IMPEDEANCE PLETHYSMOGRAPHY
A SCREENING PROCEDURE TO DETECT DEEP-VEIN THROMBOSIS

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Impedance plethysmography has great potential in the non-invasive detection of dangerous iliofemoral thrombosis. It was used to examine 198 patients undergoing total hip replacement for evidence of proximal venous segment thrombosis. There were 13 abnormal results, and subsequent venography in 12 of these revealed a false-positive rate of 4.0%; there was one false-negative result giving a sensitivity of 85.7%. A venographic study of 46 other patients clinically suspected of having a proximal deep-vein thrombosis confirmed this sensitivity.

The iliofemoral thrombosis rate was 3.9% after total hip replacement and this rate increased significantly in the group of patients over 70 kg in weight. Impedance plethysmography was found to be a useful non-invasive screening procedure for potentially fatal proximal venous thrombosis.

The incidence of deep-vein thrombosis (DVT) reported in patients undergoing hip surgery remains high, figures varying from 30% to 50% (Henderson 1927; McLachlin and Paterson 1951; Kakkar et al. 1969). The incidence of life-threatening pulmonary embolism may be as high as 2% (Crawford, Hillman and Charnley 1968; Harrold 1982). The most dangerous site for thrombosis is the proximal venous segment of the leg, that is the popliteal, femoral and iliac veins (Eklöf et al. 1981), since it is this region which gives rise to fatal emboli (Mavor and Galloway 1969; Sevitt 1974). This segment has been shown to be traumatised during operation for hip replacement, thus increasing the risk of thrombosis (Stamatakis et al. 1977). The prevention of thrombosis in this type of surgery has been unsuccessful.

A method of detection of thrombosis which is accurate in this proximal venous segment is therefore needed. The clinical signs of leg swelling, local increase in temperature, a positive Homans' sign and venous dilatation are notoriously unreliable (Howe 1970). At present, ascending venography is the most accurate and reliable form of detection available and is the reference standard for all other diagnostic techniques.

Plethysmography provides a means of estimating blood flow in organs or limbs by changes in volume. The application and release of a venous-occlusion tourniquet allows separate measurement of arterial inflow and of venous outflow. The volume of a limb segment can be recorded by changes in electrical impedance, and impedance plethysmography appears to offer a rapid, non-invasive method of screening for the early detection of the venous outflow obstruction caused by a proximal segment DVT (Nyboer 1950, 1960).

Electrodes are applied to the calf and changes in electrical impedance are recorded while arterial filling is produced by the inflation of a thigh cuff to above venous pressure. The venous capacitance of the limb segment is measured from the trace on a chart recorder, and when the cuff is released, the rate of venous outflow is recorded (Fig. 1). These values are then plotted on a graph and Hull's line (Hull et al. 1976) is used to discriminate between normal and abnormal results (Fig. 2).

The aim of this study was, first, to assess the clinical application of impedance plethysmography in screening for proximal segment DVT in patients undergoing total hip replacement. All patients with positive results were studied by venography to establish the accuracy of the technique and the rate of false-positive results. Investigation of the false-negative rate was complicated by the ethical committee's advice that venograms could not be justified on patients without clinical or plethysmographic indications. A second separate study was therefore devised, eliminating observer bias, to compare the results of plethysmography and ascending venography in patients in whom there was clinical suspicion of DVT. The third objective was to establish the incidence of proximal DVT in patients undergoing hip

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surgery, all of whom were on a standard prophylactic regime.

METHOD AND PATIENTS

The plethysmograph used in this study was an IPG 200 manufactured by the Cintor Division of Codman in the USA. To reduce the number of false-positive results obtained at the beginning of the study the recommended technique was amended. The pressure in the venous occlusion cuff was set at 65 cm (rather than 45 cm) of water and the bed, with the patient lying flat, was tilted head down by approximately 10° to empty the leg veins, rather than using simple leg elevation. A prospective clinical trial was undertaken on all patients having primary total hip replacement at the Withers Orthopaedic Centre, Musgrave Park Hospital. Clinical examination, seeking calf tenderness and oedema, and impedance plethysmography of both legs were carried out pre-operatively and on every third day until the twelfth postoperative day unless an abnormal plethysmogram was obtained, when a venogram was requested. The venograms were performed and interpreted by a radiologist using the method of Rabinov and Paulin (1972).

Prophylaxis against DVT for all the patients undergoing total hip replacement involved giving Lomodex 70 (Fisons: 6% dextran 70 in dextrose) 500 ml during the operation and 500 ml on each of the first two postoperative days. Perioperative calf stimulation was provided by the use of electrical gaiters.

In all, 198 patients were studied, 77 men and 121 women; their ages ranged from 25 to 83 years, with a mean of 64 years; their average weight was 69 kg, with a range of 35 to 173 kg. 87 patients (44%) were non-smokers and only 6% smoked more than 20 cigarettes per day.

Eighteen patients could not be followed up as planned; in 11 this was because the preoperative plethysmograms were persistently abnormal and therefore a baseline could not be established for comparative recordings. The other reasons for withdrawal were an allergic reaction to dextrose in two cases, skin infection, intestinal obstruction and a consultant's request each in one case. Two patients died: one on the night between inclusion in the study and the proposed operation, and one on the night after operation, neither having thrombo-embolic disease as a factor in their demise.

The remaining 180 patients were each examined clinically and by plethysmography of both legs on the third, sixth, ninth and twelfth postoperative days.

RESULTS

Specificity investigation

Plethysmography had become abnormal in 13 legs, always on the operated side. To ascertain that there was no failure in technique the test was repeated in these cases, and the cuff and electrodes rechecked. Twelve of these patients were subjected to venography; the thirteenth died of a massive pulmonary embolism before a venogram could be performed. The venogram findings are shown in Table I.

Table I. Results of venography in 12 patients with positive plethysmography and in 10 patients with positive clinical signs and negative plethysmography

<table>
<thead>
<tr>
<th>Venography</th>
<th>Plethysmography</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>Abnormal</td>
</tr>
<tr>
<td>Calf thrombus only</td>
<td>2</td>
</tr>
<tr>
<td>Proximal thrombus</td>
<td>5 + 1*</td>
</tr>
</tbody>
</table>

* One at postmortem

These results gave a false-positive rate for plethysmography in detecting proximal venous segment thrombosis of 4.0% (seven false-positive examinations in 174 patients) with a specificity for the technique of 96%. The presence of calf thrombi may indeed alter the plethysmogram but, in the absence of any proximal extension, was taken as a negative finding for the purpose of this study.

In 12 patients a clinician's diagnosis of DVT conflicted with a normal plethysmograph recording, and
venography was requested. In one of these patients venography failed technically, and one was not examined because of an administrative misunderstanding; both these patients were treated with heparin and warfarin. Venography in the other 10 patients with a normal plethysmogram showed five to be normal and four to have only minor calf thrombi which did not warrant anticoagulation therapy. Their further course was monitored by plethysmography and no extension into the proximal venous segment was seen. The remaining patient was shown to have a calf-vein thrombosis extending to the popliteal vein, thereby fulfilling our definition of proximal venous thrombosis.

This was the only proven false-negative examination in the series and means that 85.7% of the small number of abnormal limbs were correctly diagnosed. This single false-negative result may be explained by two factors present in this particular case: the thrombus extending from the calf into the popliteal vein was small and was not completely occluding the vein, while extensive superficial varicose veins were present which would have allowed blood to bypass the deep venous system and provide the normal results on plethysmography.

The age and sex of the patient did not appear to correlate with the incidence of proximal thrombosis within our group of patients, but the weight of the patient did have a significant relationship to the development of proximal DVT. Using 70 kg as a discriminant figure a fourfold table was constructed (Table II). Student’s $t$-test gave $p < 0.04$. The volume of blood lost during and after the operation did not appear to influence the incidence of thrombosis. The duration of the operation averaged 104 minutes in the group who developed proximal thrombosis against 85 minutes in the remainder, but this difference was not statistically significant. A significant relationship between limb swelling and proximal thrombosis could not be established.

For ethical reasons it was not possible to establish by venography the incidence of significant deep-vein thromboses in patients who had normal plethysmograms and no clinical signs or sequelae. A further study was therefore undertaken to investigate the sensitivity of impedance plethysmography.

**Table II.** Relation between the weight of the patient and the incidence of proximal thrombosis

<table>
<thead>
<tr>
<th>Weight</th>
<th>Proximal thrombosis</th>
<th>No proximal thrombosis</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>$&lt; 70$ kg</td>
<td>1</td>
<td>94</td>
<td>95</td>
</tr>
<tr>
<td>$&gt; 70$ kg</td>
<td>6</td>
<td>7</td>
<td>13</td>
</tr>
<tr>
<td>Total</td>
<td>7</td>
<td>173</td>
<td>180</td>
</tr>
</tbody>
</table>

Sensitivity investigation

In the main study false-positive plethysmography was detected by ascending venography, but false-negative examinations could remain undetected unless there were convincing clinical reasons to request a venogram. The low incidence of proximal thrombi detected in the series could therefore have been due to the fact that impedance plethysmography is a poor diagnostic technique, and it was necessary to assess the frequency of false-negative examinations to confirm or refute this suspicion. A separate group of patients was therefore studied. These were patients with clinical suspicion of DVT, for whom venography had been requested.

Impedance plethysmography was carried out on 46 patients, one bilaterally, to give results for 47 legs, which were recorded blindly without knowledge of the results of venography (Table III).

**Table III.** Comparison of impedance plethysmography and ascending venography in 47 patients with clinical suspicion of DVT

<table>
<thead>
<tr>
<th></th>
<th>Venography</th>
<th>Plethysmography</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>33</td>
<td>36</td>
</tr>
<tr>
<td>Calf thrombus only</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Proximal thrombus</td>
<td>11</td>
<td>11</td>
</tr>
</tbody>
</table>

There was complete agreement between venography and impedance plethysmography as regards thrombosis involving the popliteal, femoral or iliac veins. Venography demonstrated thrombi confined to the calf veins in three legs which had normal plethysmograms.

**DISCUSSION**

These studies indicate that impedance plethysmography is a useful procedure for the detection of thromboembolic disease after total hip replacement. The principal problem is that it requires very careful technique. It is important that the venous occlusion cuff and the calf electrodes are placed in such a way that inadvertent venous obstruction is not produced. When an abnormal result is obtained at first examination the attachment of the apparatus to the patient must be reviewed and adjusted and it may be necessary to alter the patient’s position before concluding that there is significant proximal thrombosis. To prove that a result is definitely abnormal is time-consuming and this is a disadvantage.

The very low incidence of proximal thrombosis detected (in the region of 3.9%) could be due either to effective prophylaxis or to the fact that impedance plethysmography is insensitive and was failing to detect true positive cases. The first study was not designed to assess prophylaxis, but to investigate the specificity, by
detecting false-positive results. The second study confirmed the sensitivity of the test, the accuracy of impedance plethysmography in detecting proximal segment thrombosis. Calf thrombi were not detected by plethysmography, but it is known that the majority of fatal emboli arise from the proximal segment. Calf thrombi may undergo lysis or may propagate into the thigh. If propagation occurs then detection by impedance plethysmography will be possible.

The combined investigations have demonstrated that impedance plethysmography can detect proximal thrombosis in the limbs of patients undergoing total hip replacement. The incidence of false-positive and of false-negative examinations was low. The sensitivity of the technique (the number of abnormal limbs correctly diagnosed) is 85.7%. The specificity (the number of normal limbs giving a normal test) of the impedance technique is an acceptable 96.0%.

The technique, however, is not yet ideal and requires substantial care. The incidence of false-positive examinations, means that all abnormal plethysmographs should probably be followed by ascending venography, since it is important that anticoagulant therapy be restricted to those patients who are at greater risk from thrombo-embolic disease than they would be from the development of a haematoma.

The greatest need is for a method suitable for routine screening programmes; impedance plethysmography has much to offer. The apparatus is portable, and can readily be transferred, not only from patient to patient but from ward to ward and even from hospital to hospital. It is non-invasive and painless and the result is immediately available. However, the difficulties at present associated with impedance plethysmography make it less than an ideal screening technique. Water-displacement plethysmography is the most accurate technique available but the equipment is cumbersome and confined to the research laboratory. A portable, easily applied, and accurate method of volume measurement is needed, and further research into such a plethysmographic transducer is being carried out. The low incidence of DVT in Musgrave Park Hospital Orthopaedic Centre requires further investigation to substantiate the effect of the methods of prophylaxis.

REFERENCES


