Review

Review of Preoperative Functional Evaluation for Lung Resection Using the Right Ventricular Hemodynamic Functions

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Surgery for patients with lung cancer diminishes their lung functions, due to removal of their lung lobes. Therefore, thoracic surgeons have to consider postoperative lung function of patients. In this review, we explained recent approaches of estimation of postoperative lung function by spirometrical and also pulmonary circulatory measurement values. The most common and simple way to estimate postoperative conditions for patients who undergo lung resections is calculated by numbers of segments that are removed by surgery. However, these methods are not so accurate when the patients have chronic obstructive pulmonary disease. Another method for estimating postoperative conditions using right heart catheterization is a unilateral pulmonary arterial occlusion (UPAO) test. Applying this method, surgery related deaths have been decreased. Since, UPAO test mimics the postoperative state by occluding the pulmonary artery prior to lung surgery, it is supposed to be very accurate. Recently, a novel method to estimate postoperative right heart reserve functions was developed. Using this method, postoperative right heart failures can be anticipated prior to lung resections. In this review, we explain these kinds of methods to prevent impairment of postoperative quality of life. (Ann Thorac Cardiovasc Surg 2004; 10: 333–9)

Key words: lung cancer, preoperative functional evaluation, postoperative right heart reserve function, UPAO

Introduction

The prognosis after operation for primary lung cancer is improving slowly with recent advances both in perioperative management for patients and preoperative assessment for lung resection. Lung resection leads to a decrease in the pulmonary vascular bed and an increase in the possibility of acute right heart failure. In addition, inflammation in the thorax and lungs after surgery induces acute respiratory distress syndrome (ARDS). To prevent acute post-operative complications, namely, ARDS, right heart failure or hypoxia, several proposals of preoperative assessments for lung resection were intended. We performed a unilateral pulmonary arterial occlusion (UPAO) test for the preoperative evaluation of right heart function as a loading test. The UPAO test simulates a decrease in the pulmonary vascular bed after lung resection, and also evaluates the reserve power of right heart function. The functional limits for pneumonectomy or lobectomy using total pulmonary vascular resistance index (TPVRI), mean pulmonary arterial pressure (mPAP) and cardiac index (CI) by UPAO tests have been proposed. However, some patients whose UPAO test results were within the functional limits for lobectomy or pneumonectomy, had cardiac complications after lung resections. Therefore, this novel preoperative function test was developed to predict postoperative right heart failure.

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Preoperative Functional Evaluation

1. Pulmonary function tests

Preoperative pulmonary function tests were routinely

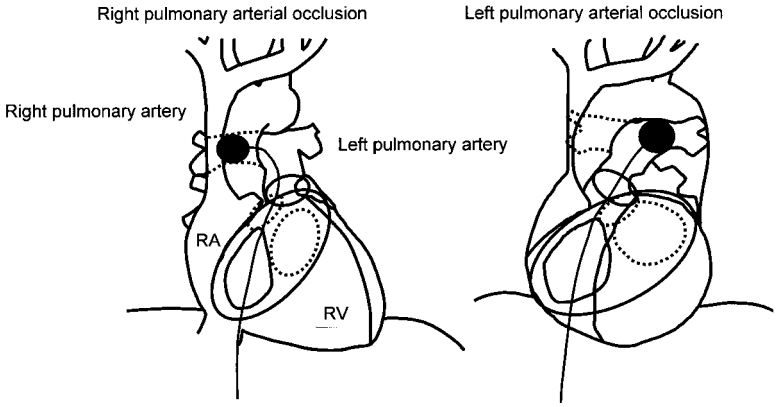

Fig. 1. An illustration of positions of balloons of the pulmonary arterial occlusion catheter during the UPAO test.
RA: right atrium; RV: right ventricle

performed by spirometry. The forced expiratory volume in one second ($FEV_{1.0}$) and the vital capacity (VC) and lung volumes were measured. Split-function studies to estimate the predicted postoperative (ppo) and the predicted contralateral (pcl) values of various parameters were performed based on the former reports.[1-3] The scintigrafic formula generally used is: $FEV_{1.0}$-ppo = preoperative $FEV_{1.0} \times (1 -$ functional contribution of the parenchyma to be resected). The functional contribution of parenchyma to be resected was calculated as (the fraction of pulmonary blood flow to be resected side) × (the number of segments to be resected) / (the number of segments of the lung to be resected). $FEV_{1.0}$-pcl = preoperative $FEV_{1.0} \times$ fraction of pulmonary blood flow of the contralateral side.

2. UPAO test

An UPAO test is performed in patients whose value of $FEV_{1.0}$-ppo/body surface area (BSA) was less than 850 $ml \cdot m^{-2}$, or value of $FEV_{1.0}$-pcl/BSA was less than 800 $ml \cdot m^{-2}$. Several days prior to the lung resection, a pulmonary arterial occlusion catheter was inserted to the pulmonary arterial trunk of the side to be resected and the right heart hemodynamics were examined (Fig. 1). Before and during a temporary unilateral occlusion of the pulmonary artery, the cardiac output (CO) and the CI ($CO \cdot BSA^{-1}$), the mPAP, using a CO computer, and a pressure transducer, respectively, are measured. Mixed venous and arterial blood gas analyses are obtained. The TPVRI ($dyne \cdot sec \cdot cm^5 \cdot m^{-2}$) is calculated as follows:

$$TPVRI = mPAP\ (mmHg) / CI\ (l \cdot min^{-1} \cdot m^2) \times 80 \quad (1)$$

3. Right ventricular end-diastolic volume ratio

During the UPAO test, right ventricular functional values can be calculated using a thermodilution method. They are right ventricular ejection fraction (RVEF), right ventricular end-diastolic volume index (RVEDVI), right ventricular end-systolic volume index (RVESVI) and right ventricular stroke volume index (RVSVI), before and during UPAO test, respectively. Right ventricular stroke work index (RVSWI) is calculated as follows:

$$RVSWI = mPAP \times CI / HR \times 0.0136 \quad (2)$$

The other formulas of indices are as follows:

$$RVEF = RVSV / RVEDV \quad (3)$$

$$RVEF\ ratio = RVEF\ during / RVEF\ before \quad (4)$$

$$RVEDV\ ratio = RVEDV\ during / RVEDV\ before \quad (5)$$

In this formula, 'ratio' stands as a suffix for the ratio of values for before and during UPAO test. (HR: heart rate)

Table 1. Functional limits by spirometrical test values

VC > 3.0 l
$FEV_{1.0}$ > 2.0 l
$FEV_{1.0}$/VC > 50%
MVV > 60 $l \cdot min^{-1}$
RV/TLC > 50%
Raw < 5.0 $cmH_2O \cdot l^{-1} \cdot sec$

VC: vital capacity; $FEV_{1.0}$: forced expiratory volume in one second; MVV: maximal voluntary ventilation; RV/TLC: residual volume/total lung capacity; Raw: airways resistance (after bronchodilators)

4. Preoperative functional limits by spirometrical test values

Some facilities use only spirometrical test values for preoperative functional limits for lung resections. These spirometrical tests are the most important methods for preoperative evaluation for surgery of lung cancer. They are listed in Table 1.[4-6] Although, these limits are easy to obtain, there are many who cannot undergo lung resections. Since spirometrical lung function tests need cooperation of patients, reserve functions can be underestimated.

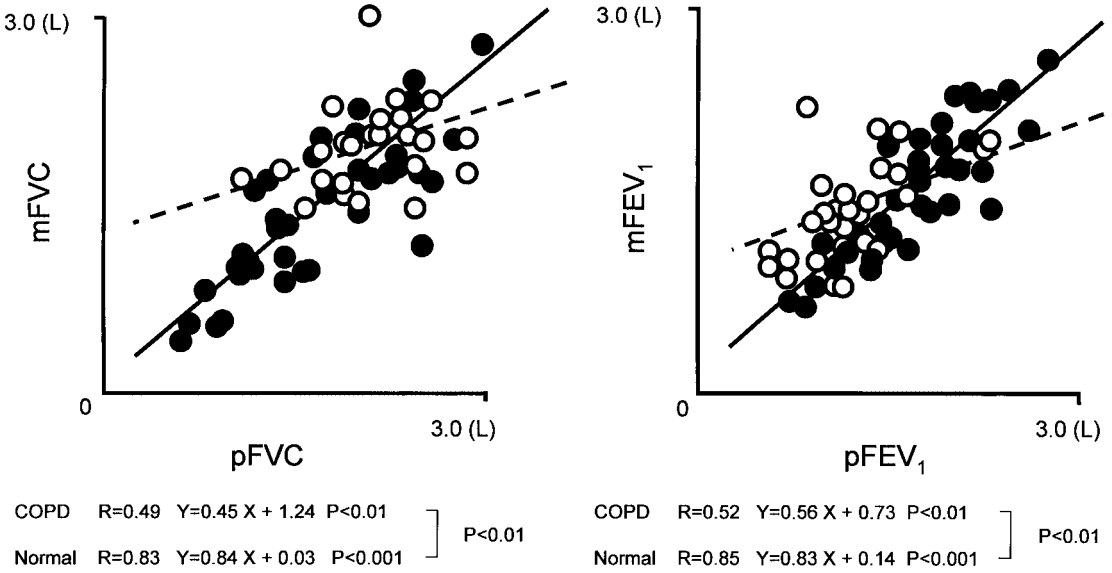

Fig. 2. The relationships between predicted values and postoperative values of patients with COPD. Data from forced vital capacity (FVC) and forced expiratory volume in one second ($FEV_{1.0}$) are shown in the figure. measured (m): postoperative measured values; predicted (p): preoperative predicted estimation
Open and closed circles represent data of COPD and normal subjects, respectively. Dotted and solid lines represent regression lines from COPD and normal subjects, respectively. Note that each slope of regression line from COPD and normal subjects in each panel is different.

5. Preoperative functional limits by split pulmonary function test

Using the formula by Ali or Ashino, we can estimate postoperative pulmonary function values preoperatively. One of the most important values after lung resection is residual $FEV_{1.0}$, because patients in whom $FEV_{1.0}$ is lower than 1.5 l start to have dyspnea on exertion and lower than 0.8 l start to have dyspnea at rest. However, the estimation of postoperative lung function values tended to shift when patients suffered from chronic obstructive pulmonary disease (COPD) (Fig. 2). Therefore, estimations of accurate postoperative pulmonary function values become more difficult when preoperative pulmonary function values are low.

6. Preoperative functional limits by UPAO test[7-9)]

Surgical operations for lung cancer, namely pneumonectomy or lobectomy decrease the pulmonary volume and vascular bed. Since CO after surgery may not be changed, relative pulmonary blood flow in the residual lung tissue will be increased. The UPAO test simulates loss of pulmonary vascular bed, and estimate an extent of increase in the pulmonary vascular resistance and pulmonary arterial pressure. When increases in pulmonary vascular resistance and/or pulmonary arterial pressure are small, there are no changes in pulmonary circulation, CO, and extravascular pulmonary water volume. Conversely, when increases in the pulmonary vascular resistance and/or pulmonary arterial pressure are large; there are decreases in CO and increases in extravascular pulmonary water volume that lead to decrease in oxygen uptake and finally developes into pulmonary and cardiac insufficiency. During the UPAO test, a decrease in the pulmonary vascular bed is mimicked by occluding the pulmonary artery using a balloon on the tip of a catheter. Our preoperative functional limits by UPAO test are listed in Table 2. The most important limits are the values of TPVRI, mPAP and CI. Although we also refer to the values of arterial

Table 2. Functional limits during UPAO test values

TPVRI < 700 ($dyne \cdot sec \cdot cm^{-5} \cdot m^{-2}$)
mPAP < 30 mmHg
CI > 2.0 ($l \cdot min^{-1} \cdot m^{2}$)
PaO_2 > 60 Torr
PvO_2 > 30 Torr

TPVRI: total pulmonary vascular resistance index; mPAP: mean pulmonary arterial pressure; CI: cardiac index; PaO_2: arterial oxygen pressure; $PaCO_2$; arterial carbon dioxide pressure

Table 3. Surgery related deaths after lung resections of primary lung cancers

Period	No. of lung resections	No. of surgical death	No. of hospital death	No. of surgery related death
1952-1959	54	8	1	9 (16.7%)
1960-1969	184	12	0	12 (6.5%)
1970-1979	421	11	0	11 (2.8%)
1980-1989	1111	19	6	25 (2.3%)
1990-1999	1624	19	18	37 (2.2%)
	3394	69	25	94 (2.8%)

Data from Tohoku University, Sendai Kousei Hospital, and Iwate Medical University.

and mixed venous partial pressure of oxygen (PaO_2 and PvO_2), they are not absolute limiting factors because of the possibility of using home oxygen therapy. Even if the PaO_2 were lower than 60 Torr during the UPAO test, that was supposed to be the same condition after surgery, the patient can be discharged from hospital with the help of home oxygen therapy.

One of the most important values for the preoperative functional limit is mPAP. The 5 year survival rate for the patients who were diagnosed with pulmonary hypertension is 10 to 54% whose mPAP is higher than 50 mmHg and is 50 to 63% whose mPAP is between 30 to 50 mmHg. Conversely, the 5 year survival rate of patients in whom mPAP is less than 30 mmHg is almost 100%.[10-12] Another important value for the preoperative functional limit is TPVRI. An increase in pulmonary vascular resistance leads to an increase in work load of the right ventricular cardiac muscle. When the increase in the TPVRI is permanent such as in a post-pneumonectomy state, exhaustion of right heart cardiac muscles leads to congestive heart failure. The last important value is CI. A decrease in CI diminishes oxygen delivery that is necessary to keep body tissues alive. Of course, a decrease in PaO_2 also diminishes oxygen delivery. On the other hand PvO_2 stands for oxygenation of peripheral tissues. When the value of PvO_2 is lower than 30 Torr, peripheral tissues are exposed to a severe hypoxic condition. However, as stated above, even when patients fall into a hypoxic state, there is another solution, namely home oxygen therapy. The operation related deaths have been decreased to 2.2% after the UPAO test was applied to the patients with impaired lung function values (Table 3).

7. Novel preoperative functional limits for preventing right heart failure[13-15]

Using the UPAO test, surgery related deaths were diminished minimally, after lung resections. However, some patients who had undergone lung resection developed cardiac complications, namely, arrhythmias and congestive heart failures that were necessary to be controlled by medication. Therefore, a novel functional limit has been developed recently. We have examined 72 lung cancer patients (26 Stage IA, 9 Stage IB, 18 Stage IIA, 11 Stage IIB and 8 Stage IIIA) in whom partial resection (14 cases), lobectomy or bilobectomies (47 cases) and pneumonectomy (8 cases) was carried out. During the UPAO test, right ventricular functional values, such as RVEF, RVEDV, and RVSVI are obtained and are calculated to the ratio of those values. These ratios before and during UPAO are results of a volume and/or pressure loading test to right heart functions. RVEF ratio contains the ratios of RVSV ratio and RVEDV ratio.

RVEF ratio = RVEF during / RVEF before
= (RVSV during / RVEDV during) / (RVSV before / RVEDV before)
= (RVSV during / RVSV before) / (RVEDV during / RVEDV before)
= RVSV ratio / RVEDV ratio (6)

Changes in the RVEF ratio were examined in the function of changes in the RVSV ratio and RVEDV ratio. Only changes in RVEDV ratio were reversely related (Fig. 3a, b). However, changes in the RVEDV ratio were not related to the TPVRI ratio (Fig. 4). We also examined relations between postoperative cardiac complications and changes in TPVRI ratio or changes in RVEDV ratio. Incidence of cardiac complications were significantly increased when the RVEDV ratio was higher than 1.2. When right ventricular reserve capacity is decreased, an increase in the right ventricular afterload tends to be compensated by changes in contractility of the myocardium.[16,17] This is seen when the values of changes in RVSWI as a function of RVEDV ratio separated at RVEDV ratio = 1.2 are plotted. The slope of changes in RVSWI and RVEDV ratio are less steep when the RVEDV ratio is higher than

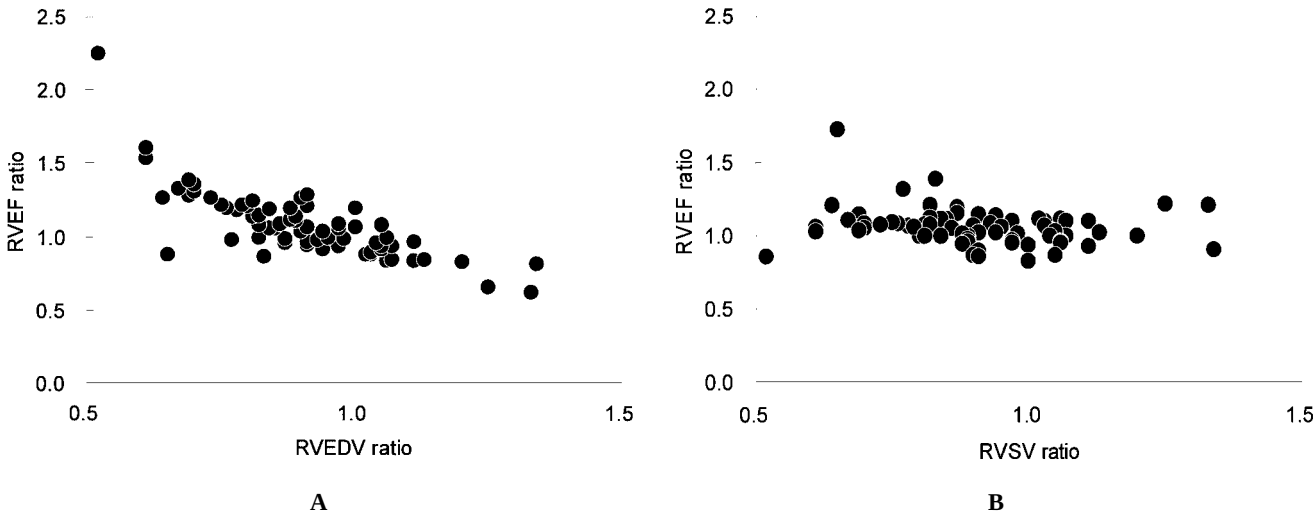

Fig. 3. The relationships of the RVEDV ratio (A) and RVSV ratio (B) as a function of RVEF ratio. Only values of RVEDV ratio and RVEF ratio were related reversely.

1.2 (Fig. 5). On the Frank-Starling's ventricular function curve, stroke volume is a function of end-diastolic length of the myocardium. However, stroke volume starts to decease at the excessive end-diastolic length of the myocardium. Those cases that developed right heart insufficiency after lung surgery could not compensate to increase CO against increase in afterload. What happened to the relationships of RVSWI and RVEDV ratio on the Starling's function curve? (Fig. 6) A point of preoperative status (A) transferred to a hyper-functional curve (B) during UPAO test; if RVEDV ratio was lower than 1.2. On the contrary, a point of preoperative state (A) transferred to a hypo-functional curve (C) during UPAO test, if RVEDV ratio was higher than 1.2. The cardiac complications after lung surgery represent an excess overload to the right ventricular myocardium because of loss of pulmonary vascular bed. An excess volume load to the right ventricle may give stretch-stimulations to intra-arterial and/or atrio-ventricular conduction systems, and then may generate arrhythmias. It also generates backward volume overload and leads to congestive heart failure. It is really important to avoid overhydration during a general anesthesia in order to prevent postoperative cardiac complications.

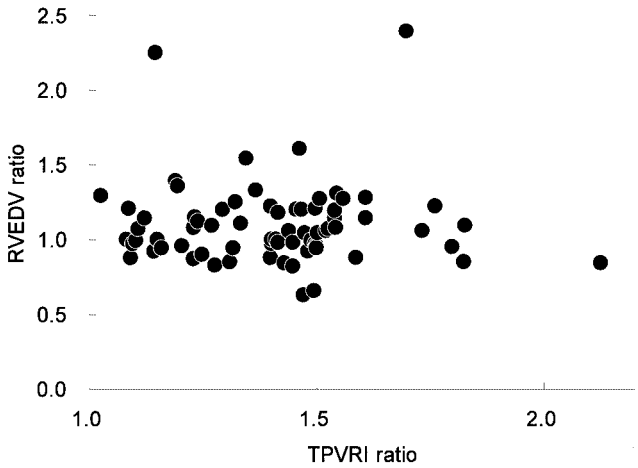

Fig. 4. The relationship between TPVRI ratio and RVEDV ratio. They are not correlated at all.

Conclusions

Surgery for lung cancer patients diminishes their lung functions, due to removal of lung lobes. Therefore, thoracic surgeons have to consider postoperative lung function of patients to prevent postoperative impairment of activities of daily living. In this manuscript we explained several methods to estimate postoperative lung function prior to their surgery. Since, each method has its pros and cons, thoracic surgeons have to make their choice on the basis of their facilities. We believe that the more accurate the assessments of postoperative pulmonary functions of lung cancer patients the safer their surgery and general anesthesia. Surgery remains the treatment of choice for lung cancer, offering the best prospects for cure and long-term survival. Therefore, quality of life for those patients after lung surgery should be guaranteed.

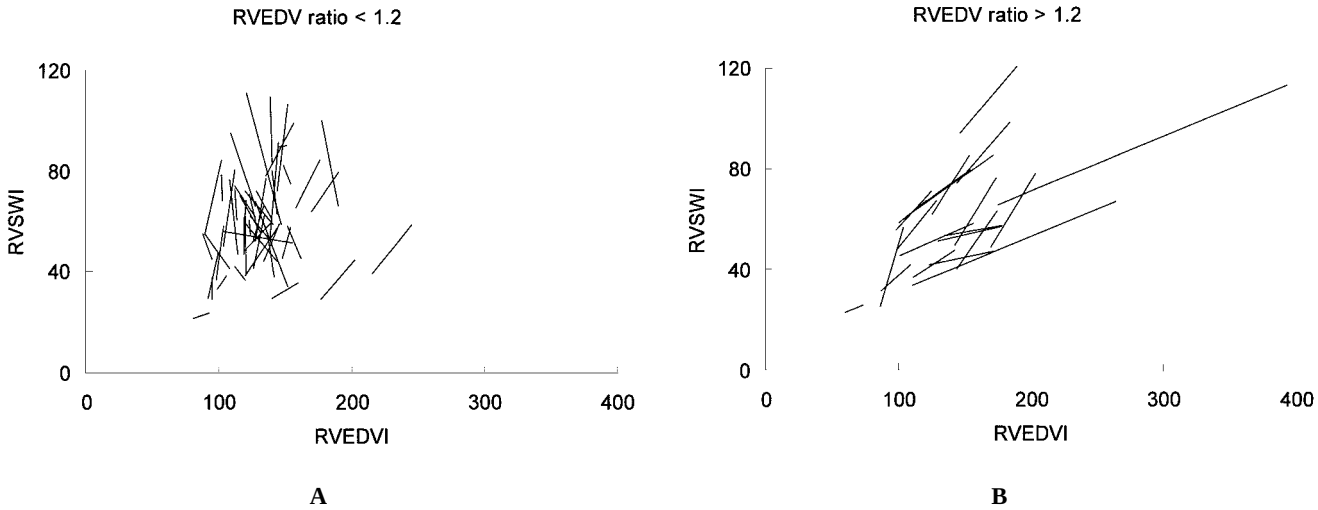

Fig. 5. The relationships of changes in RVSWI as a function of RVEDV ratio separated at RVEDV ratio = 1.2. Each bar represents the values of the pair of RVSWI and RVEDVI from before and during UPAO. Panels A and B show data from RVEDV ratio <1.2 and >1.2, respectively. Although, each bar in the upper panel stands in vertically and that in the lower panel horizontally.

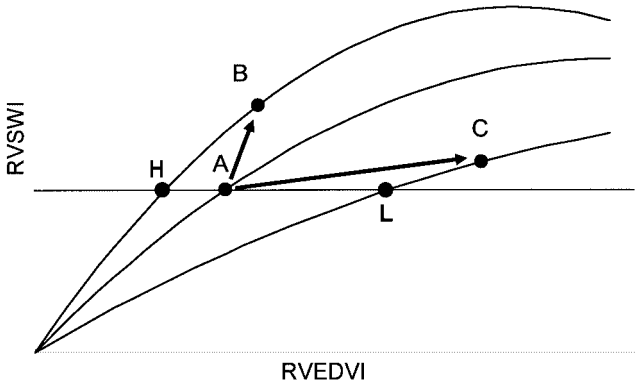

Fig. 6. Diagrammatic representation of the use of the Frank-Starling mechanism as a compensation for congestive heart failure. The three curves depict right ventricular function in normal subjects and in those with congestive heart failure and hyper function state. The points A to B and A to C represent in sequence: increase and decrease in contractility during UPAO test (A to B) and (A to C), respectively. Of note is the fact that points of H, A and L all lie on the same line in the vertical axis and thus all represents the same RVSWI, but each is on a different RVEDVI on the horizontal axis.

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