particular use is in the setting of serial measurements within the same individual or when assessing prosthetic valves, especially where the size of the valve is unknown.

B. Calculate additional parameters where relevant

- AVA indexed for BSA (AVA_i); severe <0.6cm²/m²
- SV indexed for BSA (SV_i); low flow <35ml/m²
  Either by continuity eqn / LV volumes 2D or 3D
- Impedance (valvulo-arterial), Zva significantly increased> 5.5mmHg/ml/m²

Reflects the global LV haemodynamic load, i.e. the double afterload on LV from the stenosed AV and from the vascular system (systemic arterial compliance and systemic vascular resistance):

\[ Zva \text{ calculated as } = \text{mean AVG + systolic BP} \]
\[ SV_i \]

Degenerative aortic stenosis (AS) may be associated with a reduction in systemic arterial compliance due to rigid arterial vessels. This is clinically manifested as systolic hypertension. This additional arterial afterload results in underestimation of AS severity; a greater proportion of such patients may not be referred appropriately and in a timely manner for surgery. This is typically seen in patients with low flow-low gradient severe AS in the setting of normal LVEF or in patients with presumed moderate AS with symptoms.

C. Discrepancies in these parameters can be broadly divided into three categories

1. AVA suggests severe AS, but max velocity and mean AV gradient (AVG) do not.
   i.e. AVA <1.0 cm²
   - max velocity < 4.0 m/s
   - mean AVG < 40mmHg
   a) Impaired LV function (LVEF <40%): differential diagnosis will either be
      - truly severe AS or
      - moderate (or less severe) AS with poor valve opening due to poor cardiac output

Step 1: Confirm measurements are correct (LVOT diameter, LVOT PWD, AV CWD)

Step 2: Ensure the anatomy of the AV correlates with severity (including degree of calcification and cusp mobility). Exclude concomitant mitral valve disease.

Step 3: Consider low dose dobutamine stress echocardiography to determine severity of aortic stenosis.
- start dobutamine infusion at 5mcg/kg/min to a maximum 20mcg/kg/min
- test terminated when LVOT VTI or stroke volume increases >20% and/or HR increases >10-20 beats/min (or significant-symptoms/ LV RWMA/arrhythmias occur)
- contractile reserve is present if LVOT VTI or stroke volume increase by 20%
- AS is: severe when AVA remains <1.0 and/or mean AVG increases >40
  pseudosevere (moderate or less) when AVA increases >1.0 and or mean AVG remains <40
- if no contractile reserve (no change in SV) and no change in AVA and mean AVG, then unable to comment on severity of AS
- if doubt remains then TOE may be necessary to assess AV anatomy (3D may be very useful)

b) LV function is normal: differential diagnosis will be
- low flow severe AS or
- moderate or less severe AS for that individual i.e. smaller body habitus

Step 1: Confirm measurements are correct (LVOT diameter, LVOT PWD, AV CWD)
Step 2: Ensure the anatomy of the AV correlates with severity (including degree of calcification and cusp motion)
Step 3: Calculate AVA index (AVAi), SV index (SVi) and Valvular-arterial Impedance (Zva)
  - if AVAi is >0.6 then re-evaluate patient body size and consider if less than severe AS in setting of a smaller individual.
  - if SVi <35 and/or Zva >5.5, then consider low flow severe AS with normal LVEF.
    Look for corroboratory evidence; LVH, raised LV wall thickness to radius ratio, small LV cavity, diastolic dysfunction

2. AVA does not suggest severe AS, but max velocity and mean AV gradient(AVG) do
i.e. AVA >1.0 cm²
  max velocity > 4.0 m/s
  mean AVG > 40mmHg

Differential diagnosis will be either
- the AVA is correct and there is moderate (or less severe) AS with high flow states or
- truly severe AS for that individual i.e. larger body habitus

Step 1: Confirm measurements are correct (LVOT diameter, LVOT PWD, AV CWD)
Step 2: Ensure the anatomy of the AV correlates with severity (including degree of calcification and cusp mobility)
Step 3: Calculate AVA index (AVAi) and SV and CO
  - if SV and CO are raised, consider non-severe AS with high flow states. Hence look for other causes e.g. severe aortic regurgitation, haemodialysis/A-V fistula, anaemia
  - if AVAi is <0.6, consider severe AS in setting of a taller individual (usually height >185cm).

3. Moderate aortic stenosis but the patient is symptomatic
Differential diagnosis will either be:
- AS severity is under-estimated due to hypertension (pressure difference between LV and Ao).
- AS is significant for this particular individual (consider functional/exercise testing)
- AS is truly moderate and there are other causes for breathless/symptoms; consider pulmonary disease/ coronary artery disease/anaemia/obesity

Step 1: Confirm measurements are correct (LVOT diameter, LVOT PWD, AV CWD)
Step 2: Ensure the anatomy of the AV correlates with severity (including degree of calcification and cusp motion)
Step 3: Ensure measurement of BP at time of echo study.
Step 4: Calculate AVAi and SVi and Zva
Step 5: consider exercise/functional testing (BNP may be useful)
Step 6: consider other investigations for other causes
**APPENDIX 2: TOE for TAVI assessment: specific considerations additional to TOE minimum dataset**

Please note: information on current TAVI valves is given, however new products are continually under development and the reader should consult with company literature with regards to current valve sizes and annulus sizes.

<table>
<thead>
<tr>
<th>VIEW</th>
<th>Modality</th>
<th>Measurement</th>
<th>Explanatory note</th>
<th>Image</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guide angle</td>
<td>2D</td>
<td>Anatomy</td>
<td>Number of cusps; bicuspid may be a relative contra-indication</td>
<td>Tricuspid AV</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Distribution of calcification</td>
<td></td>
<td>Bicuspid AV</td>
</tr>
<tr>
<td></td>
<td></td>
<td>AV</td>
<td>Protrusion of calcification into outflow tract below level of annulus; above in Ao root, aortic wall, extension into lumen,</td>
<td>Examples of AV annulus measurements</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LVOT Aortic Root Ascending aorta</td>
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<tr>
<td></td>
<td></td>
<td>Coronary ostia</td>
<td>LMS/RCA-could calcification impinge on coronary ostia?</td>
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<tr>
<td>SAX AV (guide 40-600)</td>
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<tr>
<td>Sweep above and below AV</td>
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<tr>
<td>Measurements: Annulus</td>
<td></td>
<td>Aim for symmetrical aortic root sinuses with ascending aorta not foreshortened</td>
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<tr>
<td></td>
<td></td>
<td>Measure maximum diameter where seen best in cardiac cycle. Measure from cusp hinge points (at point of cusp insertion into wall) and ignoring calcification May need to change level of probe within oesophagus or rotated to show RCC insertion point (if covered by echo drop out from heavy calcification)</td>
<td></td>
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<td></td>
<td>EDWARDS 23: 18-22mm 26: 21-25mm 29: 24-27mm</td>
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<td></td>
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<tr>
<td></td>
<td></td>
<td>CORVALVE 23: 17- 20mm 26: 20-23mm 29: 23-27mm 31: 26-29mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LAX AV (guide 120-1500)</td>
<td></td>
<td>Aortic Root Ascending aorta</td>
<td>Measure maximum diameter where seen best in cardiac cycle. Inner edge-inner edge (blood tissue interface) EDWARDS although no specific measurements given consideration should be given to smaller aortic root as increased risk for complications e.g root rupture CORVALVE 26:SoV width &gt;27mm SoV height &gt;15mm STJ ≤40mm</td>
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</tbody>
</table>
### Septal Bulge

- Measure height from peak bulge of septum (in systole) to AV annulus level.
- EDWARDS ≥8mm required.
- COREVALVE septum dimension should be ≤17mm; if >17mm at increased risk of complications (in diastole).

### Calcification

- Describe distribution, location and extent.
- AV cusps: free edge, body, insertion point, commissures.
- Aortic wall: include LVOT, level of annulus, aortic root, ascending aorta.

#### Specific

1. Solid sheet extending from free edge all the way into annulus insertion into wall — this suggests rigid cusp with risk that cusp will not hinge open.
2. Large ‘lumps’ of calcification in LVOT (with tendency to displace AV prosthesis upwards during deployment) or in aortic root (with tendency to displace AV prosthesis downwards during deployment).

### 3D Imaging

3D imaging may offer useful additional information.

<table>
<thead>
<tr>
<th>3D</th>
<th>Live/zoom mode</th>
<th>and/or x-plane</th>
<th>Anatomy</th>
<th>LVOT</th>
<th>AV</th>
<th>aorta</th>
</tr>
</thead>
</table>

- Can be performed in SAX and LAX planes where AV and surrounding structures (LVOT/Ao) are seen.
- Further clarify number of cusps.
- Distribution of calcification. above/below and at valve level.
- Symmetry of annulus useful predictor of risk of paravalvular AR.

### 3D Imaging

Solid ‘sheet’ of calcification RCC of AV.
Measurements:

AV annulus
Using 3D is possible however please note reference measurement is 2D long axis view (usually TOE).

Use multiplane reconstruction in to facilitate multiple annulus measurements (not just sagittal and coronal planes). Use maximum and minimum measurements to obtain an average annulus size. If the annulus is too elliptical, this is a relative contra-indication., suggested guide EDWARDS if > 1.2-1.3:1 then increased risk of complications

Coronary ostia height
Measure level of RCA and LMS ostia from annulus

EDWARDS ≥10mm
CORVALVE ≥14mm

References

2. Rosenhek et al. N Engl J Med (2000) 343; 611-7. Predictors of outcome in asymptomatic, severe aortic stenosis. Calcification of the aortic valve is scored as follows: 1, no calcification; 2, mildly calcified (small isolated spots); 3, moderately calcified (multiple larger spots); and 4, heavily calcified (extensive thickening and calcification of all cusps).
3. Measure widest diameter at any point in cardiac cycle. There is no published evidence as to the ideal time point in the cardiac cycle when measurement should be made.
5. Good correlation seen between velocity ratio and velocity time integral ratio. Hence either may be used