APG® Air Plethysmograph Advanced Course

Introduction

Over the years, we have learned much about APG® testing and interpretation. The attempt here is to provide as much of that knowledge as possible so that better data and interpretations are possible. The venous system and its assessment are complex. The ideal tools for venous assessment are the duplex ultrasonic imaging system combined with the APG® system. We suggest first performing the APG® tests. Then the technologist will have a better idea of what to look for with duplex imaging. This approach will shorten the total investigation time while providing the best possible understanding of the patient's venous problems.

This paper assumes the reader has a basic understanding of APG® testing. We are happy to supply a variety of literature that explains in detail the definitions and calculations used in APG® testing. Briefly, VFI is the venous filling index which represents the average, gravity induced, filling rate of the veins to 90% of the total venous volume (VV) after first being emptied by gravity. VFI does not rely on the calf muscle pump for complete vein emptying. Ejection fraction, EF, represents the efficiency of the calf muscle pump and is analogous to left ventricular ejection fraction used in cardiology. Residual volume fraction, RVF, is proportional to the invasively measured ambulatory venous pressure, which is a global measurement related to severity of disease. Outflow fraction, OF, tests the ability of the deep and superficial veins to empty the calf. Arterial inflow, AI, measures the filling rate of the veins by arterial inflow.

While great effort has been made to write software that automatically selects the appropriate points on the various APG® curves, the user must always check that the points are correctly chosen.

APG® users are welcome to send traces to us or to set up a no-charge training session here in ACI Medical's San Diego area factory.
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Calibration

Calibration is needed only each time the sensing cuff is applied to the limb. It need not be done between each test on a given limb. The patient is placed in the supine position with the test leg externally rotated, while the foot is elevated with foam block and the knee is slightly bent. The cuff must not touch the bed nor should it be touching the lower thigh behind the knee. If it does, use a shorter cuff length. Patients should not rest their hands on the abdomen.

Outflow obstruction tests

The outflow test sequence is done first since there is no exercise during the test. Exercise may cause hyperemia that will later affect VFI (thigh to calf reflux) tests.

Begin each test by inflating the cuff until the green light is lit on the APG controller. Do this by pressing the PUMP button once to start the inflation process and then press PUMP a second time to stop inflating. The system is sealed once the green light is lit.

The 10 cm thigh tourniquet with rapid deflator is positioned as far proximal on the leg as possible. It's inflated to 70 to 80 mmHg, until a plateau is reached as evidenced by the volume indicator in the upper right corner of the CRT screen. Once a stable plateau is reached, start recording and verify that the trace is reasonably flat. Compress the long saphenous vein (LSV) at the knee. Finger compression of the LSV is best done just above the knee to avoid compression of the posterior arch vein. You should see a small increase in calf volume by about 2 ml due to the displaced blood. If CW Doppler is done before the APG test, the LSV can be marked. Compress the LSV with a finger, increased the speed of the trace on the screen and rapidly deflate the thigh tourniquet by quickly depressing its plunger. Release the LSV after at least 2 or 3 seconds, slow the trace speed and wait for an ending baseline. Upon releasing the LSV, you will often see an acceleration of the outflow trace, which indicates you had good compression of the LSV.

If the outflow fraction with superficial compression (OFs) is normal, there is no need to repeat the test without LSV compression. These tests can be repeated without intentionally waiting between tests.

Many vascular technologists prefer not to do these outflow tests. However, this is not advised, since the results help greatly to explain aspects of VFI, EF and RVF tests. I'll explain in detail later.

There is often an apparent discrepancy between APG® and duplex imaging results. The APG® measures outflow while duplex imaging finds anatomical aberrations. OF and OFs tests may be affected by vein wall stiffness (unable to accommodate large outflow volumes), synechia and other manifestations of post-thrombotic veins such as multiple, recanalized lumens. There may not always be an anatomically identifiable obstruction. The combined OF and OFs information is helpful in understanding the effect of the superficial system as an outflow channel in post-thrombotic limbs.

Duplex imaging may identify reflux in a post-thrombotic deep vein. The obstructed vein may be so severe that the reflux rate (VFI) is actually small due to the obstruction's resistance to retrograde flow. In these cases, obstruction is the dominant factor; not reflux.

APG® has also been used to follow patients after deep vein thrombosis (DVT). Venous volume calf pump function and outflow fraction (OFs) improve as the affected vein recanalizes.

Arterial inflow tests

This type of test may not seem appropriate for venous assessment, but it is. The VFI test measures thigh to calf reflux and is influenced by arterial inflow rates. Interpretation of VFI assumes a normal arterial inflow rate of less than 2 ml/sec. If the leg has ulceration or severe skin discoloration, it may be hyperemic with an arterial inflow rate greater than 2 ml/sec. The arterial inflow may be as high as 5 ml/sec in resting, ulcerated legs and this must be taken into consideration when interpreting the VFI results. The patient remains in the same position as for the OF tests and a 10 cm tourniquet is simply reapplied to just above the knee. It may feel more comfortable if the patient rotates slightly onto the hip of the leg under test.

The trace will show rapid filling while the tourniquet is inflated to 70 mmHg due to the volume of blood displaced from under the tourniquet. Thereafter, the trace will increase linearly for awhile and that slope in ml/sec (or ml/min) is the arterial inflow rate (AI). Select the beginning point, just after the tourniquet inflation artifact.

If exercise hyperemia exists, the tourniquet must be inflated faster. Otherwise, by the time the tourniquet is inflated, the veins may be almost full, the slope of the inflow is low, and AI will be underestimated. It's good practice to always inflate the tourniquet as quickly as possible (it's good exercise for the hand).

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Venous filling index tests

It's important to recognize that VFI measures thigh to calf reflux only. Perforator reflux has no effect on VFI, nor does reflux isolated to either the calf or to the thigh. Therefore, VFI is not synonymous with "reflux". It is meant to measure what is thought to be clinically significant reflux from the thigh to the calf. There is value to quantifying reflux since not all reflux seen with Doppler/duplex imaging is clinically significant.

Since venous filling is measured, we want there to be resting arterial inflow. Therefore, when doing serial VFI tests, I suggest not doing the ten toe-up RVF test between VFI tests. I have seen exercise hyperemia from ten toe-ups lasting over 15 minutes. Certain academic investigators have failed to realize that and have paradoxically reported greater VFI's with LSV compression than without LSV compression.

Remember to begin the test sequence with the green light lit on the APG controller to ensure the test is done inside the calibration range. VFI tests can be performed serially without waiting between tests so long as there is no exercise.

The patient must help in getting a clean VFI trace by standing up smoothly and without bumping the cuff. They should stand without weight on the tested leg. As a guide to the patient, we tell them to just barely touch the floor with the big toe, which is directly to the side of the weight bearing foot. To make it easier for obese or elderly patients, they can be repositioned to the end of the bed. The untested leg is dangling and the tested leg is supported at a 45 degree angle by the test operator holding only the ankle/heel and not touching the cuff. Remind the patient to relax the leg muscles (letting the operator do the work of supporting the leg's weight) and keep the knee slightly bent to prevent popliteal entrapment. With the patient's buttocks at the edge of the bed, they can more easily stand straight up with the help of the operator. The operator should guide the tested leg down toward the floor with one hand while helping the patient up with the other. It's easier to do than it sounds.

We often see a negative trace immediately after standing. This is veno-arteriolar reflex (VAR) that causes vaso-constriction in response to the sudden increase in venous pressure. This vaso-constriction at the microcirculatory level serves to expel blood from the calf. It is not seen in patients with more severe disease (presumably because the VAR is diminished or the large amount of reflux overwhelms the VAR) but is often seen when demonstrating the APG on normal volunteers. We use the negative peak of this "artifact" as the beginning zero point of the VFI curve.

Motion artifact is not a problem so long as good beginning and ending plateau points are available. Venous volume, VV is measured from the beginning of the upslope to the filling plateau. The beginning zero is therefore selected to be both zero volume and zero time. Selecting the zero volume too early in the trace will result in underestimated VFI values.

There will usually be a difference between the venous volume (VV) measured in the VFI test and the venous capacitance (VC) measured in OF tests. These differences are due to the different venous pressures applied to fill the veins: hydrostatic standing pressures, versus supine, tourniquet pressures, respectively.

If you intend to separately quantify deep and superficial reflux, it's best to calculate the VFI immediately after acquiring the data to determine if reflux is present and immediately repeat the test with compression of the LSV. The immediately repeated VFI with superficial occlusion (VFIs) will not then be affected by exercise hyperemia induced from toe-up exercise. Generally, we have found that the single toe-up exercise performed in the EF test does not create significant hyperemia while the ten toe-up exercise of the RVF test does cause confounding hyperemia. Compressing the LSV is best done using the finger (as in the OF test) but it may be cumbersome for some operators to do well. The next best approach is up to the technologist. We supply a rubber wedge strap that is positioned over the LSV (previously marked) and tightly wrapped. Some technologists are good at using Penrose drainage tubing as a superficial tourniquet. There is the potential problem of compressing the popliteal

vein with Penrose tubing so one must be careful.

There will be patients that have such poor outflow fractions that they appear to have minimal deep reflux with correspondingly low VFI's of, say, 2 or 3 ml/sec. In these cases, the obstruction normalizes calf filling despite the complete absence of valve function as may be seen with duplex ultrasonic imaging. This is another reason to do the outflow fraction tests.

Ejection fraction tests

The EF test is explained to the patient in three steps. First, they are to apply weight on both legs equally without bumping the cuff against the other leg. Next, they do their best toe-up effort using both legs equally and without supporting their weight via their hands on the support frame. The support frame is only for balance. They remain in the toe-up position for several seconds until the ejection volume is stable (plateau). Finally, the patient returns to the resting position by removing their weight from the test leg with the toe just touching the floor. The veins will quickly refill. If they refill a little higher than the filling volume of the VFI test, it's due to the effect of exercise hyperemia. A small drop in refill volume compared to the VFI volume indicates sensing cuff slippage. Cuff slippage is common when testing over elastic stockings. We suggest applying two vertical pieces of double sided tape between the stocking and sensing cuff.

Patients with poor outflow (deep vein obstruction) will take longer to expel calf blood with the single toe-up movement. Were the patient to perform the toe-up quickly, less blood would be ejected past the obstructed vein and the calf pump would appear less effective. It can be argued that maintaining the toe-up position for several seconds demonstrates calf pump potential, while a momentary toe-up better simulates walking and the effect of chronic obstruction in reducing the calf pump to a functional level.

Whichever approach is used, always have the patient repeat the EF test after the veins completely refill to be certain the results are repeatable.

You will occasionally find that the EF is calculated to be greater than 100%. At first, this seems to make no sense. However, remember that the VFI zero point is based upon the veins being emptied by gravity. Some people have exceptionally good calf pumps such that their exercise effort empties more blood than does gravity. These are super-normals and you should avoid playing them in a tennis match.

The possible causes of poor calf muscle pump are: 1. Non-venous related problems including arthritis, ankylosis and neurological deficit (whatever prevents the patient from making a good toe-up movement). 2. Proximal obstruction that prevents blood from quickly exiting the calf veins. 3. Incompetent calf perforator veins that shunt blood from the deep to superficial system within the calf. 4. Calf varicosities that retain a large venous volume not expelled with calf muscle contraction.

Residual volume fraction tests

Before beginning the RVF test, one should be certain that VFI testing is completed. The exercise hyperemia from the 10 toe-ups will almost certainly increase VFI and may be mistaken as reflux. The 10 toe-ups are done similarly to the single toe-up in the EF test, but they are done quickly: approximately one per second. After that, the veins are allowed to refill while the patient stands in the resting position (all weight on the non-tested leg). Finally, the patient is returned to the supine position with the operator holding the heel/ankle of the test leg up at 45 degrees with the knee slightly bent. This position is held until an ending baseline is reached.

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The ending baseline (after the RVF test) may be higher or lower than the baseline value at the beginning of the VFI test. Higher ending baseline values are typically the result of exercise hyperemia and an outflow obstruction. The arterial inflow is greater than the obstructed vein's capacity for outflow and the calf cannot be completely emptied. The RVF is not reliable in this case since it will be an artificially low (normal) value due to the obstruction related, elevated baseline. Again, knowing the outflow fractions are necessary to properly interpret the RVF test results. One could use the beginning baseline from the VFI test to get a more accurate RVF measurement when poor outflows exist. Another possible cause of elevated ending baselines is that the leg is not raised high enough.

Lower ending baseline values are typically the result of cuff slippage during the ten toe-up exercises. The RVF is a ratio and is not affected by a small amount of slippage. That's why we use the ending baseline rather than the beginning (VFI) baseline.

Serial RVF tests are not recommended since the effect of exercise-induced hyperemia is quite variable and significant. After an RVF test, it is recommended to perform an arterial inflow test to ensure a return to resting levels (below 2 ml/sec) prior to doing additional VFI tests. You could be waiting 15 minutes or more.

Occasionally, you may see RVF's calculated to be a negative number. This is due to greater calf emptying with exercise than with gravity. Obstruction may play a role here along with anything else that prevents adequate emptying after exercise.

Recently, the RVF test has been modified by having the patient walk on a treadmill. Walking is no longer simulated by the 10 toe-up movements and the effect of the calf pump is a more accurate reflection of ambulating. Treadmill testing better shows the subtle differences in calf pump function found with the use of compression stockings. The toe-up movement may be such an overpowering use of the calf pump that the effect of compression stockings is overwhelmed and unnoticed.

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