OLD INSTRUMENTS HISTORY

SHORT REVIEW

A Reminiscence of the Diagnostic Value of Phleboreography in the Pioneering Work of Professor John J. Cranley at the Good Samaritan Hospital (Cincinnati, Ohio)

JM Lohr

Willian Jennings Bryan Dorn Veterans Affairs Medical Center

submitted: Aug 1, 2024, accepted: Aug 15, 2024, EPub Ahead of Print: Aug 26, 2024, published: Aug 31, 2024
Conflict of interest: None

DOI: 10.24019/jtavr.205 - Corresponding author:Dr. Joann M Lohr, jlohr@lohrss.com, reardon@ix.netcom.com

Abstract Objective: The aim of this paper is to describe the many contributions of John J. Cranley developed at Good Samaritan Hospital in Cincinnati, Ohio. This includes phleborheography which was one of the earliest noninvasive vascular tests developed by Dr. John J. Cranley. Methods: This is a retrospective review of the laboratory manual at Good Samaritan Hospital, articles and publications authored by Dr. Cranley regarding use of phleborheography for the diagnosis of DVT prior to the era of duplex imaging. Results: The development and technique for the performance of phleborheography testing is described. Interpretation criteria, sources of error, extrinsic venous compression, equivocal testing, non-occlusive thrombi, acute and chronic deep vein thrombosis, chronic occlusion of major veins, and pulmonary embolism following a negative PRG are discussed. Conclusions: This functional test was most accurate in diagnosing and localizing acute DVT. These functional principles continue to be applied currently with the air plethysmography. Dr. John J. Cranley was one of the early giants in vascular surgery especially in the development of noninvasive vascular testing and use of the vascular laboratory with applications for patient management in vascular surgery. He had a very inquiring mind. He enjoyed mentoring and sharing his knowledge with anyone who would listen or debate. It was a privilege to have him as my mentor.

Keywords DVT diagnosis, Phleboreography, John J Cranley, History vascular laboratory, Functional vascular testing

The first laboratory specifically designated for the study of human peripheral circulation is usually ascribed to Robert R. Linton and Fiorindo A Simone at MGH in 1946. Dr. Cranley completed a fellowship at MGH and transitioned to the University of Cincinnati in Cincinnati, Ohio in 1951. Unfortunately, 2 years later the chairman of the department of surgery kindly let it be known that he opposed vascular specialization and did not want a section of vascular surgery. This precipitated Dr. Cranley's move to Cincinnati's Good Samaritan Hospital and setting up a laboratory in his private office in 1954. The office laboratory consisted of a controlled temperature room, 12–lead potentiometer polygraph, steam tent, nerve blocks, oscillometer, and ohmmeter. Several instruments were developed between 1949 and 1952. A transducer for measuring volume changes with minimal pressure changes was developed and is still in use today (Grass Instrument Co PT5 transducer). During Cranley's fellowship at MGH (1949 1951), a decision was made not to spend time investigating any plethysmograph that could not be calibrated volumetrically while the instrument was still attached to the patient. Electrical calibration of the instrument self was not acceptable. For this reason, the strain gauge plethysmograph or photoelectric plethysmograph were not used. Mr. Grass (Grass Instrument Company, personal communications) strongly advised to avoid impedance plethysmography. Electrical impedance may be described as the sum total of ohmic resistance plus the resistance due to capacitance and induction when an alternating current is applied to a limb. Mr. Grass likened it to measuring "an inch at the end of a mile" and warned that he had spent a whole year trying to make it work successfully but had failed. The pulse volume recorder was a quantitative segmental plethysmograph developed in the Fluid Mechanics Laboratory of the Massachusetts Institute of Technology and clinically tested in the clinical vascular laboratory at MGH. It measured volume changes and was calibrated volumetrically while still attached to the patient. The changes in waveforms which were previously described by Dr. Eugene Strandness were utilized[1].

The phleborheograph (PRG) is a modified, simplified polygraph that is calibrated volumetrically after attachment to the patient's limb. It produced excellent results which were believed to be superior to other noninvasive techniques available at the time. Particularly since most below-knee clots in the named veins could be detected. It could not detect soleal clots since they lie outside the mainstream. It required considerable learning to perform and interpret the test. Many inadequate phlebograms were performed and interpreted. In the middle of learning this technique, many workers using the PRG would send their "pheloborheographic errors" for review. The phlebograms were requested for evaluation. In almost every case, when a true mismatch occurred, it was due to an inadequate phlebogram. For this reason, we made it a strict policy that all named veins from the ankle to the vena cava be visualized when doing a phlebogram. Since all our phlebograms were performed by one of our surgeon associates, James A Arbaugh, we were almost always able to obtain complete visualization of the venous tree, which certainly contributed to the successful use of phlebography.

In 1959 Good Samaritan Hospital offered a budding young vascular surgeon by the name of John J. Cranley space and facilities for the development of a laboratory, which he developed into the first completely dedicated surgically oriented vascular laboratory in the nation. Major developments and interventions were carried out in Cranley's laboratory including the invention and development of the Fogarty balloon embolectomy catheter, the Fogarty clamp, the Cranley-Grass Phleborheograph, and new applications for B-mode ultrasonographic imaging of veins and arteries. With continual advancements being made, Cranley's laboratory became one of the largest and busiest in the world. Cranley made numerous contributions to the surgical literature as well as also several vascular surgery texts. Although the general surgery residency program had been in existence since 1928, and accredited in 1954, it was only in 1961 when Cranley was appointed director of the residency program that he also became the first paid director of the department of surgery. In 1973 a dedicated vascular surgery residency was also established, with Cranley holding the role of director. He mentored and trained many early vascular surgeons. Cranley's name is still ever present with the continued existence of the John J. Cranley Vascular Laboratory, the annual John J. Cranley Memorial Lectureship, and until recently, the surgical group founded by Cranley[2].

The phleborheograph (PRG) is a modified, simplified polygraph that is calibrated volumetrically after attachment to the patient's limb permitting precise measurements of volume changes. Its versatility allows coupling to photoelectric transducers, unidirectional and bidirectional Doppler velocity detectors, mercury- in- rubber or indium-gallium strain gauges, an electrocardiogram (EKG) or a tape recorder. The term "phleborheograph" (the tracing of flowing currents within veins) was coined to indicate its initial, primary, and specialized use–namely, to detect deep venous thrombosis. The results obtained with the PRG and the polygraph are identical. The PRG differs from other noninvasive modalities for diagnosing deep vein thrombosis because it is based on segmental volume changes that can be accurately measured.

Normal breathing produces a rhythmic increase and decrease in the volume of the lower extremity, which is transmitted to the PRG and recorded as an oscillation on the tracing that is synchronous with the wave produced by a recording cuff around the thorax. These oscillations, called "respiratory waves", are present in all normal extremities. They are believed to be due to alterations in the volume of the extremity produced by the mechanical effects of the respiratory movements of the thorax and diaphragm. The waves from the thorax are produced by a pneumatic cuff on the epigastrium. The waves in the legs are produced by pneumatic cuffs on the limb. Augmentation of arterial pulses is a sign suggesting deep vein thrombosis. If respiratory waves in the legs are totally absent, this is a cardinal sign of acute deep vein thrombosis[3].

The absolute baseline is a plot of points connecting the minimal volume of each respiratory wave, i.e., a line drawn between the lowest points of the respiratory wave. The dynamic baseline is a plot of points representing a normal tracing of the respiratory wave without compression at a given time. The dynamic baseline is drawn across the troughs of the arterial pulsations. The dynamic baseline is therefore a reflection of phasic changes in venous volume with respiration and does not include the volume changes of arterial pulsation. "Absolute" and "dynamic" are terms suggested by Dr. Anthony Comerota et al. to emphasize that a baseline may begin at the trough or from the apex of the respiratory wave. Thus, in persons with chronic venous insufficiency one frequently sees a rise in the baseline superimposed on a large respiratory wave[4].

The tracings of the respiratory waves are significantly reduced or obliterated in the presence of acute deep vein thrombosis, just as their sound as heard by the Doppler, is reduced or absent. If collateral circulation develops, the respiratory waves that have been absent usually reappear and those that were merely reduced become larger. The respiratory waves returned within 2 weeks but differ from normal waves, being smaller and rounder. It is significant that respiratory waves may be visible on tracings from the leg of a with patient isolated femoral-iliac thrombophlebitis and patent in the leg veins, despite their absence in the thigh, thus suggesting that they can travel down the limb via collateral veins. It is also an observed, albeit unexplained, fact that respiratory waves in the lower extremity are usually larger in amplitude when the patient lies on his left side than when he lies on his back. In some patients' respiratory waves do not reappear after deep vein thrombosis. It is believed that in such cases the thrombosis is massive and collateral circulation remains minimal. Deep vein thrombosis also impedes the normal outflow of blood from the extremity in response to rhythmic compression. Like the active muscle contraction with walking, intermittent compression of the extremity propels blood toward the heart. A recording cuff proximal to the site of compression detects the momentary increase in limb volume when there is venous thrombosis or extraluminal compression and the baseline of the record rises. It remains level when compression is applied to a normal extremity in which there is no impediment to venous outflow[3].

Dynamic baseline

If the troughs of the compression waves lie above the dynamic baseline, the compression is abnormal. If the troughs of the compression waves lie below the dynamic baseline, but the trough of the following respiratory waves remain above the absolute baseline, this compression is also abnormal, because elevation of the following respiratory wave is actually an indication of an increase in volume under the cuff during the period of compression. If compressions are done at different times in the respiratory cycle, the compression troughs must lie at different levels, depending on the level of the dynamic baseline at each point in time. The rise in the baseline localizes the site of thrombosis. For example, if the tracing shows a step wise rise with foot compression but the thigh tracing does not rise when the foot and calf are compressed, the clot is localized below the thigh cuff and above the calf cuff. Extraluminal compression produces the same effect on the tracing as does intraluminal compression. A rise in the baseline, therefore, unequivocally indicates venous obstruction.

Compression of the calf has two effects: blood is propelled up the unobstructed extremity and siphoned out of the normal foot, resulting in a fall in the baseline of the recording cuff on the foot[5]. Absent or less than normal foot emptying in the presence of a rise in the baseline and absent respiratory waves are all indicative of acute deep vein thrombosis. Since it is more subject to artifacts, this maneuver has less significance than other observations. We often considered eliminating it. However, we retained it because a normal tracing can be read at a glance. On occasion, it permits a correct diagnosis when the results of the other two maneuvers are equivocal.

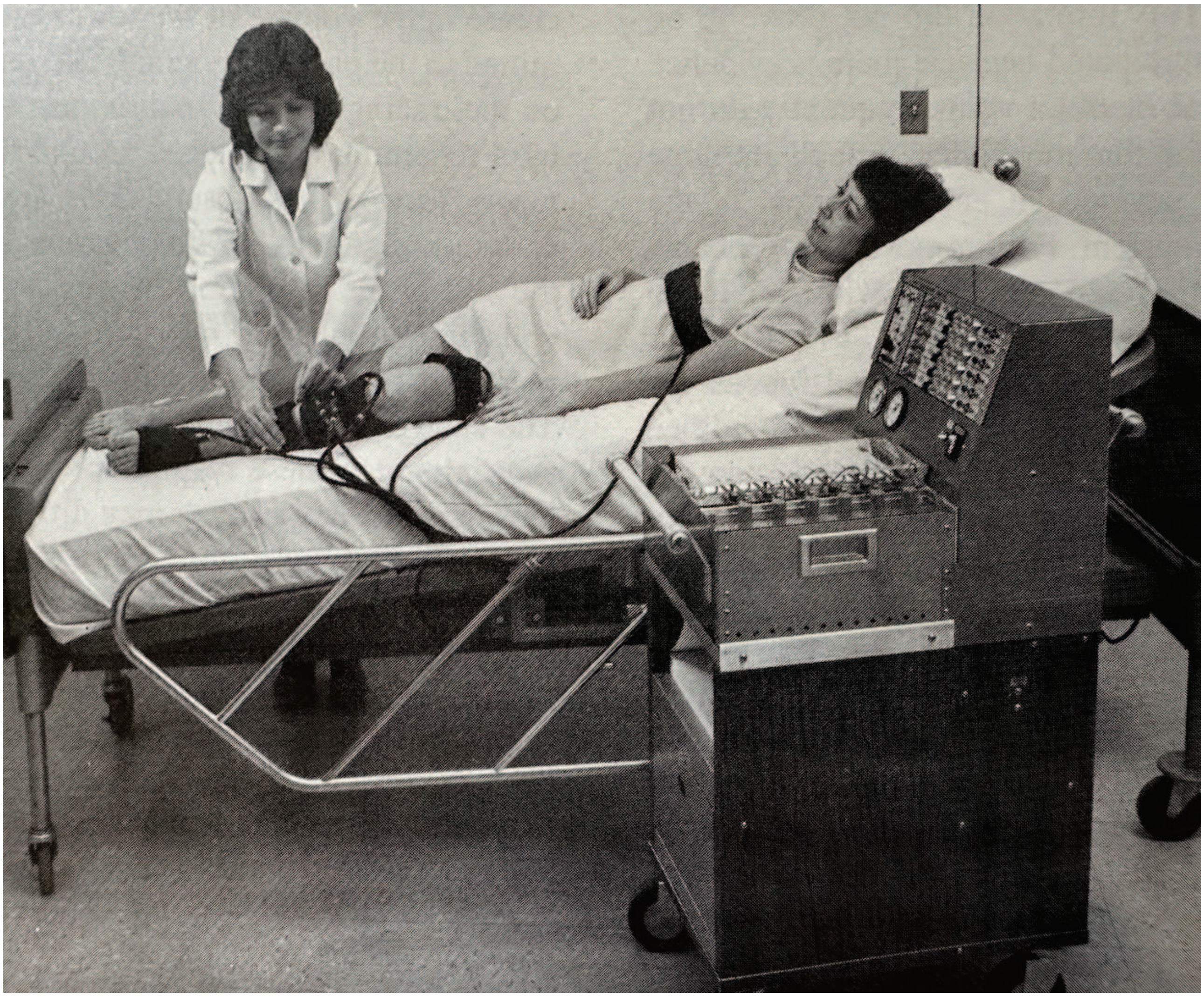
The primary purpose of phleborheography was the detection of deep venous thrombosis. In this respect, three clinical situations are commonly encountered. The first is the patient with a hugely swollen lower extremity and normal PRG results. One can be certain that the swelling in this circumstance is not due to deep venous thrombosis. No exception to this observation was ever encountered. The second is the patient with a tracing considered to be abnormal, with or without clinical symptoms. This patient should be admitted to the hospital for anticoagulant therapy on an emergency basis. The only exception is a patient who was known to have massive deep vein thrombosis in the past and whose tracing had never shown a return of respiratory waves or developing collateral circulation. The third instance is the patient with calf tenderness, his PRG results are normal. Such a patient may have early acute deep venous thrombosis and should be treated expectantly with repeat testing in 2 to 3 days.

The PRG may also be used on a patient with established deep venous thrombosis to follow the development of collateral circulation. In addition, patients at high risk of developing venous thrombosis may be screened with serial PRG studies as an alternative to prophylactic anticoagulation.

The PRG can also study venous circulation using the maximal venous outflow technique by coupling it with either a volume cuff or a mercury-in-rubber or indium-gallium strain gauge. It may be used with a blood pressure cuff or photocell to study the venous filling time and to measure arterial pulse volume changes or to make other physiologic measurements of changes in arterial or venous blood flow. This model may be used as a recorder for analysis of arterial pulse waves in the extremities and in the rectum for assessing colonic circulation[4].

Technique

As developed using state of the art electronics, 6 channels were present on the console, making it possible to apply all the pressure cuffs at once, calibrate them simultaneously, and run the test without interruption. The patient was able to quietly lie in bed with the lower extremities approximately 10 degrees below the heart level and the knee gently flexed while the cuffs were applied. (Picture #1)[3,6,7] Cuff 1 is placed around the thorax so changes in the limb are recorded synchronously with respiratory movements as measured directly from the thorax.



Picture 1 - The patient lies quietly with legs below the heart level and 6 cuffs are applied in preparation for lower extremity phleborheography (Bernstein EF, see Permissions).

This tracing monitors abnormal or involuntary nervous catching of the breath that may occur on application of pressure, causing a sudden rise in the baseline that might be misinterpreted as significant. The cuff for the second channel was placed on the thigh just above the knee. Three cuffs are placed on the leg, 1 each on the upper portion, the mid leg and the ankle. The sixth cuff was placed on the foot.

The first 4 channels record only volume changes. The fifth and sixth channels are alternately used to record volume change and to apply pressure to the limb. Thus, when the 6 cuff is used to apply pressure to the foot, the fifth cuff, as well as those above it, records volumetric changes. Similarly, when the fifth cuff is used to apply pressure to the calf, the sixth cuff records volumetric changes in the foot. The cuffs used were all available blood pressure cuffs. The strap of the chest cuff has been lengthened to permit it to extend around the epigastrium. The cuff encircling the upper thigh also has been lengthened. We used a cuff approximately twice as wide as the others for the foot.

After the cuffs are applied, an automatic inflammation sequence is activated that fills the cuffs until 10 mmHg pressure is obtained to ensure adequate coupling between the cuffs and the limb. Calibration is volumetric. Three different recording modes were used A, B1 and B2. With the selector switch on "Run A," the sixth cuff is used to apply pressure to the foot and all the other cuffs record volume changes. During the first period of tracing, the technician observes the respiratory waves and then presses a "compress" button.

The first 4 cuffs of the phleborheograph are used for recording volume changes only. Cuff 1 is placed around the thorax, cuff 2 at the mid-thigh, cuffs 3, 4, and 5 at the upper calf in close approximation to each other, and cuff 6 on the foot.

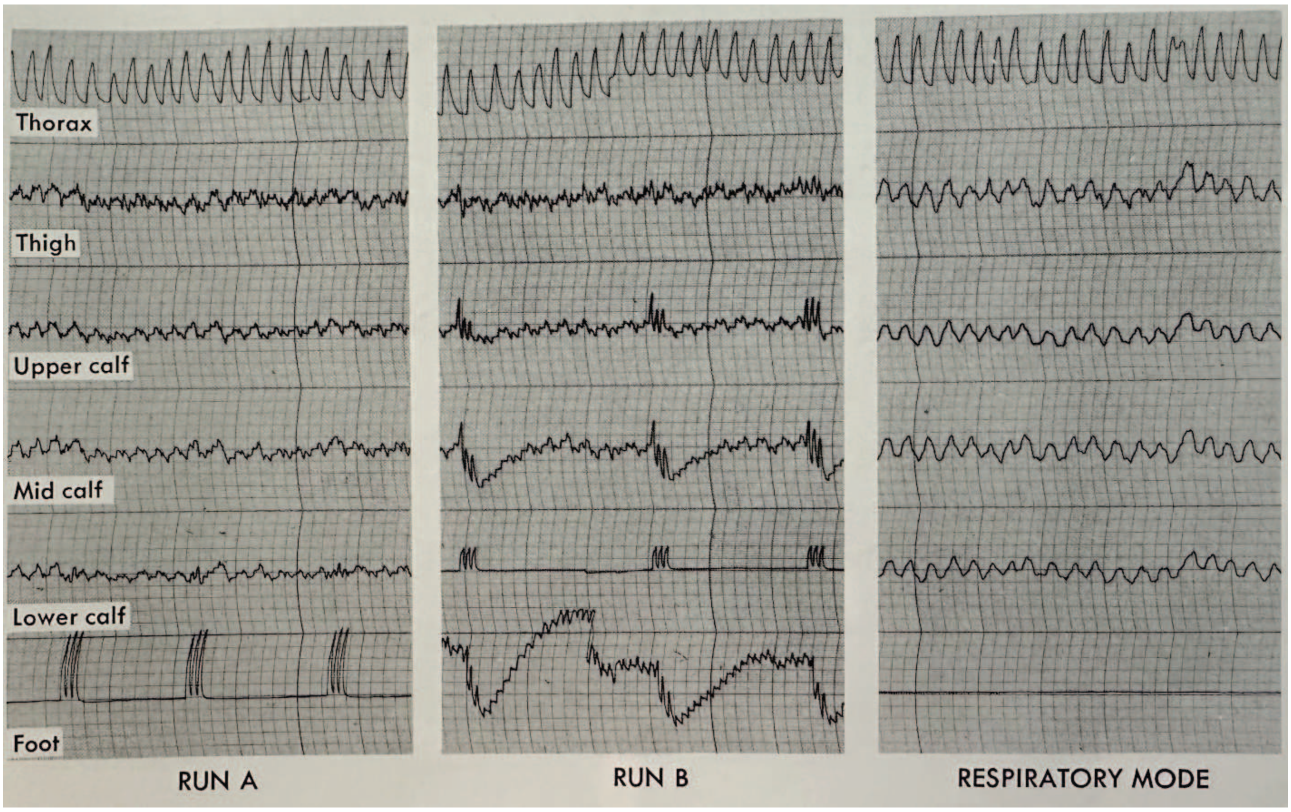


Figure 1 - Normal tracing. There are good respiratory waves throughout run A (foot cuff used as a compression cuff) and run B (lower calf cuff used as a compression cuff). Note the absence of a baseline shift when either the foot or lower cuff is compressed. Note also the good foot emptying in run B. The respiratory mode shows good respiratory waves after the arterial pulses have been filtered (Bernstein EF, see Permissions).

Cuffs 5 and 6 are used to both record transmitted impulses and apply compression. There are 3 operational modes, Run A, Run B1, and Run B2. During run A, all cuffs on the thigh and leg record the response to compression of the foot by applying pressure to the foot cuff. In run B1, pressure is applied to the midcalf (cuff 5). All other cuffs record the response, including the cuff on the foot (cuff 6), which records changes in pedal volume. In run B2, cuff 5 is moved to the ankle level and used to apply compression. The remaining cuffs are used for recording[6].

Run A: Foot compression

In run A, the recording cuffs are automatically inflated to 10 mmHg. The chart speed is 2.5 mm/s. Calibration is performed by adjusting the amplification so that the 0.2-ml volume calibrator uses a 2–cm pen deflection. Respiratory waves are observed first. Following this, the compression control is operated and 3 short bursts of 100 mmHg each are delivered to the foot cuff (cuff 6); these are 0. 5 seconds in duration and delivered at 0.5 second intervals. About 40% of the pressure is expended in inflating the cuff, so only about 60 mmHg of pressure is actually exerted on the foot.

Although the recording pen may move erratically with the application of pressure, the baseline remains level in the normal extremity (Figure #1)[3,6,7]. If there is interference with the outflow of blood from the extremity, the baseline rises with each successive compression is extremity swells. Time is allowed for venous refilling of the lower leg to occur before the next compression. This usually takes 20 seconds. This maneuver is repeated at least 3 times, but if there is any interference with the tracing, pressure may be applied as often as necessary. If the respiratory waves appear to be smaller than usual, the patient is turned on the left side with both knees slightly flexed and the right leg lying behind the left. This maneuver increases the size of the respiratory waves; however, in a patient with acute DVT, changing the position usually does not restore the obliterated waves. If the baseline continues to show a rise with each compression or if the respiratory waves remain smaller than usual, minor positional changes may be tried in an attempt to minimize the effect of compressions on the respiratory waves. Prone or near prone positions should not be used because these positions tend to produce a normal tracing in the presence of deep vein obstruction for reasons that are unclear[3,6,7].

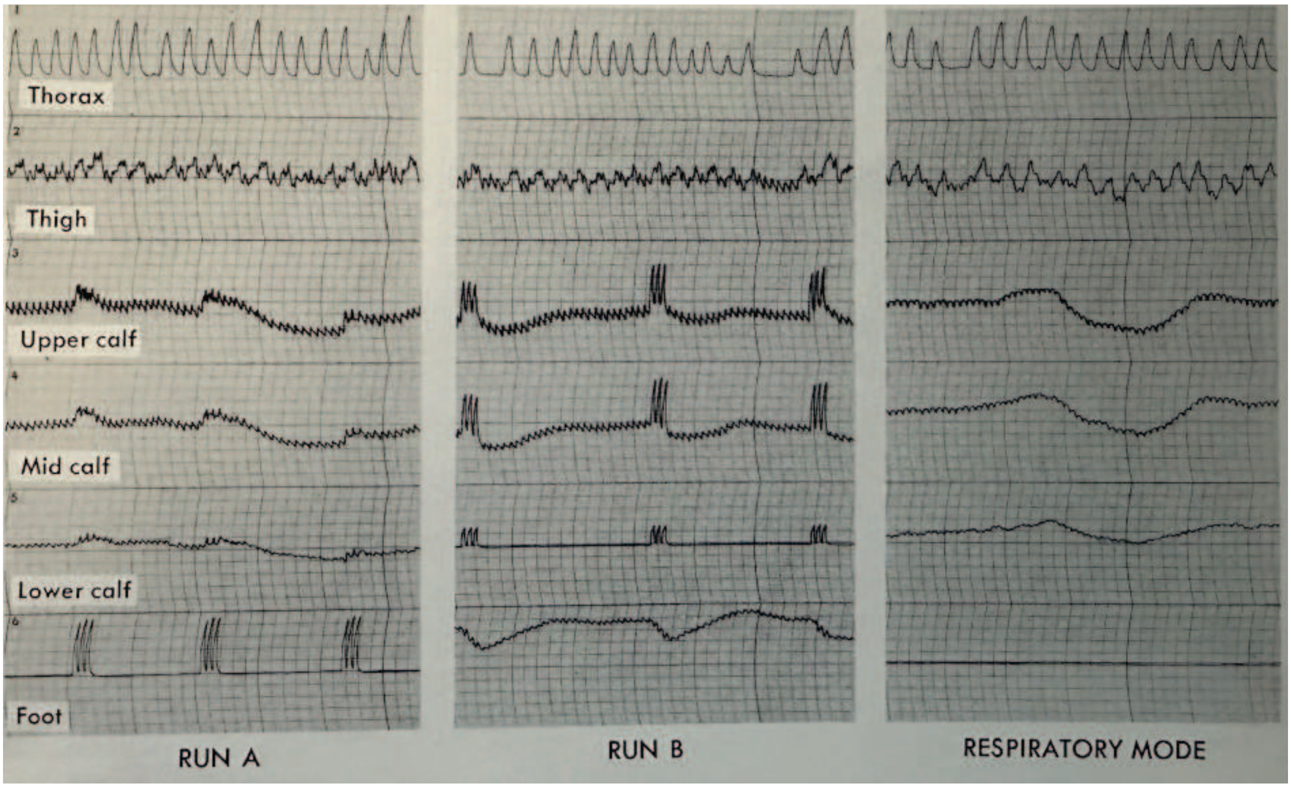


Figure 2 - Acute popliteal thrombosis. Note the normal respiratory waves and the absence of any baseline rise in the thigh: howerver, ther is obliteration of the respiratory waves in the calf and baseline evaluation secondary to the foot (run A) and calf (run B) compression, indicating deep venous obstruction. Note the total absence of respiratory waves distal to the thigh on the respiratory mode trace, indicating deep venous obstruction at the popliteal level (Bernstein EF, see Permissions).

Run B1: Calf compression

In run B1, the recording cuff on the lower part of the calf becomes a compression cuff (cuff 5) and the cuff on the foot (cuff 6) is converted to a recording cuff. In this run, operating the compress control automatically causes 50 mm Hg of pressure to compress the cuff on the calf 3 times, similar to the compression of the foot in run A. Again, about 40% of this pressure is expended in inflating the cuff, so only about 30 mmHg is actually exerted on the calf.

Emptying of the foot is observed. This decrease in volume of the foot is demonstrated in the tracing (cuff 6) by a fall in baseline. This test is repeated at least 3 times. Time must be allowed for the pen to return to its baseline before the next application of pressure. In a fully normal extremity, the pen baseline falls at least 3 cm, corresponding to a 0.3–mL volume change under the cuff, the dimensions of which are 9 x 17 cm. The return to baseline is gradual rather than abrupt.

As the lower part of the calf is compressed, the recording from the midcalf normally fall somewhat, mimicking the fall in the baseline of the foot. This is thought to be an artifact caused by the proximity of cuffs 4 and 5. Meanwhile, the baseline of the tracing from the upper part of the calf and the lower part of the thigh remains level. However, if any obstruction of the deep venous system exists above the recording cuff, a rise in the baseline occurs that is progressive with each compression. In the presence of extensive thrombophlebitis, this may be a sharp, abrupt rise: on the other hand, a stepwise rise of greater than 1 mm is significant (Figure #2)[3,6,7].

Run B2: Ankle compression

In run B2, the midcalf cuff (cuff 5) is moved to the ankle level and is used to deliver compressions. Cuffs 1 through 4 and cuff 6 are used for recording as in run B1. Compressions are identical to those used in run B1 with regard to timing, duration and pressure.

Once again, emptying of the foot is observed, as in run B1. Unlike run B1, however, the midcalf recording does not usually fall. The baseline of this recording cuff and the others remains level. If there is obstruction to venous outflow, a rise in baseline occurs. In addition, foot emptying may be reduced or absent[3,6,7].

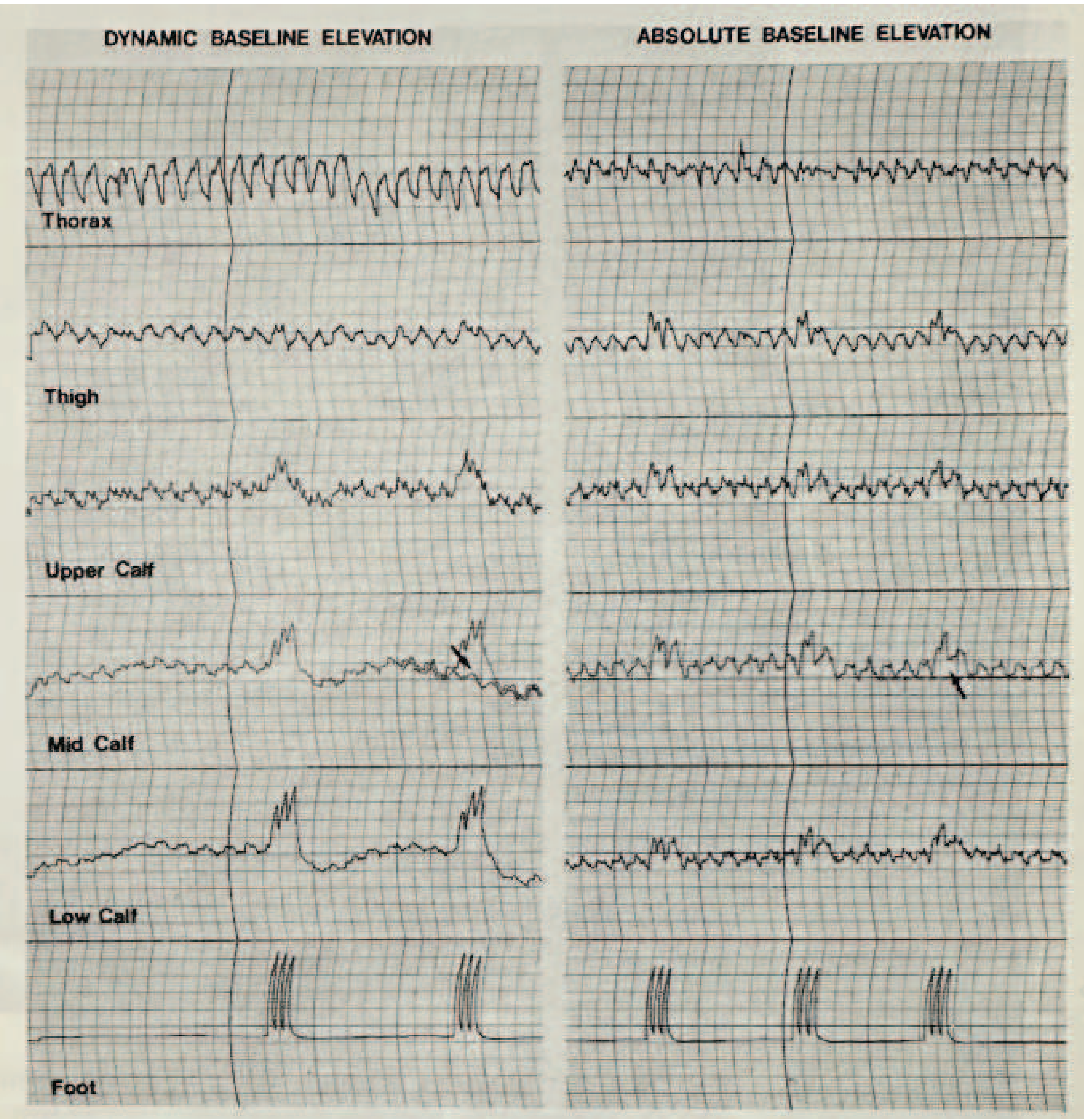


Figure 3 - Abnormality of a dynamic baseline rise and an absolute baseline rise (Bernstein EF, see Permissions).

Interpretation

Interpretation of the tracing is based on the physiologic principles previously described. Strict adherence to criteria derived from over 27,000 phleborheographs (PRGs), and 748 phlebographic correlations is required.

In tracings of the lower extremities, it is necessary to obtain 9 normal compressions, 3 each in run A, run B1 and run B2. Each set of 3 must be obtained without changing the position of the patient; however, sets need not be consecutive. The positions used for runs A, B1 and B2 may differ. Only 3 normal compressions are required in the upper extremity, all obtained in the same position.

The characteristics of a normal compression have been previously outlined. They include the following: (1) a normal respiratory wave amplitude averaging 50% or more of the amplitude of the waves in the opposite extremity, (2) no absolute baseline rise, and (3) no dynamic baseline rise with compression.

The absolute baseline is a plot of points connecting the minimal volume of each respiratory wave. The dynamic baseline is a plot of points representing a normal volume of the extremity expected at any point in the respiratory cycle. A rise greater than 1 mm in either the absolute or dynamic baseline is considered significant (Figure #3)[3,6,7].

Baseline evaluation and respiratory waves are considered major criteria must be normal, as defined, for a compression to be considered normal. The minor criteria of pulsatility and foot emptying are less important. Pulsatility refers to the amplitude of the superimposed arterial waves that are seen in the respiratory waves of every tracing.

When compared to the opposite leg, increased pulsatility suggests the presence of either deep vein obstruction (usually acute) or a popliteal artery aneurysm. Bilateral increased pulsatility may be seen in patients with congestive heart failure and tricuspid insufficiency. Foot emptying has already been described. Abnormal foot emptying and increased pulsatility are merely suggestive, however, and not diagnostic of deep vein obstruction. Their major usefulness is to clarify an equivocal tracing[3,6,7].

Further consideration of a particular tracing may allow a diagnosis of acute versus chronic or complete versus partial obstruction. For example, a persistent baseline rise (dynamic or absolute) coupled with absent respiratory waves suggests an acute complete occlusion. A baseline rise with near–normal respiratory waves suggest partial acute obstruction or complete obstruction with recanalization or collateralization (chronic versus early acute) (Figure #4)[3,6,7]. The level of obstruction can frequently be ascertained by careful scrutiny of the changes occurring in each cuff with compression.

Serial tracings can show the gradual transition from acute occlusion to the chronic state or to dissolution of the thrombi. Caution and clinical judgment must be used in diagnosing the chronic process. For example, a tracing will show obstruction and large respiratory waves, indicating excellent collateral circulation, the day after ligation of the femoral vein (not for venous thrombosis). Thus, the test reflects the actual state (i.e. obstruction and good collateral circulation), although it is obviously not long-term.

Another pitfall is a thrombus that only partially occludes a small segment of a vein, such as the popliteal or femoral, and may cause the test to show a rise in baseline but with normal respiratory waves. Instead of a chronic occlusion, this connotes an early acute lesion. When the test is repeated in a day or two, respiratory waves may be absent. In other words, the partial occluding thrombus has now propagated[3,6,7].

Upper extremity technique

Recording cuffs are placed around the thorax, upper arm, and upper and middle forearm, along with a compression cuff on the wrist. (Picture #2)[3,6,7] The mode selector is turned to run B and the wrist cuff is rapidly inflated to 50 mmHg, producing compressions that pump the blood proximally. The proximal arm cuffs record any changes in volume that occur at rest or in response to these volume challenges. In the upper extremity, respiratory waves can persist despite complete venous occlusion, probably because of the rich venous collaterals around the shoulder. Therefore, a diagnosis of upper extremity deep vein occlusion is usually based on the presence of a baseline rise alone[3,7].

Venous compression

Extrinsic compression of a vein obstructs the flow of venous blood and is indicated by a rise in baseline. This is particularly true of the extended rise. The laboratory at Good Samaritan Hospital has noted 10 patients with venous compression without DVT. Inclusion of these cases as errors is debatable, inasmuch as the test did detect the true status, namely obstruction of venous blood flow.

In addition to the previously mentioned physiologic obstruction of venous blood flow, false- positive tracings were encountered in several young, nervous, otherwise healthy individuals. Almost invariably, the false positive trainings tracings become normal after administration of a sedative or on repeat testing. The laboratory has seen two phlebograms from young patients with a positive PRG that showed quite obvious narrowing of the femoral vein in the thigh, causing what appeared to be a significant constriction of the lumen. This phenomenon cannot be explained, but it reemphasizes the accuracy of PRG showing abnormal respiratory waves, indicating obstruction to the flow of blood. It also stresses the difficulty of judging whether this is a false- positive tracing[6].

Results

An equivocal tracing is usually resolved by repeating the tracing in 24 hours. At times, vein imaging using the B-mode scanner makes it possible to confirm or to refute the phleborheographic findings immediately. Errors in interpretation have been determined by a review of the tracing after a phlebogram has been obtained. The technical errors have almost completely been eliminated. The percentage of inherent false negatives has remained at approximately 5% throughout the period of the instrument's availability. These false negatives usually stemmed from small clots below the knee. In a group of 60 patients with clots limited to the infrapopliteal area, 15 (25%) false-negative rate results have occurred.

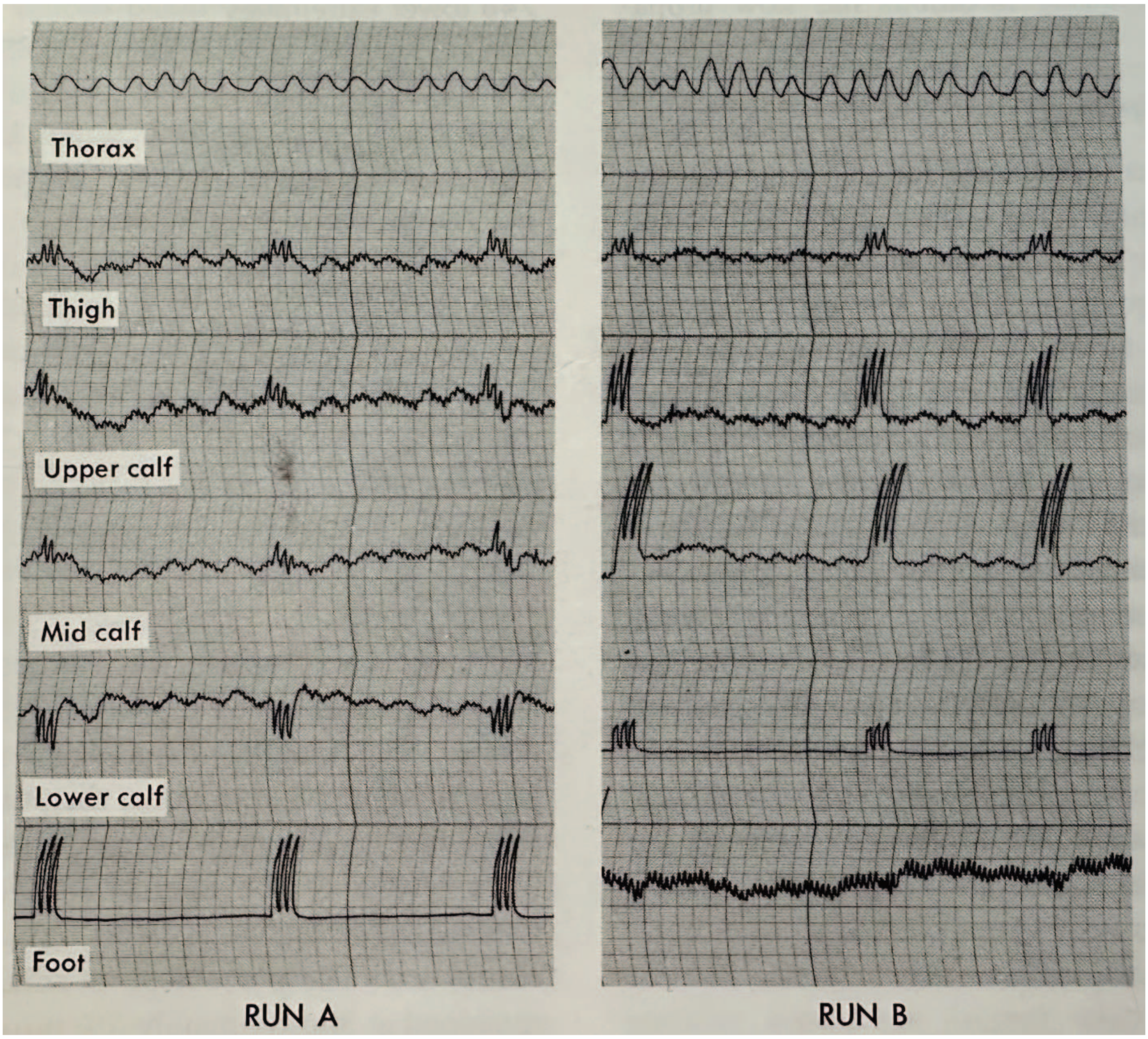
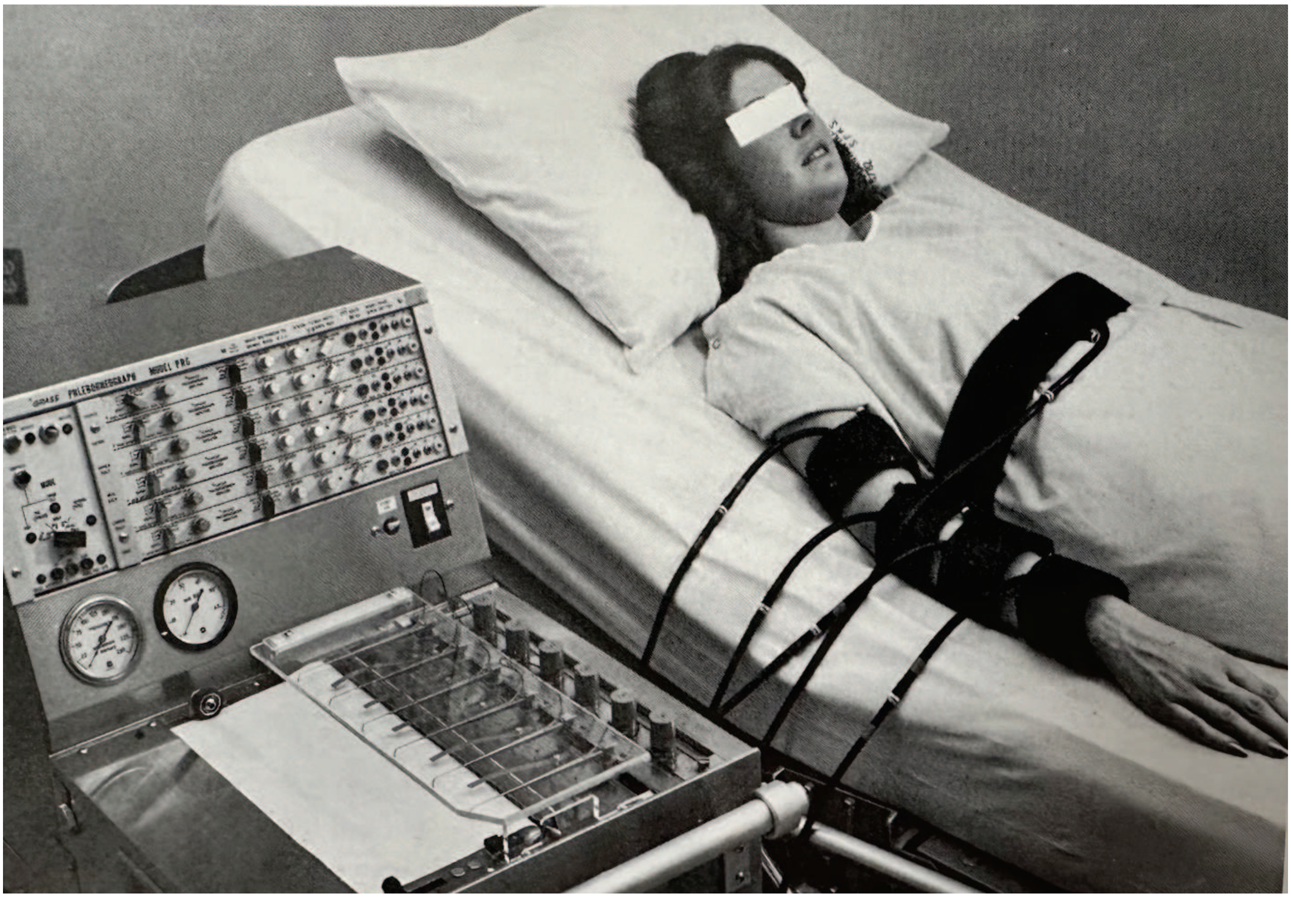


Figure 4 - A baseline rise with near normal respiratory waves suggests a partial acute obstruction with recanalization or collateralization (chronic versus early acute) (Bernstein EF, see Permissions).

False positives are more difficult to explain: thus, studying these patients has augmented knowledge of venous physiology. False negative results may also occur in patients with duplications. This has been especially common in the popliteal vein segment.

Dr Anthony Comerota and Cranley reported a 10-year experience with phleborheography in Surgery, May 1982. PRG is a physiologic volumetric plethysmography technique that was developed for the diagnosis of lower extremity deep venous thrombosis. During 10 years, 21,626 extremities were studied with 709 corresponding venograms. Overall data revealed a sensitivity of 92% (247/268) and a specificity of 95% (418/441). There were 21 false negative PRG results, and 12 of these were due to isolated calf vein thrombosis. There were 23 false positive results, and 11 of these were considered true errors of the technique. When isolated calf vein thrombosis was diagnosed disregarded, the sensitivity increased to 95%. PRG detected 45 of 57 (79%) isolated calf vein thrombi.

The modified criteria for interpretation included respiratory waves and baseline elevation as the major criteria and prominent arterial pulsation and foot emptying as the minor criteria. PRG has been used to monitor the duration of thrombolytic therapy.



Picture 2 - A modified technique for upper extremity diagnosis showing the recording cuffs around the thorax, upper arm, and middle and lower forearm with the compression cuff on the wrist (Bernstein EF, see Permissions).

This appears to be a promising contribution to the quantification of individual response to lytic therapy and may indicate an objective endpoint for treatment.

PRG is a sensitive and specific method of detecting deep vein obstruction. It is a painless, reproducible, repeatable technique that requires minimal patient cooperation. PRG is a versatile laboratory technique that can be used in a variety of applications in addition to the diagnosis of deep vein thrombosis[4].

Discussion

Phleborheography is noninvasive, painless and involves physiologic principles. Most patients can be examined in 30 to 45 minutes, although studies in acutely ill, disabled, or less cooperative patients may take longer. Interpretation must be learned by each physician, and the principles previously outlined must be applied.

Non-occlusive thrombi

A thrombus that is attached to a vein wall but does not actually, or at least nearly, obstruct the flow of blood is not detected by phleborheography. As the clot occludes more venous flow, there may be a slight rise in the baseline, but respiratory waves are still present. When the clot totally occludes the vein, the respiratory waves disappear. A thrombus attached to the vein wall over which the blood continues flow will usually lyse[6].

Acute and chronic deep vein thrombosis

An area of acute DVT may develop in an extremity with the postphlebitic syndrome. This new episode, when superimposed on chronic disease, poses some difficulties in the diagnosis in the early stage. In the postphlebitic limb, the respiratory waves are so large that even when reduced as a result of obstruction by fresh thrombus they may still appear to be within normal limits. An exacerbation of existing symptoms or the onset of new ones in such a chronically insufficient limb may be indicative of acute thrombosis, and the physician should follow the patient's clinical course[6,7].

Chronic occlusion of major veins

A negative tracing in a patient with an acute obstruction of the popliteal or femoral vein has not been encountered; however, tracings from limbs with chronic occlusion of these vessels have been negative at times. Chronicity can be detected radiographically by the presence of a large number of collateral veins around the obstruction, by clot retraction, or by irregularity (tree- barking) of the walls of the veins. Occasionally the patient's clinical history will also indicate a chronic occlusion[6,7].

Pulmonary embolism following a negative PRG

Eight instances of pulmonary embolism rising after negative PRG have been reported. In five, the interval between the negative phleborheogram the pulmonary embolism ranged from 8 to 12 days. It was 6 days for two patients. In 1 instance reported in 1991 it was 2 days. This occurred in a postpartum patient taking hormones. It is believed that DVT may propagate rapidly at times which appeared to have done in this instance.

There is a 25% rate of false-negative PRGs in patients with clots limited to veins below the knee. Usually, such thrombi are small and probably do not propagate, but they can potentially progress to involve the popliteal vein and then become lethal. Accordingly, there may be a policy of deferring diagnoses whenever the PRG is normal in a patient with a tender calf; instead repeat tests are obtained at 2-day intervals until the clinical symptoms clear or the findings become positive, indicating that propagation to the popliteal area has taken place. In this event, treatment for DVT is initiated[6].

A small occlusive acute clot, which is a potential source of later pulmonary embolism, may be interpreted as a "chronic occlusion." The terms "acute" and "chronic" are clinical judgments. The PRG is merely capable of recording the presence or absence of obstruction and either large or small respiratory waves. Usually, an obstruction in the absence of collateral circulation represents an acute obstruction, and the presence of large respiratory waves connotes a chronic obstruction. However, as already pointed out, the day after femoral vein ligation (not for venous thrombosis), a PRG tracing in that patient will indicate obstruction with normal respiratory waves. This could be interpreted as "chronic occlusion" if the clinical history were not known. Similarly, a small clot occluding a very short segment of femoral or iliac vein might be interpreted as a chronic occlusion, with the tracing showing a rising baseline combined with large respiratory waves. For this reason, tracings are reported as either normal or abnormal. If abnormal because of a rise in baseline in the absence of respiratory waves, this is interpreted as indicative of typical acute DVT. A rise in baseline and normal–appearing or larger than normal respiratory waves are interpreted as abnormal, consistent with early acute or chronic disease. If the symptoms are acute, the patient should be followed with a repeat testing at 2 to 3-day intervals.

Finally, retrospective analysis has shown that some patients have pulmonary embolism before the PRG is obtained. If a large clot breaks off totally, leaving an empty vein behind, the PRG would be normal. This problem has not been solved. However, proved clots in the lung may occur in the patient whose phlebogram shows a patent venous tree from the ankles to the vena cava. A similar situation may occur when B-mode venous duplex studies are ordered after a pulmonary embolus has been diagnosed[6,7].

Sources of errors in interpretation

Most false positive testing findings are probably a result of temporary physiologic obstruction of the venous tree. Changing the position of the patient by flexing the knee, straightening the thigh or shifting them from side to side may normalize the study. This has been confirmed with phlebography.

A very common drawback is pelvic vein thrombosis which may not be visualized on phlebograms and can be difficult to assess. Skill and experience in reading the PRG tracings is important. Interpretation of the tracing is not always easy. This did require intense training of the physician interpreters. The test is technologist sensitive and thus the technologist must be highly trained. The use of maneuvers to avoid false positive and false negative testing is critical. The most common artifact encountered was compression of the popliteal vein by the extended knee. Similarly, flexing the thigh in some patients may have obstructed the femoral vein in the inguinal area. In young athletic adults, compression of the veins by a muscle mass may result in a false positive tracing. Many times, there is no explanation for compression of the veins in a particular position. When the test results appear to be positive, the technologist turns the patient first on the left side: if the results remain abnormal, the patient is turned on the right side. Occasionally, a positive PRG then becomes normal. The technologist must be aware of these hemodynamic vagaries[6,7].

Conclusions

Phleborheography has provided physicians with a highly practical, useful modality for detecting DVT, which has great value in the clinical setting. A negative PRG in a patient with a hugely swollen lower extremity indicates that the swelling is not caused by DVT. There was no exception to this. The patient with a positive PRG with or without clinical symptoms was admitted to the hospital for anticoagulant therapy. The patient with calf tenderness whose PRG is negative was instructed to return with repeat testing in 2 or 3 days if the clinical symptoms persisted[7].

Phleborheography's rate of successful detection is keyed to certain limitations of the physiologic transmission of hydraulic impulses. Although not perfect, it was the most accurate functional test for diagnosing acute DVT. Phleborheography has been replaced by duplex scanning which is both functional and anatomic. To quote Dr. John Cranley "Seeing is Believing". These principles continue to be used with functional testing and the application of air plethysmography[7].

Permissions

References

1) Cranley JJ, Lohr JM. Evolution of the Vascular Laboratory: David Phillips Memorial Lecture. Journal of Vascular Technology 2001;25(4):185-93.

2) Our History: TriHealth (Personal Communication)

3) Kempczinski RE, Yao JS. Practical Noninvasive Vascular Diagnosis. Second Edition; 1987 Yearbook Publishers, Chapter21, Cranley JJ, pp. 438-464.

4) Comerota AJ, Cranley JJ, Cook SE, Sipple P. Phleborheography–results of a 10-year experience. Surgery 1982 May;91(5):573-81.

5) Winsor T, Hyman C. Objective venous studies (insufficiency, obstruction, and inflammation). General cardiovascular surgery space 1961;2:146.

6) Cranley JJ. Diagnosis of Deep Vein Thrombosis By Phleborheography. In Bernstein EF. Vascular Diagnosis. Fourth Edition; 1993 Mosby; Chapter 96, pp 801-811.

7) Cranley JJ. Vascular Laboratory Guide. (Personal Communication).