Impedance Phlebography
Critical Evaluation of its Relation to Inspiratory Capacity

By ROBERT HARRIS SCHULMAN, M.D., SANDOR A. FRIEDMAN, M.D.,
AND GEORGE DEGENSHEIN, M.D.

SUMMARY
Impedance phlebography, a noninvasive approach to the diagnosis of venous thrombosis, depends on decreasing calf electrical impedance in normal subjects during inspiration. In order to assess the relationship between impedance changes and inspiratory volume, normal subjects were studied at various depths of inspiration. The mean inspiration volume required for a result indicating no evidence of venous thrombosis was over 1500 ml. There was significant variation between subjects and between limbs in the same subject. Routine postoperative patients were not generally able to achieve these inspiration volumes. It is concluded that insufficient tidal volume is responsible for many false positive results. Impedance phlebography is not reliable without simultaneous spirometric evidence of high inspiratory volume.

Additional Indexing Words:
Venous thrombosis   Thromboembolism

IMPEDANCE PHLEBOGRAPHY is a noninvasive, bedside technique for the diagnosis of venous thrombosis, but its accuracy is controversial. The procedure is based on an increasing venous volume in the leg during deep inspiration, leading to decreased electrical impedance in the calf of normal individuals; there is no significant fluctuation in the presence of venous obstruction. In previous studies with this technique, the depth of inspiration was not simultaneously monitored. In order to determine the relationship of tidal volume to changes in electrical impedance in the lower extremities, the procedure was evaluated in a group of normal subjects.

Method
Twenty-three normal subjects, 20 to 30 years old, were studied in the supine position. None had a previous history of cardiovascular disease, venous thrombosis, or leg edema. For each subject, height and weight were recorded, and body surface area calculated from the standard nomogram. Leg circumference was measured 2 in above the medial malleolus and 3 in below the patella.

Plethysmography was performed in the midcalf area with the Codman Impedance Phlebograph using the method of Wheeler et al. Four circumferential electrodes were attached to the leg, the inner two electrodes 5 cm above and below the midcalf and the two outer electrodes 3 cm above and below the inner ones. An alternating current of 25 kHz and less than 1 milliampere strength was delivered through the outer electrodes, and the change in voltage required to transmit this current was measured through a Kelvin bridge circuit connected to the inner electrodes. A continuous recording of voltage changes was obtained with a strip recorder adjusted so that a calibration signal equal to 0.2% change in voltage (and conversely impedance) produced a 20 mm stylus excursion. In this way, one records the peripheral pulse wave as blood enters and leaves the leg with each cardiac cycle, changing impedance. If venous return is occluded, there is a general baseline excursion, indicating decreased impedance and increased blood volume in the extremity.

In each subject, recordings were first obtained in both legs during quiet respiration, and then measurements of impedance changes were made during controlled respirations of various depths. Each controlled inspiration began after a quiet expiration, consumed 5 to 10 sec, was held for an additional 5 sec, and was followed by a slow passive expiration. Inspiratory volume from the end of a quiet expiration to the peak of inspiration was measured with a Jones Pulmoman. One observer followed the plethysmographic tracings, and another monitored inspiratory volume, instructing the patient to stop inspiring when the desired volume was reached. In this way, impedance plethysmography was performed with increasing tidal volume, starting from

From the Department of Medicine, Coney Island Hospital, affiliated with Maimonides Medical Center, and Department of Surgery, Maimonides Medical Center, Brooklyn, New York.
Address for reprints: Sandor A. Friedman, M.D., New York City Health and Hospitals Corporation, Coney Island Hospital, 2601 Ocean Parkway, Brooklyn, New York 11235.
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approximately 400 ml and increasing 100-200 ml at a
time until a respiratory excursion of more than 0.25% of
baseline was obtained. The latter figure represents the
minimal impedance change with deep inspiration
considered to indicate no evidence of venous obstruc-
tion. A change of 0.20%–0.24% is considered borderline
and less than 0.20% as abnormal. At least two tracings
were taken for each limb at each inspiratory volume.
Two subjects could not attain a normal result in the
supine position even with their maximal inspiration
and were restudied with the knees bent at 45°.

For comparison to the normal subjects, maximal
inspiratory volume after quiet expiration was measured
in 15 consecutive patients after routine abdominal
surgery.

Results

Table 1 lists the inspiratory volumes required for
normal impedance phlebograph results. The mean
inspiratory volume from a normal expiration
necessary for 0.25% and 0.30% changes in impedance
were 1509 ml (300-3100) and 1627 ml (600-4050)
respectively.

Analysis of the relationship between body surface
area and inspiratory volume required for an 0.25%
impedance change revealed a correlation coefficient
of +0.37% (P < 0.05) for the right leg and +0.40%
(P < 0.025) for the left leg. When these data are
analyzed by ranges of body surface area (table 1), it
is apparent that a significant rise in mean
inspiratory volume requirement occurs only when
body surface area is above 1.9 square meters.

Mean calf diameters 3 in below the patella and 2
in above the medial malleolus were respectively
14.0 (11.3-17.5) in and 8.9 (7.5-10.5) in. There was
no relationship between calf diameter and required
inspiratory volume (correlation coefficients of −0.03
and +0.11 for the right and left legs respectively).

The required inspiratory volume was not always
the same in both legs; there was a difference of at
least 900 ml between the limbs in six subjects, 600
ml in 7 and 500 ml in 11. In ten of the latter 11, a
greater inspiratory effort was required for the
left than the right leg.

The 15 postoperative patients had a mean
maximal inspiratory capacity of 1033 ml. Individual
results, body surface area, surgical procedures, and
postoperative day are given in table 2. There was a
highly significant difference between the mean
inspiratory volume of the postoperative patients
and the mean volume required for a 0.25% change in
electrical impedance (P < 0.01).

Discussion

Previous work has shown that thromboembolism
in the lungs is one of the major immediate causes of
death in hospitalized patients. Freiman, Suyemoto,
and Wessler demonstrated gross and/or micro-
scopic evidence of pulmonary thromboembolism in
64% of a consecutive series of necropsies. Since
the source of these emboli is often the veins of the
lower extremities, and since most peripheral venous
thromboses are silent, a reliable laboratory test for
this entity might delineate those patients most likely
to develop pulmonary embolism. Venography is
generally quite accurate and safe, but it is
cumbersome and expensive and unsuitable as a
mass screening procedure.

The use of intravenous radio-iodinated fibrino-
gen, which becomes incorporated into a fresh
thrombus, has been found quite useful in diag-
nosing clinically inapparent venous thrombosis. With
this method, it has been shown that 10.7 to
40% of patients after routine surgery have evidence
of peripheral venous thrombosis and that this risk
is considerably higher in patients over the age of 60.
The incidences for patients with congestive heart
failure, myocardial infarction and cerebralvascular
accidents are also very high. Unfortunately, the
use of radioiodinated fibrinogen requires special
equipment not available in all institutions.

Impedance phlebography was introduced by
Wheeler and associates as a simple, noninvasive
screening procedure in high risk patients. This
method utilizes impedance plethysmography and
depends upon the normal decrease in electrical
resistance in the calf as its blood volume increases.

Table 1

<table>
<thead>
<tr>
<th>Inspiratory Volumes Required for Impedance Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body surface area (m²)</td>
</tr>
<tr>
<td>------------------------</td>
</tr>
<tr>
<td>1.45 - 1.65</td>
</tr>
<tr>
<td>1.66 - 1.90</td>
</tr>
<tr>
<td>1.91 - 2.30</td>
</tr>
<tr>
<td>Mean ± 1.77 ± 0.25 SD</td>
</tr>
</tbody>
</table>

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during deep inspiration. The increase in blood volume is thought to be related to transient obstruction of venous return either because of a pinococh effect of the descending diaphragms on the inferior vena cava or to a simultaneous decrease in intracaval pressure and increase in intra-abdominal pressure. If venous obstruction is already present, one would not expect inspiration to affect the venous volume of the limb significantly. Wheeler et al.\(^\text{1}\) reported a 14% incidence of detectable venous thrombosis in postoperative patients and agreement between the impedance method and venography in 77 of 79 cases.

Dmochowski, Adams, and Couch\(^\text{18}\) used impedance measurements in 50 limbs of 25 normal subjects and 43 limbs of 24 patients with suspected venous thrombosis. Sixteen of the 50 normal limbs had impedance changes with inspiration of less than 0.20% (abnormal result). Among the patients comparison with venography showed six false positives and one false negative result. Although the accuracy of impedance phlebography was only 53.5%, the authors believed that the procedure had merit in screening because of the low incidence (5%) of false negative results. Deuvaert, Dmochowski, and Couch,\(^\text{14}\) in a later study, found a false negative rate of 16.7%. On the other hand, Steer et al.\(^\text{15}\) have reported false negative results in more than one third of their patients with venogram-proven venous thrombi.

In none of the previous studies with impedance phlebography was the depth of inspiration monitored. Our results indicate that decrease in electrical impedance is highly dependent on the volume of inspired air entering the lungs. In normal subjects, there was little or no impedance change with shallow respiration, but the change gradually increased with the depth of inspiration. The findings that 39 of 46 normal limbs tested did not show a 0.25% fall in impedance unless inspiratory volume following a quiet expiration reached at least one liter and that the mean requirement for a normal result was over 1500 ml may explain the frequency of false positive results when this test is performed in clinical situations. This suggestion is supported further by the results of pulmonary function testing in our postoperative patients. Eight of 15 patients tested had maximal inspiratory volumes of less than one liter (see table 2). These postoperative patients did not have pulmonary disease and appeared to be limited in their respiratory effort by incisional pain. Others at high risk for venous thromboembolism who might not inspire adequately for this examination include elderly patients and those with chronic obstructive lung disease and cerebrovascular accidents.

The results of this study indicate a marked variation among subjects in the minimum inspiratory volume required to perform impedance phlebography accurately. Although there is a positive correlation between body surface area and required inspiratory volume, it is of a low order of

Table 2

**Inspiratory Volumes of Postoperative Patients**

<table>
<thead>
<tr>
<th>Age/Sex</th>
<th>BSA (m(^2))</th>
<th>Operation</th>
<th>Postoperative day</th>
<th>Inspiratory Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>25-F</td>
<td>1.68</td>
<td>Cholecystectomy</td>
<td>1</td>
<td>1000</td>
</tr>
<tr>
<td>71-F</td>
<td>1.65</td>
<td>Cholecystectomy</td>
<td>1</td>
<td>500</td>
</tr>
<tr>
<td>35-F</td>
<td>1.98</td>
<td>Radical hysterectomy</td>
<td>1</td>
<td>1100</td>
</tr>
<tr>
<td>42-F</td>
<td>2.14</td>
<td>Cholecystectomy</td>
<td>1</td>
<td>500</td>
</tr>
<tr>
<td>75-F</td>
<td>1.52</td>
<td>Cholecystectomy</td>
<td>2</td>
<td>900</td>
</tr>
<tr>
<td>32-F</td>
<td>1.58</td>
<td>Cholecystectomy</td>
<td>3</td>
<td>600</td>
</tr>
<tr>
<td>57-F</td>
<td>1.88</td>
<td>Cholecystectomy</td>
<td>1</td>
<td>2000</td>
</tr>
<tr>
<td>53-F</td>
<td>1.67</td>
<td>Total abdominal hysterectomy</td>
<td>1</td>
<td>800</td>
</tr>
<tr>
<td>24-F</td>
<td>1.94</td>
<td>Modified hysterectomy</td>
<td>3</td>
<td>1500</td>
</tr>
<tr>
<td>60-F</td>
<td>1.74</td>
<td>Transthoracic hiatal hernia repair</td>
<td>3</td>
<td>1000</td>
</tr>
<tr>
<td>60-M</td>
<td>1.56</td>
<td>Cholecystectomy</td>
<td>2</td>
<td>600</td>
</tr>
<tr>
<td>38-M</td>
<td>1.82</td>
<td>Exploratory laparotomy for stab wound</td>
<td>2</td>
<td>2000</td>
</tr>
<tr>
<td>69-M</td>
<td>1.74</td>
<td>Cholecystectomy</td>
<td>2</td>
<td>700</td>
</tr>
<tr>
<td>65-M</td>
<td>2.02</td>
<td>Cholecystectomy</td>
<td>2</td>
<td>700</td>
</tr>
<tr>
<td>28-M</td>
<td>1.66</td>
<td>Cholecystectomy</td>
<td>2</td>
<td>1600</td>
</tr>
</tbody>
</table>

Mean = 1.77 ± 0.18 SD

BSA = body surface area.

\(^{1}\) Deuvaert, Dmochowski, and Couch (1971) used impedance measurements in 50 limbs of 25 normal subjects and 43 limbs of 24 patients with suspected venous thrombosis. Sixteen of the 50 normal limbs had impedance changes with inspiration of less than 0.20% (abnormal result). Among the patients comparison with venography showed six false positives and one false negative result. Although the accuracy of impedance phlebography was only 53.5%, the authors believed that the procedure had merit in screening because of the low incidence (5%) of false negative results.

\(^{15}\) Steer et al. (1972) have reported false negative results in more than one third of their patients with venogram-proven venous thrombi.
significance so that it is difficult to predict requirements for subjects of small to medium body surface area. For example, one subject with a surface area of 1.56 square meters required a 2700 ml inspiratory volume for an 0.30% change in impedance while another with a surface area of 1.72 square meters required 700 ml. Only at body surface areas over two square meters was the relationship reliable.

If the necessary inspiratory volume were always the same for both legs, one could depend on recognizing a false positive result due to inadequate ventilation by its bilaterality. However, in approximately 50% of the subjects there was a significant discrepancy between the two legs. If a patient's maximum inspiration were to fall between the values required for each leg, an erroneous diagnosis of unilateral venous thrombosis might be made. It is of interest that in ten of 11 cases where there was a difference between the extremities, the left leg required a greater inspiration than the right. This may be related to the anatomical position of the inferior vena cava to the right of the midline. It is possible that compression of the left common iliac vein by the right common iliac artery, as the former crosses the midline to join the right iliac vein and form the cava, leads to mild functional obstruction that must be superseded by a greater obstruction before an impedance change will occur.

In conclusion, our results suggest that impedance phlebography performed without simultaneous measurement of the depth of inspiration may not be valid. Insufficient tidal volume may be the explanation for many of the false positive results, and positive results in patients not inspiring at least 1500-2000 ml should be looked upon with great suspicion. The limitations described here and the recent reporting of many false negative results\(^{15}\) bring into serious question the value of impedance phlebography in the diagnosis of asymptomatic venous thrombosis.

References

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