Non-Invasive Cardiovascular Examination  
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The physician knowledgeable and skilled in non-invasive cardiovascular examination has an armamentarium of reliable, cost-effective, bedside diagnostic methods of assessment of the health or diseased status of the cardiovascular system. In this era of invasive, risky, high-cost, technology-dependent diagnostic methods, the art of non-invasive diagnostic methods often is lost; however with the impetus of medical economic considerations and managed care cost-consciousness, technology-independent cost-effective care is now being emphasized.

The Arterial Pulse

The arterial pulse is best palpated (and visualized) in carotid arteries, brachial arteries or radial arteries, however palpation of the pulses of the aorta and femoral, popliteal, dorsalis pedis and posterior tibial arteries is important in the assessment of peripheral vascular disease.

- **Pulsus parvus et tardus** (small and slow, weak) is due to diminished left ventricular stroke volume producing a narrow pulse pressure. It is commonly found in patients with aortic stenosis and is frequently associated with a systolic murmur and thrill at the sternal border at the second right intercostal space.
- **Hypokinetic pulse** is a weak, low pulse pressure pulse due to low cardiac output (shock), left ventricular failure or hypovolemia.
- **Hyperkinetic pulse** is a bounding pulse with a high pulse pressure and stroke volume and decreased peripheral resistance frequently seen in patients with anxiety, fever or during exercise. Cardiovascular diseases that may produce this finding include AV fistula, aortic valvular regurgitation, mitral regurgitation and ventricular septal defect.
- **Bisferiens pulse** is a double systolic pulse characteristic of aortic valvular regurgitation and hypertrophic obstructive cardiomyopathy (IHSS).
- **Dicrotic pulse** is a systolic and diastolic double pulse is due to a very low left ventricular ejection fraction and is commonly found to be due to dilated cardiomyopathy.
- **Pulsus alternans** is an alternating strong-weak pulse pattern with a regular rhythm due to alternating left ventricular contractile force. It is often found with S₃ and is due to left ventricular failure.
- **Pulsus bigeminus** is a regular alternation of strong and weak (or absent) coupled pulses with a long and short pulse interval in patients with bigeminal premature ventricular contractions.
- **Pulsus paradoxus** is an augmentation of the decrease in systolic arterial pressure and pulse pressure normally occurring during inspiration. Decreases in systolic pressure >10 mmHg with inspiration are abnormal and most often are due to pericardial tamponade, obstructive airway disease and SVC obstruction.

The Jugular Pulse (JVP)

The jugular pulse examination is important in assessing abnormalities of waveform and estimation of central venous pressure. Examination is best performed with trunk inclination of 30° or more depending on jugular pressure. Jugular pulsations can be visualized rather than palpated. Palpated neck pulses are usually of carotid origin. Jugular pressure reflects right atrial pressure and can be estimated in cm/H₂O by measuring the vertical extent of the expanded jugular vein above the sternal angle.

- **a wave**
  - **Cannon a waves** are regular or irregular large presystolic pulses synchronous with atrial contraction and are usually due to tricuspid stenosis, pulmonary hypertension or junctional tachycardia (regular) or 3° AV block or ventricular tachycardia (irregular). No a waves are seen in atrial fibrillation.
- **c waves** are small waves due to bulging of the closed tricuspid valve during isovolumetric ventricular contraction and are rarely detected. They are of no clinical diagnostic value.
v waves normally are due to right atrial and superior vena cava filling during ventricular systole when the tricuspid valve is closed. Ventricularization (enlargement) of the v wave is most often seen with rapid early diastolic y descent in patients with tricuspid regurgitation.

y descent is due to tricuspid opening releasing pressure as blood enters the right ventricle. Prominent y descent occurs in severe tricuspid regurgitation. A sharp y descent and rapid ascent to the baseline (square-root sign) occurs in constrictive pericarditis or severe right ventricular failure. A slow y descent indicates obstruction to right ventricular filling as seen in patients with tricuspid stenosis or right atrial myxoma.

Hepatojugular reflux (abdominojugular test) is prominent jugular expansion in response to sustained abdominal pressure with greater than 4 cm fall upon release of abdominal pressure. A positive test is usually due to right ventricular failure.

Kussmaul sign is an increase in pressure (expansion) of the jugular vein rather than the normal decrease in CVP during inspiration and indicates severe right ventricular failure, right ventricular infarction or constrictive pericarditis.

The Precordial Pulse

Palpation of the precordium can best be performed with the fingertips. By palpation and characterization of the cardiac impulse diagnosis of some cardiac conditions is enhanced.

Left parasternal lift usually suggests right ventricular hypertrophy or, less commonly, mitral regurgitation with large left atrium.

Apical lift is typical of left ventricular hypertrophy.

Thrills are palpable low-frequency vibrations associated with the heart murmurs of aortic stenosis, ventricular septal defect or pulmonic stenosis.

Heart Sounds

Heart sounds can be appreciated best by auscultation over the four valvular regions of the precordium. The normal heart sounds are due to closure of the cardiac valves. Additional sounds may be heard from ventricular filling and the abnormal flow of blood through the heart resulting in turbulence, producing murmurs.

S1 is due to mitral and tricuspid valve closure and may normally be split. Wider splitting is heard in right bundle branch block (RBBB). Increased intensity of the first heart sound may be heard in mitral stenosis.

S2 is due to aortic and pulmonic valve closure and is physiologically split during inspiration due to delayed closure of the pulmonic valve (A2P2). Constant splitting, wider during inspiration, is heard in RBBB. Paradoxical splitting (splitting during exhalation) is heard in left bundle branch block (LBBB), left ventricular failure and aortic stenosis. Fixed splitting is heard in atrial septal defect (ASD).

S3 is an early diastolic sound which may be normal in children and in adults with high cardiac output. In older patients a third heart sound usually indicates left ventricular failure.

Opening snap is a high-pitched early diastolic sound due to stenosis of the mitral (or tricuspid) valve.

S4 is a presystolic sound associated with atrial contraction filling the left (or right) ventricle which has decreased compliance usually due to hypertrophy or increased myocardial tone. Conditions frequently associated with a fourth heart sound include hypertension, aortic stenosis, hypertrophic cardiomyopathy, coronary artery disease, acute myocardial infarction and acute mitral regurgitation. Fourth heart sounds are not heard in patients with atrial fibrillation.

Ejection sounds are early systolic sounds associated with dilated aorta or pulmonary artery in patients with aortic or pulmonic stenosis.

Midystolic clicks are midsystolic, nonejection sounds associated with mitral or tricuspid leaflet prolapse.
Murmurs are systolic or diastolic vibrations due to turbulence of blood flow within the heart. Systolic murmurs are due to aortic (or pulmonic) stenosis, mitral (or tricuspid) regurgitation, hypertrophic obstructive cardiomyopathy (IHSS) and ventricular septal defect. Diastolic murmurs are due to aortic (or pulmonic) regurgitation and mitral (or tricuspid) stenosis. A mid-diastolic murmur may be heard in acute rheumatic fever due to AV valve inflammation or mitral regurgitation (Carey-Coombs murmur). Aortic regurgitation may produce partial mitral valve closure also resulting in a diastolic murmur of mitral origin (Austin-Flint murmur). Pulmonary hypertension and dilation, from whatever etiology, may result in a diastolic murmur of pulmonary valvular regurgitation (Graham Steell murmur). Continuous murmurs throughout systole and diastole may be due to patent ductus arteriosis (PDA), AV fistula, or coarctation of the aorta.

<table>
<thead>
<tr>
<th>Maneuver</th>
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<th>Mitral Regurgitation</th>
<th>Aortic Stenosis</th>
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Pharmacologic and Physical Effects on Murmurs

Pericardial friction rubs are scratchy, leathery sounds from pericardial inflammation with presystolic, systolic and early diastolic components.

The Electrocardiogram (ECG)

The electrocardiogram record surface (and intravascular) electrical potential changes during depolarization and repolarization. As an electrical recording modality, the ECG is of primary diagnostic importance (sensitivity 100%) in diagnosis of cardiac electrical abnormalities of repolarization and depolarization (arrhythmias and conduction abnormalities). The ECG is a secondary diagnostic tool (sensitivity <100%) for the detection of anatomic cardiac abnormalities (hypertrophy, chamber enlargement, infarction, etc.). A thorough understanding of cardiac electrophysiology enables the most accurate interpretation of resting and exercise ECG’s.

Arrhythmias can only be differentially diagnosed by ECG and include supraventricular and ventricular ectopy and tachycardias with differentiation of their various forms. Sinus tachycardia, bradycardia, arrhythmia and block are also revealed only by ECG.

Conduction abnormalities of the AV node, aberrant AV bundles and intraventricular bundles can only be found by ECG methods.

Myocardial infarction is an anatomic/biochemical abnormality that can only variably be diagnosed by ECG. The diagnosis of myocardial infarction is obscured by LBBB. It can be diagnosed in error in the following conditions:

1. WPW syndrome, type A may mimic inferoposterior MI;
2. WPW syndrome, type B may mimic anteroseptal MI;
3. IHSS may mimic inferior or lateral MI;
4. Dilated cardiomyopathy may mimic anteroseptal MI;
5. LVH and LBBB may mimic anteroseptal MI;
6. RVH may mimic posterior MI;
7. LAFB may mimic inferior MI and mask lateral MI;
8. COPD may mimic inferior MI;
9. Straight back syndrome may mimic anteroseptal MI.
♦ **Myocardial ischemia** may be evident by T-wave or ST abnormality at rest or provoked by exercise. Diagnostic accuracy is enhanced by combining stress ECG with echocardiographic or radionuclide imaging at rest and following exercise.

♦ **Hypertrophy** of the atria typically produces widened, notched p-waves (left atrial enlargement, p-mitrale) or peaked, high voltage p-waves (right atrial enlargement, p-pulmonale).

♦ **Hypertrophy** of the ventricles is manifested by:
  1. Increased QRS voltage of the leads overlying the hypertrophied chamber;
  2. Delayed intrinsicoid deflection of the involved QRS complex;
  3. ST-segment depression in leads overlying the hypertrophied chamber;
  4. Reversal of repolarization-inverted T-waves in involved leads;
  5. QRS axis shift towards the hypertrophied chamber.

♦ **Electrolyte** abnormalities may manifest ECG changes that may be “classic” or quite subtle.

♦ **Drug effects** may produce “physiologic” or “toxic” ECG changes (digitalis, antiarrhythmics, beta-blockers, etc).

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**The Signal-Averaged Electrocardiogram**

Signal-averaged ECG (SAECG) is a computer “averaged” ECG recording of 200 cardiac cycles with elimination of baseline “noise” signals. The resultant recording of cardiac electrical activity shows abnormal low voltage “late potentials” which are predictive of risk of **malignant arrhythmias following MI**. Criteria for late potentials include:

1. QRS duration > 114 ms,
2. The last 40 ms of the QRS potential < 20 uV,
3. The terminal filtered QRS complex below 40 uV is > 38 ms.

**The Echocardiogram**

Visualization of cardiac anatomy, physiology and intracardiac blood flow can best be determined with the echocardiogram. An understanding of normal cardiac anatomy and physiology is important to differentiate hypertrophy, chamber enlargement and valvular disease. Pressure gradients can be determined by the relationship: \( \Delta P = 4V^2 \).

♦ **Valvular stenosis** can be readily visualized and severity quantitated in terms of pressure gradient and valve area. Classic images distinguish mitral stenosis from left atrial myxoma.

♦ **Valvular regurgitation** can be quantified by doppler mapping characteristics. Pressure measurements from tricuspid regurgitation doppler signals accurately diagnose pulmonary hypertension.

♦ **Pericardial effusion** and tamponade can readily be diagnosed.

♦ **Cardiac masses**, particularly atrial myxomas and intracardiac thrombi, can best be detected by echocardiography.

♦ **Cardiac chamber dimensions** and function can be visualized by echocardiography permitting diagnosis of hypertrophy, infarction, heart failure (and its etiology) and cardiomyopathies.

♦ **Congenital heart disease** can safely and easily be diagnosed by echocardiography.

♦ **Coronary artery disease** may be inferred by the finding akinetic (infarction) left ventricular wall segments or by hypokinetic segments (ischemia) at rest or following exercise.

♦ **Aortic dissection** may be detected in ascending and descending segments most reliably by transesophageal echocardiography.
Radionuclide Imaging

By the injection of radio-tagged biochemical substances, radionuclide studies of the heart provide non-invasive imaging of certain cardiac abnormalities.

- **Ventricular performance** is assessed by using technitium-99 tagged red blood cells injected intravenously. “First-pass” imaging of the cardiac chambers and lungs and “gated” (ECG triggered computer averaging of multiple cardiac cycles) are useful in the measurement of right and left ventricular ejection fraction, chamber dimensions and rates of ventricular filling and emptying. This method is useful in diagnosis of chronic ischemic heart disease, septal rupture, ventricular aneurysms and mitral regurgitation. Scans at rest and peak exercise helps detected provoked ischemia.

- **Shunt** detection by using a modified first-pass technique can aide in the diagnosis and quantification of left-to-right and right-to-left shunts.

- **Myocardial perfusion** is assessed by the intravenous injection of Thallium-201, sestamibi or other commercial analogues of potassium at rest and peak exercise. SPECT (single photon emission computed tomography) imaging of tracer uptake by normally perfused myocardial cells produces a “cold spot” (deficit of uptake) in areas of ischemia. Myocardial infarction, “hibernating” myocardium and exercise induced ischemia can be diagnosed by this method.

- **Acute myocardial infarction** scanning utilizes technitium-99-pyrophosphate injection which binds to irreversibly damaged myocardial cells. Such “hot spot” scans show areas of myocardial infarction best at 48-72 hours.

Newer Cardiac Image Techniques

Technology is in a constant, rapid state of transition. Newer technology is currently under study to establish its role in diagnosis.

- **Cine CT** is only available at larger medical centers and remains to have established a cost-effective role in the diagnosis of heart disease. Some areas of usefulness and study include: thoracic aortic aneurysm and dissection, cardiac masses, coronary artery bypass graft patency and ventricular infarctions and aneurysm.

- **Ultra-fast CT** is being used to detect calcified or thickened coronary arteries for the diagnosis and prognostication of asymptomatic coronary artery disease.

- **ECG-gated magnetic resonance imaging (MRI)** may be useful in the diagnosis of thoracic aorta disease; pericardial disease; cardiac masses; hypertrophic cardiomyopathy; left ventricular infarction, aneurysm and thrombus; analysis of ventricular function; and congenital heart disease.

- **Positron emission tomography (PET)** is of most value in assessing regional myocardial blood flow and metabolism.

- **Magnetic resonance spectroscopy (MRS)** is being investigated as new method of assessing myocardial metabolism and may be helpful in evaluating response to pharmacologic interventions, myocardial viability and reperfusion effects on ischemic injury.

- **CT coronary angiography** is a noninvasive visualization of the coronary arteries following IV contrast injection recorded with video CT. The same technology can be used for coronary calcium scoring risk stratification.
Risk Factors for Atherosclerosis

Risk factors for atherosclerosis and coronary risk can be categorized as follows:

- **Category I** – Intervention definitely reduces risk (hypertension, tobacco use, high LDL-cholesterol, left ventricular hypertrophy and thrombogenic factors).
- **Category II** – Intervention likely reduces risk (diabetes mellitus, low HDL-cholesterol, obesity, physical inactivity).
- **Category III** – Intervention might reduce risk (hypertriglyceridemia, high lipoprotein-a, oxidative stress, homocysteinemia, alcohol consumption, psychosocial factors, hs-CRP).
- **Category IV** – Cannot change reduce risk (family history of CAD; age: males >45, females >55; gender: men, postmenopausal women).
Questions

1. Pulsus parvus et tardus is suggestive of which one of the following conditions?
   a. Hypertrophic obstructive cardiomyopathy.
   * b. Aortic stenosis.
   c. Mitral regurgitation.
   d. Congestive heart failure.
   e. Hypotension.

2. Which of the following conditions can not be visualized by transthoracic echocardiography?
   a. Left atrial myxoma.
   b. Pericardial effusion
   c. Mitral stenosis
   * d. Tricuspid regurgitation
   e. Coronary artery stenosis

3. Intervention of which of the following risk factors definitely reduces the risk of coronary heart disease?
   a. High serum triglyceride
   b. High serum lipoprotein-a
   * c. High serum LDL-cholesterol
   d. High serum homocysteine
   e. High serum hs-CRP