Quantification of Left-to-Right Cardiac Shunt

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1. Introduction

In conditions with a left-to-right (L-R) shunt, blood from the systemic arterial circulation mixes with systemic venous blood. This results in oxygenated blood flowing into the right side of the heart and back to the lungs. To maintain an adequate amount of blood circulating throughout the body, cardiac output from the left side of the heart must increase to maintain normal forward flow through the aorta in the setting of abnormal flow being shunted to the right side of the heart. Output from the right side of the heart is also increased, as it must eject both the normal volume of blood returning from the body plus the volume being shunted from the left side of the heart. These effects can lead to elevated pulmonary pressure and heart failure.

Nuclear medicine assessment of an L-R shunt uses a first pass analysis technique, in which an intravenous bolus of a radiopharmaceutical is tracked using rapid dynamic imaging through the heart and lungs. The study is predicated on demonstrating early return of activity to the lungs after the initial flow.

2. Methodology

This guideline is based on available scientific literature on the subject, the previous guideline (Aanbevelingen Nucleaire Geneeskunde 2007), international guidelines from EANM and/or SNMMI if available and applicable to the Dutch situation.

3. Indications

a. Quantification of an intracardiac shunt diagnosed by echographic Doppler
b. Follow-up examination after treatment
c. Assessment for further angiographic analysis

4. Relation to other diagnostic procedures

a. Echo-Doppler cardiography

This diagnostic modality is a highly sensitive method for the detection of shunts. The consequences of haemodynamic changes can also be assessed on the basis of abnormal dimensions of the heart chambers and cardiac muscle. The actual shunt size is difficult to measure using this method. Transesophageal Doppler ultrasound is highly sensitive for detecting atrial septal defects and also highly specific for detecting ventricular septal defects.

b. Angiografic and Oximetric method

The position of the shunt can be determined and its size calculated using the oxygen saturation measurements of the right atrium and pulmonary artery, in combination with arterial oxygen saturation measurements of the left side of the heart. The oximetric method is regarded as the gold standard.

c. MRI

MRI allows non-invasive quantification of pulmonary-to-systemic flow ratio (QP/QS).

There is a good correlation with echocardiographic and catheterization data. MRI is complementary to echocardiography when findings are equivocal or in difficult cases. MRI can confirm the importance of the shunt avoiding the necessity for invasive cardiac catheterization. MRI is particularly useful in the assessment of interventricular septal and ventricular septal defects. MR angiography can estimate the pulmonary flow, and the importance of a left-to-right shunt can be assessed by measuring flow in the right and left pulmonary branches with VEC-MRI.

5. Medical information necessary for planning

a. Indication
b. Clinical manifestations (e.g. heart sounds, murmurs,..)
c. Echo-doppler findings
d. Previously calculated shunt size
e. Angiocardiography findings

6. Radiopharmaceutical

Tracer:	^{99m}Tc-pentetaat (DTPA) or ^{99m}Tc pertechnetate
Nuclide:	Technetium-99m
Activity:	750 MBq
Administration:	intravenous in an antecubital vein

7. Radiation safety

a. Pregnancy

The radiation dose to the unborn child is approximately equal to the radiation dose to the uterus.

- ^{99m}Tc DTPA: 0,0079 mGy/MBq
- ^{99m}Tc pertechnetate: 0,0081 mGy/MBq
- ^{99m}Tc pertechnetate passes through the placenta.

b. Lactation

There is no need for interruption breastfeeding after using ^{99m}Tc DTPA according ICRP 106, but due to possible free ^{99m}Tcpertechnetate it is advisable to interrupt the feeding for 4 h. hours. When using ^{99m}Tc pertechnetate breast feeding should be interrupted for 12 h.

c. Radiation exposure

The examination can be carried out using either ^{99m}Tc DTPA, or ^{99m}Tc MDP or pertechnetate. ^{99m}Tc pertechnetate gives approximately twice the radiation dose of ^{99m}Tc MDP, which gives approximately the same radiation dose as ^{99m}Tc DTPA.

- ^{99m}Tc DTPA: 0,0049 mSv/MBq in adults
- 0,0062-0,016 mSv/MBq in children depending age
- ^{99m}Tc pertechnetate: 0,013 mSv/MBq in adults
- 0,017-0,079 mSv/MBq in children depending age

7. Patient preparation/essentials for procedure

No special patient preparation required.
Intravenous catheter with an extension set, two syringes (max. 2 mL and max 10 mL) for the injection of the radiopharmaceutical and flushing with saline respectively.

8. Acquisition and processing

Energy:	^{99m}Tc, 140 keV
Window:	15-20%
Collimator:	LEAP or LEHS
Counts:	dynamic series with a minimum time resolution of 1 sec for at least 30 sec
Computer:	matrix 64x64, frame time of maximum 0,5 sec for 30 sec

a. Patient is placed in supine position under the gamma camera. Hemi body anterior acquisitions with heart and lungs in field of view.
b. A cannula is inserted into a cubital vein of the right arm and connected to a three-way tap. The syringe containing ^{99m}Tc DTPA in the smallest possible volume is connected to the side opening. The other opening is used to connect a syringe containing at least 10 ml saline solution.
c. The tourniquet is released once the gamma camera and computer have been started. The radioactivity is then administered immediately, followed by a 'push' bolus of saline solution.
d. Time activity curves with regions of interest (ROI's) are generated over the superior vena cava superior (VCS) and right lung. The VCS curve is a control parameter for the bolus injection. The ROI of the right lung must not overlap those of the vena cava, VCS and right ventricle. Therefore three separate frames are used to visualise the vena subclavia, the VCS and the right ventricle. Less accuracy is necessary when delineating the lateral lung boundary.
After generating the lung curve a curve, fitting is carried out using a gamma variate function. This function displays a curve with a rapid upslope followed by an exponential down slope. Subtraction of the fitted curve from the original curve results in a 'recirculation curve'. If an early recirculation peak is identified, a second curve fitting is applied to the resulting curve using the gamma variate function. An early recirculation peak appears compared to findings in a normal recirculation, which occurs only after the circulation has passed through the systemic capillary bed. Whether or not a recirculation peak is abnormal can be evaluated by comparing the lung curve to a curve generated over the proximal abdominal aorta: an early recirculation peak appears at the same time as a peak over the abdominal aorta.
e. The QP/QS ratio (QP = pulmonary circulation and QS = systemic circulation) is calculated by dividing the surface area under the fitted curve (A1) by the difference between this surface area and the surface area under the fitted early recirculation curve (A2). *QP / QS = A1/A1-A2*
The LR shunt formula in percentages is as follows:
L-R–shunt = (A2/A1) x 100 [%] = [1 - (1/QP/QS)] x 100 [%]

9. Interpretation

a. The time-activity curve over the superior vena cava must contain a single peak. A fractionated bolus, sometimes due to poor injection technique, can lead to inaccurate results.
b. There will be an overestimation of the shunt fraction when the investigations is performed on a crying child. The reason being increased resistance in the pulmonary

capillaries. The Valsalva manoeuvre can also affect the continuity of the bolus flow before it reaches the right side of the heart. Severe congestive heart failure, severe valve disease (both right and left) and severe pulmonary stenosis can lead to inaccurate results.

c. Significant errors can be made if the region over the right lung is drawn inaccurately (e.g. overlapping other structures).
d. Fitting the recirculation curve can also generate errors. A relatively large surface area may be created if there is no clear peak; this can result in over-estimation of the shunt or even an entirely false positive result.
e. Lung curves must be evaluated visually. If no clear early or premature recirculation peak can be seen in the descending part of the curve, shunt calculation will not be reliable. Shunt detection as described in this protocol is reliable between QP/QS values of 1,2 and 2,0 (L-R shunt between 20% and 50%). The risk of a false positive result is extremely high for values lower than 1,2. Values over 2 over estimate the shunt size.

10. Report

The report should contain the following information: bolus quality, presence or absence of L-R shunt and the size of this shunt.

11. Literature

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