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*Original Article*

# Balloon occlusion pulmonary wedge angiography and lung biopsy assessment in the child with a congenital cardiac defect

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Balloon occlusion pulmonary wedge angiography is a valuable adjunct to the hemodynamic assessment of pulmonary hypertension at the time of cardiac catheter study and should be considered in light of those hemodynamic data and not to their exclusion. Technical details of the procedure are previously published and are briefly described below.[1] The information gained provides a qualitative assessment of the filling of distal precapillary vessels seen as a 'background haze' and therefore is helpful in assessing loss of distal vessels. It provides a semi-quantitative assessment of pulmonary venous return and can reflect reduced cardiac output or impaired venous return because of intrapulmonary venous abnormalities, since deflation of the balloon allows clear separation of the arterial and post-capillary vasculature. It allows for the identification of segmental and subsegmental pulmonary arterial branch stenoses. It can be useful in detecting ateriovenous shunting. In children less than two years of age rate of taper of the pulmonary arteries between 2.5 and 1.5 mm lumen diameter has proven useful in predicting severe pulmonary vascular disease, although in older children this feature was less reliable and when there is severe disease and reduced background filling the lumen diameter can be extremely narrow all the way to the hilum. This measurement is also unreliable in the presence of a previous pulmonary arterial band or when there is post-stenotic dilation of the central pulmonary arteries. However, in children under a year of age as a rule, an axial artery length between 2–5 to 1.5 mm of greater than 15 mm denoted normal biopsy findings or grade A and between 10–15 mm of at least grade B (medial hypertrophy) and less than 7 mm then grade C (loss of arteries ± neointimal formation).

The preferred or standardized location of the catheter is directed to the posterobasal segment artery of the right or left lower lobe (one rib space below the takeoff of the right pulmonary artery or two rib spaces below the takeoff of the left pulmonary artery). Once the balloon is inflated contrast is injected at 0.3 ml/kg a minimum of 2 ml, at a flow rate of 5 ml/sec. Then the balloon is let down and the contrast is followed until it enters the left atrium. To quantify tapering anteroposterior and lateral calibration marks, X-ray source and image intensifier position are recorded.

## Lung biopsy

Lung biopsy is a valuable adjunct to the hemodynamic evaluation and information derived from the balloon occlusion wedge angiography, but should be considered in light of these assessments and not to their exclusion.[2–5]

### *Technique*

The ideal location for biopsy tissue is from the right upper lobe and the size of the tissue is an inflated

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segment of lung isolated by C clamp of no smaller than $2 \times 1 \times 1$ cm. The lung is excised between two C clamps and the tissue between the clamps is oversewn. The lingula although more easily accessible is not a good location because there is extensive connective tissue relative to the lung parenchyma available for evaluation.

The biopsy is helpful when the hemodynamic and wedge angiographic data reveal borderline indications for surgical correction. Assessments can be made on a frozen section providing the tissue is lightly fixed in warmed gluteraldehyde (37°C) prior to embedding in OCT. These assessments should only be made when the reading pathologist is confident of the quality of the fixed and stained specimens. If there is any question then it is wise to wait until careful examination of the fixed tissue can be made, even if that necessitates a second surgery.

To visualize fully the extent of the vascular pathology, elastic tissue or Movat stain should be carried out. In making the assessments either on a frozen or a fixed section, it is imperative to examine all fields of the biopsy and all blood vessels and while the focus is on the arteries, qualitative examination of the veins is important as we have anticipated in some cases, the evolution of pulmonary venous obstruction.

The lung biopsy specimen is given first a morphometric grade.

- Grade A: Extension of muscle into peripheral arteries normally nonmuscular, either as a solitary finding or associated with a mild increase in the medial wall thickness of the normally muscular arteries (less than 1.5 times normal)
- Grade B: Extension as in grade A but greater medial hypertrophy; subdivided into B (mild) if medial wall thickness is greater than 1.5 but less than 2 times normal and B (severe) if wall thickness is 2 times normal or greater
- Grade C: Features of B (severe), with a decreased number of peripheral arteries relative to alveoli and usually decreased arterial size; subdivided into C (mild) when more than half the normal number of arteries is present and C (severe) when half the normal number of arteries or less is observed.

Each biopsy section is also graded according to the Heath-Edwards classification.[6] In Heath-Edwards grade N (normal) there is no striking evidence of medial hypertrophy (i.e., equivalent to morphometric grade A or B [mild]). In Heath-Edwards grade I medial hypertrophy can be appreciated subjectively (i.e., equivalent to morphometric grade B [severe]). Heath-Edwards grade II describes the presence of eccentric or concentric intimal hyperplasia, and in grade III occlusive intimal hyperplasia with hyalinization of the media is observed. Heath Edwards Grade IV denotes plexiform lesions with areas of thinning of the media and obliteration of the lumen at branch points and also vascular dilatation complexes. In Grade V, extensive angiomata are seen both within the neointima and in the adventitia and Grade VI denotes fibrinoid necrosis. This change is rarely seen.

In interpreting the lung biopsy, a few guidelines are helpful based upon our previous studies. These guidelines, however, are based on a relatively small sample size and may need refinement. Our previous studies have also shown uniformity in the appearance of the vascular pathology in different sections of the lung.[5]

In infants between 6 months and 2 years of age, there is still a greater than 50% chance that even advanced lesions may regress. In older children, regression will occur if there is evidence that the pressure can be appreciably reduced by the intervention. In our experience the net flow may be reduced but the resistance has remained essentially unchanged. In any age group, the presence of medial hypertrophy, extension of muscle into distal vessels, is always associated with return to normal hemodynamics. In infants under 6 months of age, there were no structural changes that we found that in-and-of themselves preclude surgical intervention. That is, in infants below 6 months of age, with a net left-to-right shunt, even advanced vascular changes including loss of vessels and occlusive neointimal formation resulted in return to normal hemodynamics after surgical correction. We have no experience with plexiform lesions in this age group. However, in children between 6 months and two years, loss of vessels, and neointimal formation when occlusive resulted in a 50% chance of regression of elevated pulmonary vascular resistance. In children of this age group, plexiform lesions were again rare, but in older children with plexiform lesions, persistent and progressive elevation in pulmonary vascular resistance is expected.

Lung biopsies are not routinely performed in many institutions, in particular since the opinion of expert pathologists is needed for an adequate interpretation of pathologic findings. Prognosis cannot be established purely on the basis of qualitative analysis of pulmonary vascular lesions. Rather, morphometric data must be provided, with detailed information on the status of small intraacinary vessels (number relative to alveoli, atrophy and dilation of small arteries, etc.). Information must be provided on the presence or absence of perivascular inflammatory elements or infiltrates throughout the vascular wall. These data can be complemented with targeting of specific biomarkers

to provide helpful intraoperative information on the potential for reversibility of lesions, in particular in subjects with moderate to severe disease who are potential candidates for long-term medical therapies following repair of the congenital cardiac anomalies.

### *Caveat*

When considering children with more complex congenital cardiac defects, where even mild pulmonary hypertension may preclude surgery that requires a venous to pulmonary arterial conection[7] or when evaluating pulmonary hypertension in the setting of major aortopulmonary collateral arteries, one must be aware, both on wedge angiography and on biopsy, of the great variability in the pulmonary arterial changes. In these groups in particular, previous surgical interventions will lead to scarring of the pleura with vessels that show extensive neointimal formation. The vessels that need to be assessed are within the lung parenchyma. Our previous unpublished studies have shown that even medial hypertrophy can result in elevated systemic venous pressures and a prolonged hospital course and this is consistent with postmortem findings.[7]

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