Special organ scan: Part 4

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When G. N. Hounsfield announced the development of a revolutionary technique called computerised axial tomography in 1972, it was thought that nuclear imaging will get relegated to the pages of history. Since then the world has witnessed the development of MRI, spiral CT etc. Though the role of nuclear imaging has decreased with the advent of these techniques, it still occupies a niche for itself which cannot be usurped. In this issue radio-nuclide scans of a few special organs will be discussed.

Brain scan

Isotopes and imaging

Though radio-arsenic and $^{197,\ 203}$Hg (mercury) have been used for brain scanning, ^{99m}Tc-pertechnetate is the most commonly used. Following IV injection its gamma emission is captured by a gamma camera. The scanned image may be seen on a cathode ray tube or a developed photographic plate, where increased gamma emission correspond to areas of increased brightness or blackness, respectively.

TcO_4^- and BBB*:* The *pertechnetate* ($^{99m}TcO_4^-$) ion binds to plasma proteins, quickly moves into the extra-cellular space and distributes itself like the Cl^- ion in various organs except the normal brain because of the blood brain barrier (BBB). Thus, negligible uptake of the isotope by the normal brain prevents its effective visualisation by isotope scan, unlike other organs. *Lesions:* Any pathological process can break down the BBB, allowing the $^{99m}TcO_4^-$ to localise in the area as a 'hot' spot (positive scan), contrasting with the low uptake in the normal areas of the brain with intact BBB (negative scan). The difference in uptake are accentuated on immediate and/or delayed scans. *Vascularity:* The more vascular the lesion, the more consistent is its demonstration by radioisotope scan. Tumours, inflammatory masses, abscesses, infarction, intra- and extra-cerebral haemorrhage all give positive scans. The $^{99m}TcO_4^-$ localisation is not specific for any lesion but occurs in any lesion where disruption of the BBB and the vascularity of the lesion allows high lesion-to-brain distribution ratio.

^{99m}Tc pentetate scan: This is DTPA (diethylene-triamino-penta-acetic (pentetic) acid) complexed with ^{99m}Tc in a sterile NaCl solution. Administered IV, it is used in renal (most commonly), brain and lung scanning (table 1A).

Space-occupying lesions

Certain space-occupying lesions (SOL) such as meningioma, acoustic tumour, malignant glioma and brain abscess appear particularly prominent in scan. Since this technique images the entire head as opposed to slices, accurate localisation of lesions with respect to external observable landmarks is possible. On the other hand, in contrast to CT scan, radio-nuclide scan provides very little anatomical detail.

Positrocephalogram: This is a record produced by the emission of positrons by isotopes of arsenic (AN=33, AW=74.922), administered to facilitate localisation of brain tumours (infra).

Vascular lesions

They are divided into; (a) infarcts; (b) haematomas; and (c) arterio-venous malformations (AVM). The last is described under dynamic radio-nuclide angioscan (DRA). Some *infarcts* may be successfully imaged in their sub-acute stage (days to weeks) and they are often positive especially in the 2nd or 3rd week. Many *haematomas* are positive in the sub-acute stage (first week), remain positive for several weeks and then return to normal on radio-nuclide scan. They cannot be seen in the late stages (months or years). Thus serial brain scanning can help to differentiate tumours from vascular lesions.

Dynamic radio-nuclide angioscan: This involves obtaining rapid (1-second interval) images shortly after an IV bolus injection of ^{99m}Tc. It depicts blood flow through the brain and is particularly useful in patients with AVM. In this condition, gamma camera viewing of the posterior of the head and neck shows; (a) early appearance of radioactivity over the lesion (typical of AVM) compared to rest of the brain; (b) higher peak density of gamma emission and; (c) delayed washout of radioactivity in the delayed images. This can be compared with static scan images to confirm the increased amount of tracer localised in the region of AVM.

Scans to assess function

One major application of radio-nuclide scan which have not been supplanted by the newer imaging modalities is the study of dynamic physiological and metabolic events in the brain. CT scan provides accurate anatomical information but no physiological details. The special applications of radio-nuclide scan include the following.

Radio-nuclide cisternogram: After a radioisotope is injected into the ventriculo-subarachnoid space, sequential scans are taken to demonstrate the circulatory pattern of CSF and delineate abnormalities of flow.

Radioencephalogram: This is a curve showing the passage of an injected tracer through the cerebral blood vessels, as revealed by an external scintillation counter. Placing the same over 2 sides of the skull provides a comparative index of the circulation in the two carotid systems.

^{133}Xenon perfusion scan: This measures the actual blood flow per unit volume of brain (i.e. perfusion of brain at the tissue level), which cannot be adequately demonstrated by angiography (which demonstrates only larger vessels). Following a short period of inhalation of ^{133}Xenon(Xe) gas it rapidly enters the brain. External scintillation counters record the rate at which the radioactivity leaves the brain, which is proportional to the blood flow per unit volume of brain in the field of the detector. This investigative (rather than diagnostic) tool demonstrates areas of global or focal cerebral ischaemia.

Positron scan: A positron (positive electron) (e^+) is a positively-charged anti-particle of electron possessing the same mass as the latter. It is emitted by radio-arsenic (q.v.) and other short-lived artificial radioisotopes which are produced on-site by a cyclotron. This scanning system (a.k.a. positron emission tomography; PET scan), like the CT scanner, produces axial images of the brain, but unlike the latter, uses positron beam to do so. Moreover, by imaging the isotopes of carbon, nitrogen and oxygen in the molecules it enables visualisation of areas of metabolic dysfunction in the brain, in contrast to the anatomical information provided by the CT scanner.

MR spectroscopy: Magnetic resonance (MR) spectroscopic analysis of ^{31}P(phosphorus) atoms allow non-invasive study of metabolic energy pathways of tissues. PET scan, MRI scan (infra) and MR spectroscopy are scanning techniques which involve imaging the nuclei of various atoms in tissues.

Gd contrast and MRI

Gadolinium (Gd) is a rare element (AN=64, AW=157.25) whose radioisotope will be described under "Bone scan" (next issue). In brain scan the stable element is used as gadopentate dimeglumine (dimeglumine salt of Gd complex of pentetic acid). Administered IV, it acts as a paramagnetic contrast agent* in MRI (magnetic resonance imaging) of intra-cranial and spinal lesions. MRI images the special magnetic properties of protons (nuclei of hydrogen atoms; H^+) by subjecting them to radio-frequency electromagnetic radiation after placing them in a magnetic field. The nuclei absorb the energy and emit a signal which the scanner picks up and gives a cross-sectional image showing normal and pathological tissue with excellent contrast and detail. T1 images (which reflect the T1 property of protons) give good demonstration of normal anatomy, and T2 images (which reflect the T2 property of protons) are more sensitive to pathological changes. Both reflect the state of cellular and tissue water and fat, giving a discrimination of different tissue types.

*{*Iron oxide is also used as a super-paramagnetic contrast agent in MRI of portal vein.}*

Pulmonary scan

There are three groups of scanning techniques, viz. (a) ventilation scan; (b) perfusion scan {collectively known as pulmonary scintiphotography (PSP)}; and (c) scanning for inflammatory and neoplastic disorders in the lungs and mediastinum (discussed under "Mediastinal scan"). PSP provides a visual image and quantitative data of distribution of blood flow and ventilation in the lungs. It is particularly useful in pulmonary embolism (PE) and inhalation thermal injury (ITI).

Perfusion scan

This involves IV injection of a gamma-emitting radioligand or pharmaceutical (table 1B) followed by scanning the lung fields and recording the radiation output.

^{133}Xe gas: Following IV injection of a solution of ^{133}Xe gas in saline the patient holds his breath as the isotope perfuses the lungs, and the scan is performed. The distribution of ^{133}Xe evolving in the pulmonary in the pulmonary capillaries gives the blood flow distribution. This technique does not give sufficient anatomical resolution to be of clinical value.

Labelled MAA: In 1964 Wagner et al showed that micro-spheres or macro-aggregates of albumin (MAA), produced by denaturing normal human serum, of controlled particle size (10-50 μ, 10-75 μ, 50-100 μ), labelled with ^{99m}Tc (technetated aggregated albumin), ^{131}I, ^{111}Indium (In) or ^{51}Chromium (Cr), when injected IV as a sterile aqueous suspension, give better image resolution. These particles pass through the right heart, get distributed in the lungs in proportion to the regional blood flow, remain trapped in the pulmonary capillaries (10 μ diameter) and pre-capillary arterioles for 6 hours, occlude only 0.1% of the total circulation and then fragment and disappear without any adverse effects. A gamma-detecting device records the pattern of radioactivity within the lungs and produces an image on a TV screen or records it on a special photographic or radiographic film or on videotape. The pattern of radioactivity reflects the distribution of labelled MAA in the pulmonary circulation, which in turn accurately depicts the distribution of pulmonary blood flow.

Normal scan: There is a homogeneous distribution of radioactivity with uniform gradation from apices to bases, smooth margins and a configuration which corresponds to the normal anatomy of the lung. A normal scan essentially excludes the diagnosis of PE (normal chest x-ray does not exclude the same).

Uses/advantages: (1) It gives excellent correlation with x-ray, ventilation scan and pulmonary angiography and gives a more accurate assessment of regional function than chest x-ray. (2) Because it is safe, simple and rapid, it can (and often should) be repeated to define resolution/recurrence of obstructive vascular phenomenon. (3) Its role in; (a) PE (diagnosis, response to treatment); (b) ITI (diagnosis); and (c) bronchial carcinoma (clue to resectability) is described below. (4) It gives a quantitative estimation of regional blood flow in; (a) mitral stenosis (degree of increased apical perfusion indexes the severity of stenosis); and (b) therapeutic subclavian-pulmonary shunt for congenital heart disease (shift of pulmonary artery perfusion away from the side of shunt). (5) It is particularly useful for evaluating the response to treatment in bronchiectasis, cystic lung disease, congenital vascular abnormalities and lobar emphysema.

Disadvantages: (1) Lesions are often not visible in one view; multiple scan views may be needed. (2) It demonstrates only abnormalities of flow distribution; it does not provide anatomical information. (3) Abnormalities in flow distribution may occur in lesions other than

PE (table 2); perfusion scan thus lacks specificity. It has to be read in conjunction with other modalities of investigation (infra) in order to increase its diagnostic specificity.

Ventilation scan

The patient is asked to breathe in $^{127 \text{ or } 133}Xe$ gas. The scanning and recording procedures are same as in perfusion scan, with which it is often combined (PSP) in order to increase the specificity of the latter and to differentiate other causes of perfusion defects (table 2) from PE. PSP is particularly useful in inhalation thermal injury (ITI).

ITI: ^{133}Xe gas ventilation-perfusion pulmonary scintiphotography (PSP) is one of the 3 investigations (other 2 being fibre-optic bronchoscopy (FOB) and pulmonary function tests) that gives quick and reliable diagnosis of ITI. It should be done after haemodynamic stability has been achieved and after FOB (in fact, the latter may obviate the need for the former), but before 72 hours post-burn, because beyond that period increased post-burn hyperventilation gives false-negative results.

^{133}Xe in normal saline (10 μ Ci) is injected into a peripheral vein and serial scintiphotographs are obtained. ITI is indicated by; (a) unequal radiation density in the lung fields; and (b) retention of gas in the lungs beyond 90 seconds post-injection. False-negative result (escape of gas before 90 seconds in spite of ITI; 5% of cases) is due to pronounced hyperventilation. False-positive result (retention beyond 90 seconds without ITI; 8% of cases) is seen in heavy smokers with bronchitis.

Lung cancer: Grossly abnormal ventilation-perfusion relationships (determined by ^{99m}Tc-MAA, ^{133}Xe PSP and pulmonary angiography) is a laboratory evidence of indication of non-operability. ^{67}Ga(Gallium) citrate localises in soft tissue neoplasm and inflammation. Tomographic cuts of various sections in such a scan is very specific and sensitive for lung cancer and mediastinal lymph nodes (see "Mediastinal scan").

Pulmonary embolism

Perfusion scan constitutes the most important investigation (others being ventilation scan, pulmonary angiography (PA), chest x-ray, fluoroscopy, arterial blood gas analysis). It is particularly useful in; (a) diagnosis (zones of absent or hypo-perfusion, compatible with PE); and (b) assessing response to treatment (resolution or recurrence of PE, incomplete restoration of perfusion), by serial scans.

Findings: The blocked pulmonary arteries produce zones of absent or sharply decreased radioactivity which appear as 'filling defects'. *Scattered small emboli* produce crescent-shaped defects along a pleural surface. *Segmental arterial occlusion* cause perfusion defects in the corresponding bronchopulmonary segments. Embolism in the lobar arteries produce large, obvious perfusion defects. Table 2 gives a list of pulmonary pathologies which can mimic perfusion defects similar to PE. Their differentiation requires correlation of perfusion scan with other modalities of investigation.

With chest x-ray: Many of these abnormalities will be clarified when perfusion scan is correlated with chest x-ray. Only if the isotope perfusion defect is in an area which is radiologically normal can a diagnosis of PE be entertained. *Radiopulmonography* is a rapid method for estimation of ventilation of localised lung areas, based on measurement of variation in intensity of low voltage x-rays passed through the lungs during breathing.

With ventilation scan: If vascular obstruction (e.g. PE) is present, ventilation scan will demonstrate normal 'wash-in' and, more importantly, normal 'wash-out' of radioactivity from the embolised lung zones. Thus poor perfusion in a normally ventilated lung area is virtually diagnostic of PE. However, if parenchymal disease is responsible for the perfusion abnormality, both 'wash-in' and 'wash-out' in ventilation scan will be abnormal. Thus, ventilation-perfusion 'mismatch' is characteristic of vascular obstruction; 'match' is suggestive of parenchymal disease.

With pulmonary angiography: Perfusion scan and PA are complementary procedures that usually depict similar patterns of pulmonary arterial perfusion. Because PA is potentially risky, invasive and uncomfortable, it should be performed only if an infiltrate on chest x-ray or a history of asthma hinders lung scan interpretation or if the scan diagnosis is inconclusive.

Cardiac scan

^{99m}Tc-(sestamibi, teboroxime, pertechnetate)

The first is ^{99m}Tc-containing lipophilic monovalent cation complex of hexakis 2-methoxy-isobutyl isonitrile (sestamibi) and the second is a lipophilic neutral complex of boronic acid, ^{99m}Tc and 8-hydroxyquinoline (BATO). Both are used in cardiac studies due to good myocardial uptake. Sestamibi is used in cardiac imaging because it has minimum redistribution over several hours, while the rapid myocardial clearance of teboroxime makes it useful for perfusion studies. Pertechnetate has been described earlier. IV injection of one of these γ emitters permits rapid, sequential visualisation of the heart, great vessels and pulmonary vasculature by Anger gamma scintillation camera. The image may be tape recorded for storage and retrieval or photographed. This technique is used in the diagnosis of a variety of congenital and acquired cardiac lesions, pulmonary emboli and pericardial effusion. Table 3 gives list of cardiac isotopes.

^{131}I-MAA

Apart from PE, it is also used to scan the cardiac silhouette (CS), following IV injection. The area of CS occupied by the labelled intra-cardiac blood pool is then compared with that seen in chest x-ray for the detection of pericardial effusion.

^{201}Tl(Thallium)

After its first introduction in 1977 it has become the most commonly used radio-nuclide for detecting myocardial ischaemia in patients with coronary artery disease (CAD). ^{201}Tl ($T_{1/2}$=3 days**)** has biological properties similar to K^+. After IV injection the myocardial distribution is proportional to its blood flow. A gamma camera positioned over the praecordium records low flow areas (acute ischaemia, MI, scar) as filling defects or 'cold' spots.

Stress ^{201}Tl

Principle: Most patients with CAD but no infarction will have normal ^{201}Tl scan at rest. But when myocardial O_2 consumption is increased by exercise (stress), relatively less tracer is delivered to the area distal to the coronary lesion, which then appears as a 'cold' spot.

Indication: It is a useful adjunct to stress ECG in patients with; (a) abnormal ECG; (b) exercise-induced conduction defects or arrhythmias; and (c) failure to achieve a predicted heart rate during TMT due to dyspnoea or fatigue. Stress and dipyridamole ^{201}Tl scans are also indicated as a pre-operative assessment program for all patients undergoing elective surgery for aortic aneurysm and peripheral vascular disease. In these patients incipient CAD is likely to be present which will show in stress ^{201}Tl scan, and which should be corrected first in order to reduce mortality following surgery for the vascular pathology[1,2].

Procedure: Stress ^{201}Tl scan is performed in conjunction with treadmill test (TMT). When the patient develops; (a) chest discomfort; (b) ischemic ECG changes; or (c) extreme fatigue during TMT, ^{201}Tl is injected IV and when possible, exercise is continued for 30-60 seconds to allow the isotope to distribute in the myocardium. Immediately thereafter myocardial scintigrams are obtained in at least 3 projections. If a perfusion defect is present in the exercise scans a second scan is taken at rest 4 hours later (when the tracer has redistributed in the myocardium) and/or 1 week later. Based on the comparison of resting and stress scans patients are grouped as; (a) normal; (b) those with transient ischaemia; and (c) those with infarction or scar in whom scan is abnormal at rest.

Sensitivity: This depends on the number of coronary vessels involved, the location and severity of narrowing. Thus, sensitivity is 60% for single-vessel disease and 90-95% for triple-vessel disease. If stress scan is normal, the chances of triple-vessel disease is only 10% and severe LAD narrowing (>90%) is 15%. However, isolated circumflex disease or moderate 1 or 2-vessel disease may give a normal scan.

^{99m}Tc-PYP

Apart from its bone-seeking properties it has high affinity for acutely infarcted myocardium where it produces a 'hot' spot on imaging. ^{99m}Tc stannous pyrophosphate (PYP) is flow-dependent and at least partial perfusion must continue in the area of myocardial damage in order to increase the uptake of tracer. The greatest affinity for the infarcted tissue occurs from 1 to 7 days after MI and corresponds to the time of maximum Ca^{++} influx into the mitochondria of the injured myocardial cells. This imaging is useful in determining the presence (or absence) of infarction, its approximate location and relative size. It is particularly useful for documenting MI following cardiac surgery.

Time span: Within about 12-24 hours after MI, a 'hot' spot image appears and becomes increasingly positive over the next 24 to 72 hours. Most transmural and the majority of non-transmural infarctions can be imaged 24-48 hours after the onset of pain. In most patients the scan fades or becomes negative after 1 week of MI. In a small sub-group it remains positive for weeks or months. This is associated with poor prognosis and dystrophic calcification.

Variable findings: Apart from acute MI where it is most specific, localised positive scans (intensity equal to or greater than in the ribs) is also seen in some cases of ; (a) calcified valves; (b) unstable angina; and (c) ventricular aneurysm. Diffusely positive scan (less intense uptake) may be seen in some cases of; (a) acute MI; (b) angina with no infarction; and (c) some normal subjects. A totally normal scan occurs in 5% of patients with acute MI.

^{85} Krypton (Kr)

Either as inhaled gas or injected as saline solution, ^{85}Kr is used to detect ventricular / atrial septal defects (VSD / ASD) with left to right or right to left shunts (L-RS / R-LS). These tests are simple, quick, sensitive (detect small L-RS) and can be used to locate the site of entry of a shunt. *^{131}I-albumin* may also be used for shunt detection. It is a true indicator (does not diffuse freely into the extra-/intracellular spaces). Other non-radioactive materials for shunt detection are NO, H_2 and Na-ascorbate.

Findings: *(1) VSD; L-RS:* Inhaled ^{85}Kr appears in the left ventricle rapidly and freely diffuses in the interstitial and cellular compartments. Normal right heart : left heart ratio of ^{85}Kr is < 15%. A ratio of > 20% is diagnostic of VSD with left to right shunt. *(2) ASD; L-RS:* When saline solution of ^{85}Kr is injected into the left atrium it normally appears in the expired air in 5 seconds in ASD with L-RS (normal time is 25 seconds). Injecting into the left ventricle in ASD with L-RS also causes it to appear in the expired air in 25 seconds, thus confirming the diagnosis. *(3) VSD; R-LS:* After the saline solution is injected into the right heart 95% of the injected dose is normally excreted during the first pulmonary passage. In VSD with R-LS, > 6% of the injected dose of radioactivity can be sampled from a peripheral artery.

^{99m}Tc-albumin

In dynamic radio-nuclide angiocardiography (DRA), bolus peripheral IV injection of ^{99m}Tc-albumin is followed by computerised gamma camera monitoring over the praecordium for recording the passage of radioactivity through the heart. The resulting image of the blood flow through the heart gives a real-time computerised ventriculogram. It aids recognition of abnormal haemodynamics and is particularly useful in congenital heart disorders. These studies also provide a means of calculating the various cardiac parameters (table 4).

First-pass technique: This is very useful for assessing left ventricular function (ejection fraction, wall motion). With a single injection of the isotope only one view is recorded over the praecordium during the 'first pass' of the tracer through the heart. The computer plots an activity vs. time curve, each curve consisting of an end-diastolic peak and an end-systolic valley, both together representing a cardiac cycle. Several such cycles are summed to give the ejection fraction. Conversion of this into a film format allows wall motion to be evaluated.

MUGA scan: Multiple update gated acquisition (MUGA), *a.k.a. gated blood pool scan*, is another method of assessing segmental wall motion and measuring ventricular performance. Following IV injection of ^{99m}Tc-albimin, the blood pool tracer is allowed to equilibrate in the vasculature. Images are recorded over a 10-minute period. Multiple 'gates' or 'time-windows' at various times after the QRS complex are used to gather data throughout many cardiac cycles, utilising 20-30 frames per cardiac cycle. The end-diastolic, end-systolic volumes and ejection fraction are determined by geometric means or from graphs. Segmental wall motion is defined by combining the MUGA data into a cinefilm, with each frame representing a fraction of cardiac cycle.

Applications: The dynamic radio-nuclide studies have been applied to the following situations; (a) serial assessment of ventricular performance in patients with acute MI; (b) screening and identification of patients suspected of having significant atherosclerotic CAD (using studies at rest and after exercise); (c) selection of patients for operation; and (d) assessment of the effects of myocardial revascularisation procedures on resting and post-exercise ventricular performance and wall motion. The dynamic studies are more reliable than stress ECG testing. Exercise ventriculography by single-pass technique is considered superior to stress ^{201}Tl testing.

References

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Table 1A	
Isotopes in brain scan	
$^{99m}TcO_4$ (pertechnetate)	All space occupying lesions (inflammatory, neoplastic etc.)
^{99m}Tc-DTPA (pentetate)	
^{133}Xe (gas)	Perfusion scan (for cerebral blood flow)
Radioarsenic	Positrocephalography
Short-lived artificial isotopes	PET scan
Gadolinium (stable isotope)	Paramagnetic contrast in MRI scan

Table 1B	
Isotopes in lung scan	
MAA – ^{99m}Tc	Perfusion scan, preliminary radio-nuclide phlebography
MAA – ^{131}I, ^{111}In, ^{51}Cr	Lung perfusion scan
^{133}Xe in saline	Pulmonary scintiphotography
^{127,133}Xe gas	Ventilation scan
^{67}Ga citrate	Lung cancer, mediastinal nodes

Table 2	
Conditions producing perfusion scan defects	
♦ Pneumonia ♦ Pneumothorax ♦ Pleural effusion ♦ Atelectasis	These reduce ventilation of a lung zone and decrease its perfusion
♦ Emphysema ♦ Sarcoidosis ♦ Carcinoma ♦ Tuberculosis ♦ Bronchiectasis	Parenchymal diseases which produce perfusion scan defects

Table 3	
Isotopes in cardiac disorders	
^{99m}Tc sestamibi	Cardiac imaging
^{99m}Tc teboroxime	Cardiac perfusion studies
^{99m}Tc pertechnetate	Congenital, acquired disorders (wide variety), pericardial effusion, pulmonary embolism
^{131}I-MAA	PE, Pericardial effusion
^{201}Thallium	Myocardial ischaemia
^{99m}Tc PYP	Acute myocardial infarction
^{85}Krypton (gas)	VSD with L-R shunt
^{85}Krypton (saline)	ASD with L-R shunt, VSD with R-L shunt
^{131}I-albumin	Shunt studies (supra)
^{99m}Tc-albumin	Dynamic radio-nuclide angiocardiography (MUGA scan)

Table 4		
Parameters derived from left ventricular volumes		
Parameter	***Formula***	***Normal values***
End-diastolic volume (EDV)		70-85 ml./m.^{2}
End-systolic volume (ESV)		25-30 ml./m.^{2}
Stroke volume (SV)	EDV – ESV	45-55 ml./m.^{2}
Ejection fraction (EF)	$\frac{EDV - ESV}{EDV}$	0.65-0.75
Stroke work (SW)	SV x Mean systolic aortic pr.	50-80 gm.-M./m.^{2}
Function index	$\frac{SW}{EDV}$	1.0 gm.-M./ml.
Effective stroke volume (SVE)		45-55 ml./m.^{2}
Regurgitant volume (VR)	SV - SVE	0 ml./m.^{2}
Regurgitant fraction	$\frac{VR}{SV}$	0
LVV is derived from washout curve obtained by praecordial counting of passage of γ-emitting tracer or by formula of ellipsoid from cineangiocardiographic film. Thus $V = 8A^2 / 3\pi L$, where V=left ventr.vol.; A=chamber area; L=longest chamber length (measured on film). This formula is not applicable to right ventricle.		