# EVALUATION OF SYSTOLIC HYPERTENSION IN THE PEDIATRIC POPULATION: A CARDIOLOGIST PERSPECTIVE

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# Objectives

- Review of AAP Key Action Statements (cardiac perspective)
- Understand the potential **cardiac <u>etiologies</u>** of hypertension
- Understand the **cardiac <u>consequences</u>** of chronic hypertension
- Understand which patients require **activity restriction** while promoting regular exercise and overall cardiovascular health

# AAP Key Action Statements (KAS) (“Clinical Practice Guideline for Screening and Management of High Blood Pressure in Children and Adolescents”)

- KAS-7: Routine performance of ABPM should be strongly considered in children and adolescents with high-risk conditions (see Table 12) to assess HTN severity and determine if abnormal circadian BP patterns are present, which may indicated increased risk for target organ damage
- KAS-12: Children and adolescents who have undergone coarctation repair should undergo ABPM for the detection of HTN (including MH)
- KAS-14: Clinicians should not perform electrocardiography in hypertensive children and adolescents being evaluated for LVH.

# AAP Key Action Statements

- KAS-15:
- 15-1: It is recommended that echocardiography be performed to assess for cardiac target organ damage (LV mass, geometry, and function) at the time of consideration of pharmacologic treatment of HTN.
- 15-2: LV hypertrophy should be defined as LV mass > 51g/m2.7 (boys and girls) for children and adolescents older than age 8 years and defined by LV mass > 115g/BSA for boys nd LV mass > 95g/BSA for girls
- 15-3: Repeat echocardiography may be performed to monitor improvement or progression of target organ damage at 6-12 month intervals. Indications to repeat echocardiography include persistent HTN despite treatment, concentric LV hypertrophy or reduced LV ejection fraction.
- 15-4: In patients without LV target organ injury at initial echocardiographic assessment, repeat echocardiography at yearly intervals may be considered in those with Stage 2 HTN, secondary HTN, or chronic stage 1 HTN incompletely treated (noncompliance or drug resistance), to assess for the development of worsening LV target organ injury.

# AAP Key Action Statements

- KAS-20: At the time of diagnosis of elevated BP or HTN in a child or adolescent, clinicians should provide advice on the DASH diet and recommend moderate to vigorous physical activity at least 3-5 days per week (30-60 min per session) to help reduce BP.
- KAS-28: Children and adolescents with HTN may participate in competitive sports once hypertensive target organ effects and cardiovascular risk have been assessed.
- KAS-29: Children and adolescents with HTN should receive treatment to lower BP below Stage 2 thresholds before participation in competitive sports.

# BP Measurement – Key Points:
# WHY

- HTN is truly a "silent killer" and early detection is vital
  - Increased risk for CVD, stroke, MI, etc.
- Elevated BP in childhood increases the risk of adult HTN and metabolic syndrome
- Higher incidence of accelerated vascular aging (confirmed with autopsy reports and cardiovascular imaging – increased LV mass, cardiac intimal-media thickness, etc)
- 1 in 3 US adults have HTN which is a major contributor to CVD
  - Adult CVD likely has it's origins in childhood
    - Extrapolated date from intravascular imaging in Kawasaki pts
  - Almost ½ of US teenagers have elevated BMI
  - < ½ of school-aged boys and < 1/3 of school-aged girls meet the goal for physical activity levels

# BP Measurement – Key Points: WHO/WHEN

- **<u>All</u>** children and adolescents >= 3 years of age
  - Annually, or …
  - At every clinic visit if …
    - Obesity (BMI > 95%)
    - Taking medications known to increase BP
      - Decongestants, stimulants, caffeine, NSAID's, TCA's, steroids, ilicit drungs (cocaine, amphetamine)
    - Renal disease
    - Cardiac disease (history of aortic arch obstruction or coarctation)
    - Diabetes

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# BP Measurement – Key Points: WHO/WHEN

- Children < 3 y/o …
  - History of prematurity (< 32wks GA, SGA, VLBW, hx of UA line)
  - CHD
  - Renal disease, recurrent UTI
  - Transplant recipients (solid organ or BMT)
  - Treatment with drugs known to raise BP
  - Systemic illness (NF, TS, SSA)
  - Neurologic disease, increased intracranial pressure

# BP Measurement – Key Points:
# WHEN - followup

**TABLE 11** Patient Evaluation and Management According to BP Level

| BP Category (See Table [illegible]) | BP Screening Schedule | Lifestyle Counseling (Weight and Nutrition) | Check Upper and Lower Extremity BP | ABPM[a] | Diagnostic Evaluation[b] | Initiate Treatment[c] | Consider Subspecialty Referral |
|---|---|---|---|---|---|---|---|
| Normal | Annual | X | — | — | — | — | — |
| Elevated BP | Initial measurement | X | — | — | — | — | — |
| | Second measurement: repeat in 6 mo | X | X | — | — | — | — |
| | Third measurement: repeat in 6 mo | X | — | X | X | — | X |
| Stage 1 HTN | Initial measurement | X | — | — | — | — | — |
| | Second measurement: repeat in 1–2 wk | X | X | — | — | — | — |
| | Third measurement: repeat in 3 mo | X | — | X | X | X | X |

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# BP Measurement – Key Points: WHEN - followup

**TABLE 11** Patient Evaluation and Management According to BP Level

| BP Category (See Table 3) | BP Screening Schedule | Lifestyle Counseling (Weight and Nutrition) | Check Upper and Lower Extremity BP | ABPM[a] | Diagnostic Evaluation[b] | Initiate Treatment[c] | Consider Subspecialty Referral |
|---|---|---|---|---|---|---|---|
| Stage 2 HTN[d] | Initial measurement | X | X | — | — | — | — |
| | Second measurement: repeat, refer to specialty care within 1 wk | X | — | X | X | X | X |

X, recommended intervention; —, not applicable.

[a] ABPM is done to confirm HTN before initiating a diagnostic evaluation.

[b] See Table 15 for recommended studies.

[c] Treatment may be initiated by a primary care provider or subspecialist.

[d] If the patient is symptomatic or BP is >30 mm Hg above the 95th percentile (or >180/120 mm Hg in an adolescent), send to an ED.

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# BP Measurement – Key Points:
# WHAT

- Defining HTN
  - **Auscultatory**-confirmed (oscillometric readings for screening)
  - >= 95%
  - 3 different clinical visits

# BP Measurement – Key Points: HOW - Technical considerations

- BP in childhood may vary considerably between visits and even during the same visit. BP generally decreases with repeated measurement during a single visit
  - If the initial BP is elevated (>90%), take 2 additional oscillometric or auscultatory measurements at the same visit and take the average
- <u>KAS-10</u>: Home BP monitoring should <u>*not*</u> be used to diagnosed HTN, MH, or WCH, but may be a useful adjunct to office and ambulatory BP measurements <u>*after*</u> HTN has been diagnosed

# BP Measurement – Key Points:
# HOW - Technical considerations

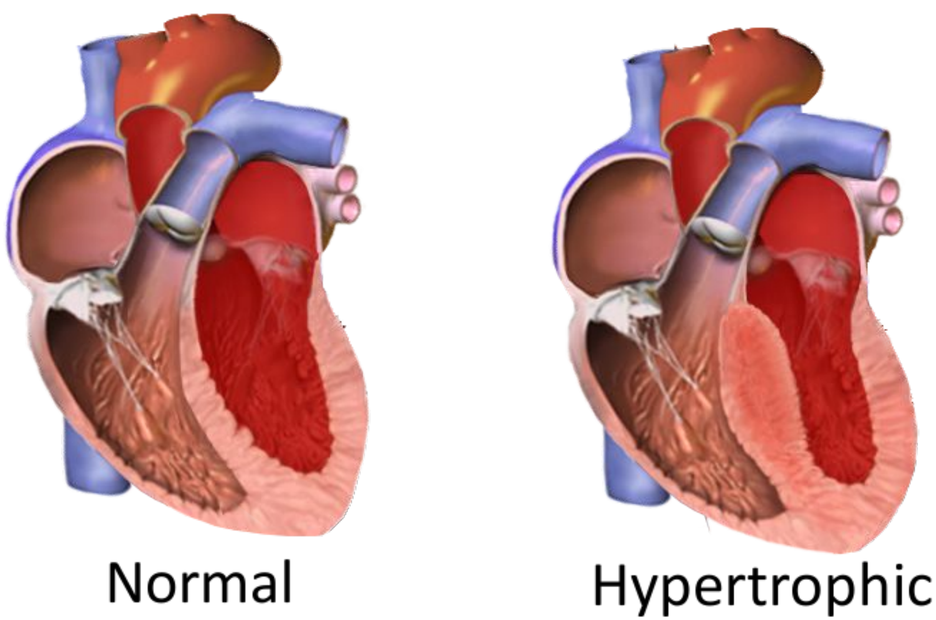
- BP should be measured in the **right arm** unless the child has atypical aortic arch anatomy (ie, left aortic arch with an aberrant right subclavian artery, right aortic arch with coarctation)
- BP cuffs must exhibit proper size (for patient age/body habitus) and placement

# 1. Cardiac Etiologies of Hypertension

- Hypertrophic cardiomyopathy
- Left heart obstructive lesions
  - Aortic valve stenosis
  - Supravalvar aortic stenosis
  - **Coarctation of the aorta**

# Hypertrophic Cardiomyopathy

- Pathologic hypertrophy secondary to intrinsic myocardial/myofibrlllar disarray
- Hyperdynamic systolic function  Systolic HTN



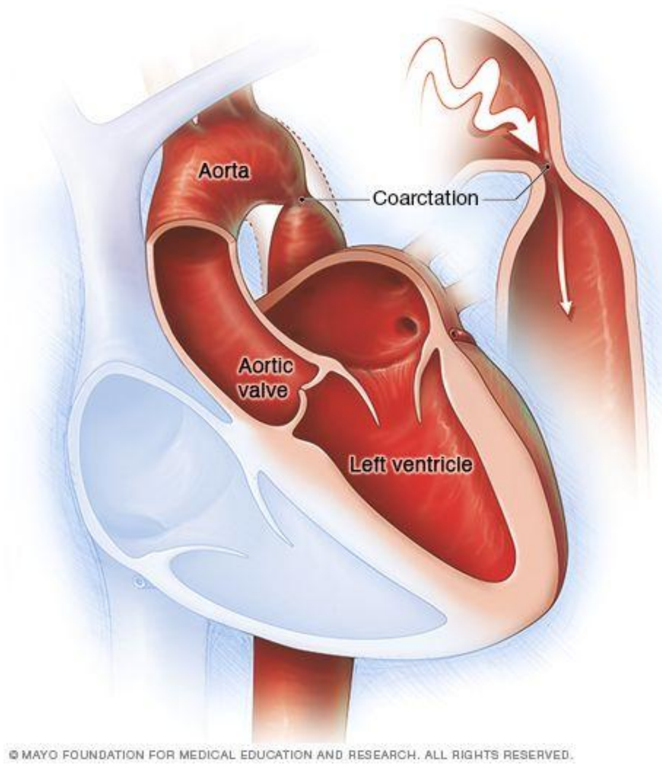
# Coarctation of the Aorta - Presentation

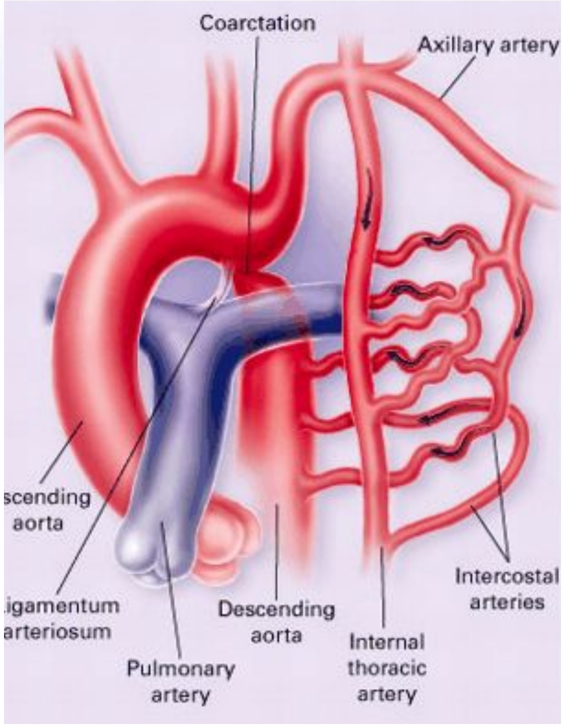
- Clinical: presentation depends on severity and age
  - Juvenille (childhood through adolescence): usually asymptomatic though associated with systolic HTN and 20mmHg upper/lower extremity BP gradient
  - Infantile:
    - May present as above – asymptomatic though associated with systolic HTN and 20mmHg upper/lower extremity BP gradient
    - May present with lethargy, shock (ie, critical coarctation)
  - Murmurs may or may not be present depending upon the degree of coarctation (and age at presentation)
    - Typically associated with a harsh murmur along the left upper/mid sternal border, though severe coarctation may not manifest with a murmur once bypass collaterals develop

# Coarctation of the Aorta - Anatomy

- Coarctation anatomy
  - Localized: discrete, isolated narrowing, typically at the aortic “isthmus” (site of embryologic insertion of the ductus arteriosus)
  - “Long-segment”: diffuse hypoplasia, most often of the transverse aortic arch and isthmus
    - More common when other cardiac morbidities involved
  - Abdominal coarctation: rare, though plausible in von-recklinghausen neurofibromatosis, Williams syndrome, Alagille syndrome, Takayasu arteritis

# Coarctation of the Aorta - Anatomy




- Coarctation (juvenile vs neonatal)
  - High velocity shunt (high pressure gradient)
  - High frequency, harsh
  - LUSB
  - Radiation to the back
  - Severe CoA with collaterals – No murmur!

# Coarctation of the Aorta - Repair

- General considerations
  - Timing and nature of repair depends on age, anatomy, severity
  - Infants, young children: surgical repair remains the gold standard
  - Older children/adolescents: catheterization – balloon angioplasty/stent implantation

- Surgical approach
  - Subclavian flap repair
    - Use caution in measuring/interpreting upper extremity BP’s
  - Extended end to end anastomosis
  - Arch patch augmentation (ie, long-segment hypoplasia)

# Coarctation of the Aorta - Post repair

- HTN after coarctation repair
  - Recurrent HTN due to recurrent coarctation
  - HTN without recurrent coarctation
    - Patients can remain hypertensive or develop HTN even after early and successful repair (17-77%)
      - Early: adrenergic output (beta blockers commonly used postop)
      - Late: surgical scarring
- "Masked HTN" (MH)
  - Children who have undergone coarctation repair may have normal in-office BP but high BP out of the office.
    - 45% of children with CoA have MH 1-14 years post repair
      - Risk for LVH, HTN, MH
  - ABPM: now the gold standard for diagnosing HTN in this population
    - Annual, starting approximately 12 years post repair

# Coarctation of the Aorta

- KAS-7: Routine performance of ABPM should be strongly considered in children and adolescents with high-risk conditions (see Table 12) to assess HTN severity and determine if abnormal circadian BP patterns are present, which may indicated increased risk for target organ damage
- KAS-12: Children and adolescents who have undergone coarctation repair should undergo ABPM for the detection of HTN (including MH)

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# 2. Cardiac Consequences of (chronic) Hypertension (cHTN)

- Screening/assessment of cardiac end-organ injury
- ECG: high specificity but poor sensitivity for LVH in children. The positive predictive value of ECG’s for detection of LVH is low
  - KAS-14: Clinicians should not perform electrocardiography in hypertensive children and adolescents being evaluated for LVH.
- Echocardiography: gold standard for evaluation of cardiac **causes** and **consequences** of HTN

# Cardiac Consequences of cHTN

- Why does it matter?
  - Well-defined/strong relationship between LVH and adverse CVD outcomes in adults
  - A significant % of children/adolescents with HTN have significant enough LVH to manifest those adverse long-term outcomes
  - Anti-hypertensives reduce LVH

# AAP Key Action Statements

- KAS 15-1: It is recommended that **echocardiography be performed to assess for cardiac target organ damage** (*LV mass, geometry, and function*) at the time of consideration of pharmacologic treatment of HTN.
- KAS 15-2: LV should be defined as **LV mass > 51g/m2.7** (boys and girls) for children and adolescents older than age 8 years and defined by **LV mass > 115g/BSA for boys** or **LV mass > 95g/BSA for girls**
- KAS 15-3: **Repeat echocardiography** may be performed to **monitor improvement or progression of target organ damage at *6-12 month intervals***. Indications to repeat echocardiography include persistent HTN despite treatment, concentric LV hypertrophy or reduced LV ejection fraction.
- KAS 15-4: In patients without LV target organ injury at initial echocardiographic assessment, **repeat echocardiography yearly intervals** may be considered in those with Stage 2 HTN, secondary HTN, or chronic stage 1 HTN incompletely treated (noncompliance or drug resistance), to assess for the development of worsening LV target organ injury.

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# Role of Echocardiography in HTN

- Why: assess for cardiac cause and/or cardiac consequence (target organ damage) of HTN
  - LV mass, geometry, and function.
- When: when considering pharmacologic treatment
- How often:
  - Q6-12mo: monitor improvement or progression of **target organ damage**
    - persistent HTN despite Rx, concentric LV hypertrophy or reduced LV ejection fraction
  - Q12mo: patients **without** LV target organ injury at initial echo but …
    - Stage 2 HTN, secondary HTN, or chronic stage 1 HTN incompletely treated (noncompliance or drug resistance)

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# Echocardiographic Assessment

- LV structure – geometry and mass

| Geometry | LV Mass | LV Wall Thickness |
|---|---|---|
| Normal geometry | Normal LV mass | Normal LV wall thickness |
| Concentric LVH | Normal LV mass | Increased LV wall thickness |
| Eccentric LVH | Increased LV mass | Normal LV wall thickness |
| Concentric LVH | Increased LV mass | Increased LV wall thickness |

- LV function
  - LF function can be significantly decreased in severe or **<u>acute</u>** onset HTN with associated CHF
  - Rarely, LV function may be mildly depressed in **<u>c</u>**HTN
    - Compensatory (though pathologic) hypertrophy

# LV Mass – Quantitative challenges

- LV mass – so what do the numbers really mean?
- Not all hearts are created equal and any heart can change
  - The heart increases in size relative to body size
    - Particularly important in infants and younger children due to rapid growth
  - The heart increases in size relative to activity
    - Compensatory and physiologic hypertrophy in response to athletic training  Healthy increase in LV mass
      - LV mass correlates better with Lean body mass than fat mass
- Body composition (ie, “lean”) is not routinely measured clinically

# LV Mass – Quantitative challenges

- Therefore, the “most accurate/precise” method/formula for indexing LV mass remains controversial
  - Who’s the ideal reference range/population?
    - Normal BP and normal weight
    - Normal BP but obese/overweight
- Inherent limitations of echocardiography
  - Limited acoustic windows in overweight/obese patients
  - Quantification of a 3D organ with 2D technology
  - Subjectivity of quantification tools
  - Limitations of assessing cardiac “function”
    - Quantification of a 3D organ with 2D technology
    - Intricacy of “function” – volumetric change in chamber sizevs. Contractility vs. regional/segmental motion

# 3. Activity Management: Restriction vs. Promotion

- Understanding which patients require activity restriction while promoting regular exercise and overall cardiovascular health

# 3. Activity Management: Promotion

- Meta-analyses and RCT's *consistently* show lower BP after exercise training *in adults*, yet similar data is not available in children
- Observational data support a relationship between physical activity and lower BP in children, but the data is scant and not necessarily statistically significant
- There is some evidence that exercise has a beneficial effect on cardiac structure in adolescents.
- KAS-20: At the time of diagnosis of elevated BP or HTN in a child or adolescent, clinicians should provide advice on the DASH diet and recommend moderate to vigorous physical activity at least 3-5 days per week (30-60 min per session) to help reduce BP.

# 3. Activity Management: Restriction

- AHA and ACC guidelines:
  - Limiting competitive athletic participation among athletes with ***LVH beyond*** that seen with the athlete's heart, *until* BP is normalized by appropriate anti-HTN Rx
    - HTN and pathologic LVH
  - Restricting athletes with Stage 2 HTN (even those without evidence of target organ injury) from participating in high-static sports (ie, weight lifting, boxing, wrestling), until HTN is controlled (lifestyle modification or Rx).
    - Stage 2 HTN, regardless of LVH

# AAP Key Action Statements

- KAS-28: Children and adolescents with HTN may participate in competitive sports once hypertensive target organ effects and cardiovascular risk have been assessed.
- KAS-29: Children and adolescents with HTN should receive treatment to lower BP below Stage 2 thresholds before participation in competitive sports.

# LVMI

- LVMI is a well-established measure to independently predict adverse cardiovascular events and premature death.
- Population-based studies have revealed that increased LV mass (LVM) and LV hypertrophy (LVH) as assessed by 2D echo provides prognostic information beyond traditional CVD risk factors.
  - Framingham Heart Study – the relative risk for coronary disease increased in both men and women per 50gram/meter increment in LVM

# LVMI

- LVM is strongly influenced by body size
  - Males have larger LVM than females, even after adjustment for anthropometric variables
  - Athletes have increased LVM compared to non-athletes
  - Black men and women have larger LVM than white or Asian counterparts
  - Obesity is associated with increased LVM
  - Age and blood pressure also affect LVM

# LVM Calculation and Indexing

- Normal reference values for LVM are derived from studies of the general population, without HTN or obesity.
- There remains controversy regarding the best method to index LVM
  - Body Surface Area (BSA) was the 1st variable used
    - Stronger statistical correlation with LVH than height
    - Better identification of HTN-related HTN
    - BUT … indexing by BSA can minimize the effect of obesity on LVM and thus underestimates the prevalence of obesity-related LVH
    - BSA has been adopted by the American Society of Echocardiography and European Association of CV imaging as the preferred method of indexing

# LVM Calculation and Indexing

- Height has been used to index LVM
  - LVM indexed to height raised to a power of 2.7 (grams/m^2.7) has been shown to have better predictive value for CVD outcomes, better detection of obesity-related LVH, and less variability of LVM among normal individuals, when compared to indexing to BSA or height alone (without raised power)

# LVM Calculation via Echocardiography

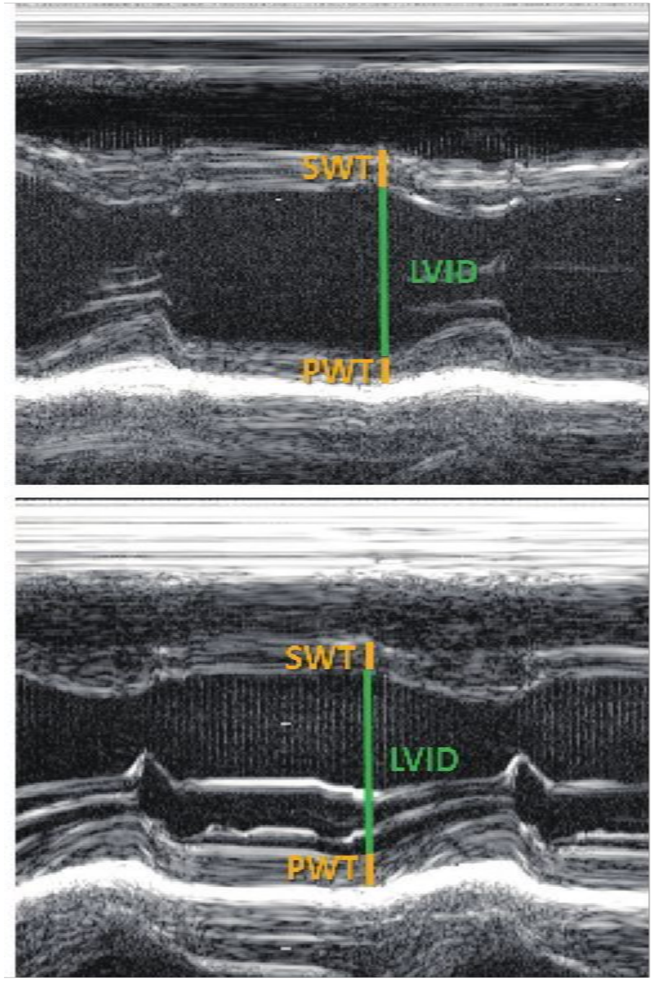
- LVM is derived by converting LV volume to mass
  - LVM = LV Volume (L) x Myocardial density (1.05g/mL)
- Measurements obtained via **M-mode** echo
- Measurements obtained via direct **2D imaging**
- Measurements obtained via **3D echo**

# LV Calculation via M-Mode Echocardiography

- Measurements obtained via M-mode echo
  - Initial measurements made on a 2D plane, then converted into a volume based upon geometric assumptions, namely that the LV is a “prolate ellipsoid” with a major axis and minor axis that has a 2:1 ratio (major to minor)
  - Linear measurements are subjective
  - Errors in linear measurements can result in significant inaccuracies in LVM because all measurements are cubed by this formula
- Measurements in asymmetric LVH, dilated CM or other conditions with regional differences in LV wall thickness will

# LV Calculation via M-Mode Echocardiography

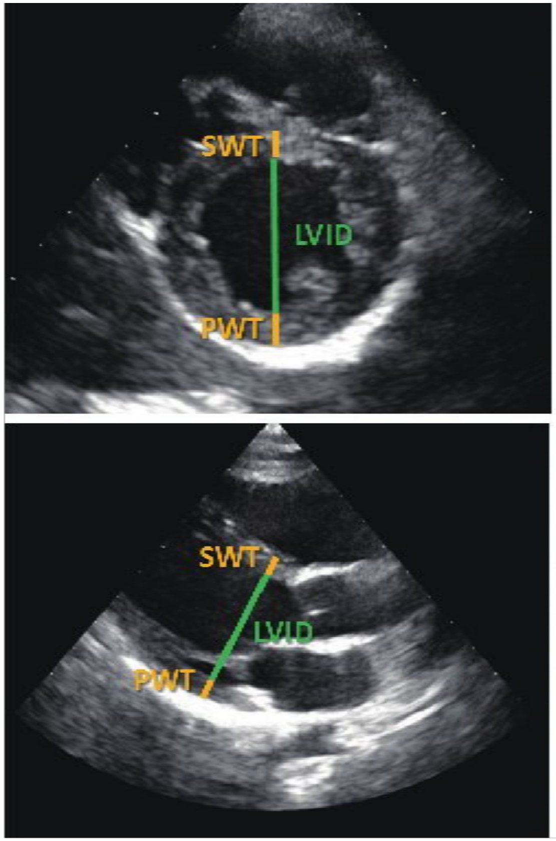
M-mode



# LV Calculation via direct 2D Echocardiography

- Measurements obtained via direct 2D imaging
- Area-length method and "truncated ellipsoid"
  - The LV area and length are measured from orthogonal planes, 90 degrees to one another and used to subsequently calculate a volume
- Comparable with post-mortem, autopsy derived LVM
- Limitations:
  - reliance on geometric assumptions that are not applicable when the LV is foreshortened or there are major LV distortions.
  - Require very clear acoustic windows to accurately identify endocardial and pericardial borders (calculation of an entire area, rather than calculation in one plane then cubed)

# LV Calculation via direct 2D Echocardiography



# LV Calculation via 3D Echocardiography

- Measurements obtained via 3D echo
- Relies on direct LV measurement without geometric assumptions
  - Theoretically can provide a more accurate estimation of LVM
  - Better correlation with cardiac MR measurements
  - Inter- and intra-observer variability were better than with 2D and M-mode
- BUT … highly dependent on the equipment used, quality of images obtained, requires additional technical training and training regarding image post-processing
- 3D echo currently more expensive and less readily available

# Summary

- **Cardiac <u>etiologies</u>** of hypertension
- **Cardiac <u>consequences</u>** of chronic hypertension
  - LVMI assessment
- Balance between **activity restriction** and promoting regular exercise and overall cardiovascular health