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Computer-assisted venous occlusion plethysmography in the diagnosis of acute deep venous thrombosis

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Summary

Suspicion of deep venous thrombosis (DVT) is a common reason for acute medical admission. The clinical diagnosis is difficult, and thus significant numbers are investigated and found to be normal. Provision of 24-h radiology is costly, and there may be a delay in investigation. We assessed computer-assisted venous occlusion plethysmography as a screening test for DVT, compared with standard radiology. The test has the advantage of being performed on the ward and if reliable would significantly reduce the number of radiological investigations required. We enrolled 215 consecutive patients presenting with the possible diagnosis of DVT, of whom 144 had technically adequate plethysmography results. Plethysmography had a sensitivity of 96% (95%CI 88–99%) and a negative predictive value of 97% (95%CI 91–99%). Patients excluded because of technically inadequate results were older (by a mean 7 years, $p=0.003$). Computer-assisted venous occlusion plethysmography is a non-invasive method of rapidly screening for DVT which may be safely used as an initial screening test. The test is less useful in older patients, or patients unable to keep still for a period of 2 min.

Introduction

The suspicion of deep venous thrombosis (DVT) is a frequent cause of acute medical admissions. The clinical diagnosis of DVT is notoriously unreliable[1] and therefore a large number of people are investigated who subsequently prove not to have the condition. Contrast venography is considered the gold standard investigation;[2] however, this procedure is invasive, not always technically possible and itself carries a small risk of venous thrombosis or reaction to the contrast.[3] A further practical disadvantage is that venography is not always available on a 24-h basis; the patient may have to wait for the investigation, exposing them to the risks of anticoagulation, and occupying an acute medical bed. Ultrasound venography (sonovenography) is an alternative non-invasive procedure that assesses venous patency by compression and colour Doppler imaging. Sonovenography is now frequently used in the diagnosis of DVT, but this procedure is less objective and more operator dependent.[4] Again the patient may have to wait for the investigation. A fast and reliable screening test that can be performed on the ward is therefore needed, and in recent years, interest has focused on the use of haematological tests of clotting activation such as the D-dimer assay.[5,6]

We have assessed a relatively new approach to the diagnosis of DVT using strain-gauge plethysmography combined with computer-assisted diagnosis. This technique employs the standard plethysmographic procedure of inducing venous filling and emptying by applying a pressure cuff to the upper thigh. The volume change in the calf region is measured using a strain gauge which is placed around the calf. A number of plethysmographic systems have been described,[7–9] but these have the disadvantage of requiring manual calibration and mathematical calculation to quantify flow from recorded changes in calf circumference. The novel

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approach in the device described is that calibration of the strain gauge and calculations of limb blood flow measurements are performed using computer software. This gives an immediate and objective measure of the presence or absence of DVT. We describe an evaluation of this technique as an initial screening test for DVT in the acute medical setting.

Methods

The study was approved by the local ethics committee. All patients admitted to the Royal Bournemouth Hospital over a period of 13 months with suspected DVT were screened using strain-gauge plethysmography with computer-assisted diagnosis (Belfast DVT Screener, AMT Ltd, Orthopaedic Research Unit, Musgrave Park Hospital, Belfast). Details of the technique have been described by Croal *et al.*[10] Plethysmography was performed within 3–4 h of admission.

To perform the test, the patient lies semi-recumbent with the calf raised above the level of the heart. A standard thigh cuff (50 × 17 cm) is positioned around the upper thigh and the strain gauge (Medasonics SG-33) is placed around the calf at the point of maximum circumference. The subject lies in this position for a period of at least 4 min (Figure 1). When the operator is sure that the patient is comfortable, the screening test begins. The test is fully automated, and begins with a self-test and calibration of the strain gauge. The cuff inflates for a period of 2 min and then deflates. Two parameters are derived from this test; the venous capacitance (fractional increase in calf volume) and venous outflow (the rate of calf diminution between 0.5 and 2 s). A combination of the measures of venous capacitance and venous outflow have been found to be the most discriminatory for DVT,[10] and the device automatically computes the probability of DVT. The result is given immediately as to whether the subject is positive or negative for DVT. It is extremely important that the patient is comfortable and able to lie with the leg completely still for a period of over 2 min. Any movement during the test period will result in movement of the strain-gauge, which may influence either the measure of venous capacitance or the measure of venous outflow. This may give a false positive or false negative result. The device is unable to detect this movement artefact, and will still report the result as being positive or negative. Before accepting the predicted diagnosis the operator has to analyse the final result for evidence of movement artefact and reject the test if this is present. As the purpose of the study was to use the device as a screening test for DVT on the admissions ward, a number of nurses underwent a 2-h training session on the use of the machine. Thirty nurses were trained, but the validity of the plethysmography results were assessed by a single investigator blind to the results of radiology. During this study, if the result was not satisfactory the test was not repeated, as the patient has to wait for at least 2 h for the venous capacitance of the leg to return to pretest levels. All patients were then investigated for DVT

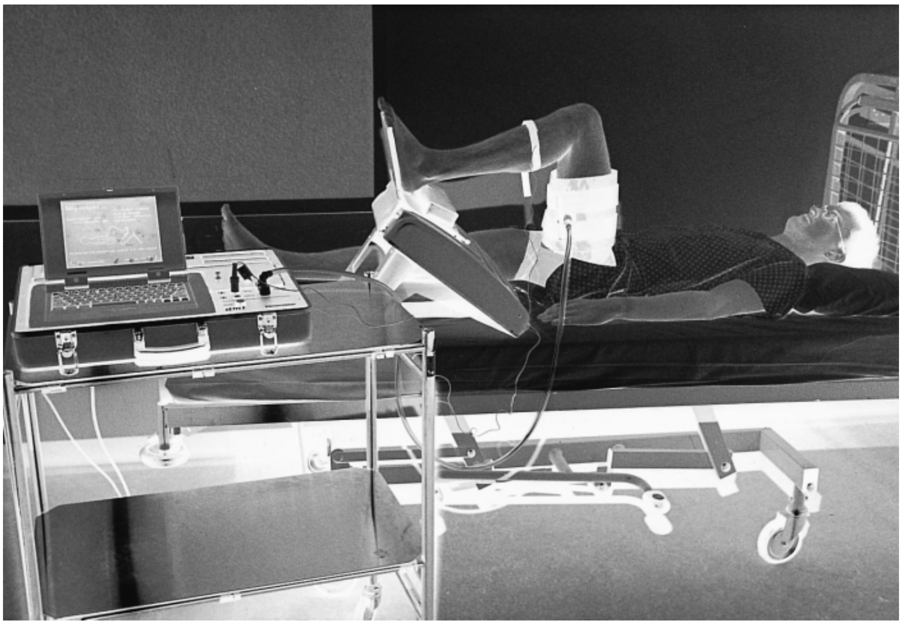

Figure 1. The position of the subject during plethysmography. The patient lies flat during the procedure and must be able to keep still for the period of the test (2 min). Older subjects found maintaining this position for the required length of time difficult.

using ascending contrast venography. An iodine-based water-soluble contrast agent (50–100 ml iohexol or iopamidol 300) was injected into a vein on the dorsum of the foot, with subsequent imaging of the deep venous system of the leg. Contrast venograms were reported by a consultant radiologist blind to the result of plethysmography. In a number of cases, patients were either unwilling to undergo contrast venography, contrast venography was technically not possible or was not available. In these cases the patient then underwent sonovenography by a consultant radiologist or a senior ultrasonographer, again blind to the results of plethysmography. Thrombosis involving popliteal, femoral or iliac veins was defined as proximal. Thrombosis below the popliteal vein was defined as distal.

Details of the patient's age, gender and presenting symptoms and signs were recorded.

Statistical analysis

The independent samples t-test was used to compare mean age between satisfactory and unsatisfactory plethysmography results. The χ^2 test was used to examine the influence of pain, swelling and gender on the proportion of unsatisfactory plethysmography results. The χ^2 test was also used to examine the relationship between the validity of plethysmography and the subsequent result of radiological investigation. The diagnostic data was summarized using sensitivity, specificity, positive and negative predictive values and the post-test probability of a positive venogram if the test was negative (1-negative predictive value). Exact mid-*p* 95% confidence intervals were calculated for each. The level of statistical significance was set at 5%. The definitions of the summary terms used are as follows: positive predictive value, the percentage found to have a DVT among those with positive plethysmography; negative predictive value, the percentage found to have normal radiology among those with negative plethysmography; sensitivity, the percentage with positive plethysmography among those with DVT; specificity, the percentage with negative plethysmography among those without DVT. Data were analysed using SPSS version 7.5.1 and Confidence Interval Analysis statistical programs.

Results

A total of 215 consecutive patients (102 men, 113 women) underwent strain-gauge plethysmography and were subsequently investigated with either an ascending venogram or sonovenogram; 149 (69.3%) underwent venography and 66 (30.7%) underwent sonovenography. Their mean age was 64.6 years, range 17–95 years. Of the 215 subjects initially studied, 77 (36%) were subsequently found to have DVT on radiological investigation; 64 had proximal DVT and 14 distal DVT. Four had evidence of extrinsic compression of proximal veins on venography. These four patients all required further investigation of the abnormality.

The strain-gauge plethysmography results were assessed for validity by a single investigator blind to the results of the radiological investigations. Some 71 plethysmography results (33%) were technically unsuitable and not included in further analysis, leaving 144 patients, of whom 100 underwent venography, and 44 underwent sonovenography. As ascending venography is considered the 'gold standard' investigation for diagnosis of DVT, the results in Table 1 compare plethysmography with venography alone.

Plethysmography gave two false-negative results, giving a false-negative rate of 5%. Both of these were small distal DVTs. Plethysmography gave 15 false-positive results, giving a false-positive rate of 25%. Of the 15 false-positive plethysmography results, two of the contrast venograms showed evidence of extrinsic venous compression likely to cause obstruction of venous outflow. Both of these patients required further investigation.

As the routine investigation of DVT in many centres includes the use of sonovenography, we have included the results of the analysis of both forms of imaging with plethysmography in Table 2. The rate of positive plethysmography was similar in those with contrast venography (54/100 = 54%) and those with sonovenography (21/44 = 48%). When sonovenograms were added to the analysis, there were no more false negatives, giving an overall false-negative rate of 4%. The overall false-positive rate was very similar at 26%. As the aim of the study was to use plethysmography as a screening test, with all positive results proceeding to further radiological investigation no DVTs requiring treatment were missed using this technique. If we were to look at proximal DVTs only, the post-test probability of disease after a negative test (95% confidence interval) would be 0/44 = 0% (0–7%). This means that the underlying post-test probability of disease after a negative test is unlikely to be more than 7%. If all patients with negative plethysmography had been discharged from hospital on the basis of plethysmography alone, using the data from Table 2, 69/144 patients (48%) would not have needed radiological investigation.

We excluded 71 (33%) of the initial 215 patients who underwent plethysmography because their results were considered unsatisfactory. Table 3 compares the data from the subjects included in the study with that for those excluded. There was no

Table 1 Plethysmography results compared with ascending contrast venography results for 100 patients

Plethysmography results	Contrast venography positive	Contrast venography negative	Total
Positive	39	15	54
Negative	2	44	46
Total	41	59	100

Summary measures (95%CIs) as follows. Sensitivity = 39/41 = 95% (85–99%). Specificity = 44/59 = 75% (62–84%). False positive rate = 15/59 = 25% (16–38%). False negative rate = 2/41 = 5% (1–17%). Positive predictive value = 39/54 = 72% (59–83%). Negative predictive value = 44/46 = 96% (86–99%). Post test probability of DVT after a negative test = 2/46 = 4% (1–14%).

Table 2 Plethysmography compared with contrast venography or sonovenography for 144 patients (in some patients contrast venography was not performed and sonovenography was used as an alternative)

Plethysmography results	Contrast or sonovenography positive	Contrast or sonovenography negative	Total
Positive	52	23	75
Negative	2	67	69
Total	54	90	144

Summary measures (95%CIs) as follows. Sensitivity = 52/54 = 96% (88–99%). Specificity = 67/90 = 74% (65–83%). False positive rate = 23/90 = 26% (17–35%). False negative rate = 2/54 = 4% (1–12%) Positive predictive value = 52/75 = 69% (58–79%). Negative predictive value = 67/69 = 97% (91–99%). Post test probability of DVT after a negative test = 2/69 = 3% (1–9%).

Table 3 A comparison of the proportion of DVTs and site of DVT between subjects with valid plethysmography results and subjects with invalid plethysmography results

	Patients with valid plethysmography (percentage of total)	Patients with invalid plethysmography (percentage of total)
No DVT	88 (61.1)	46 (64.8)
Above knee DVT	44 (30.5)	19 (25.8)
Below knee DVT	10 (6.3)	4 (5.6)
Total	144	71

χ^2: $p = 0.759$.

Table 4 Age, gender and presenting symptoms and signs in 144 patients with valid plethysmography results and 71 with invalid plethysmography results

	Valid plethysmography	Invalid plethysmography	*p* for difference between groups
Age (years)	62.7 (17.9)	69.7 (13.1)	0.003
Male gender	71 (49.3)	31 (43.7)	0.436
Pain	116 (80.5)	56 (78.9)	0.994
Swelling	119 (82.6)	61 (85.9)	0.541
Erythema	75 (52.1)	33 (46.5)	0.440
Total	144	71	

Figure are numbers (%) apart from age, which is mean (SD).

significant difference in the rate of positive DVTs, and no significant difference in the number of subjects with above-knee or below-knee DVTs. Table 4 compares the age, gender and presenting symptoms and signs between those whose results were included in the study and those excluded. The presences of pain, swelling and erythema were not significantly different between the groups. The group with results that were discarded was significantly older than those with useable plethysmography results.

An advantage of this technique is that patients do not have to be referred to the radiology department for investigation. This may significantly reduce the time that the patient has to wait for initial screening: 53 patients (37%) had radiological investigation of DVT on the same day as plethysmography, 66 patients (46%) had radiological investigation the next day and the remaining 25 patients (17%) took 2 or more days from the time of plethysmography.

Discussion

We compared venous occlusion plethysmography with the standard radiological methods of diagnosing DVT in 215 consecutive patients presenting to a district general hospital with symptoms and signs of DVT. Firstly, we compared plethysmography with ascending contrast venography alone, as this is considered to be the 'gold standard' for the diagnosis of DVT. The sensitivity of 95% and false-negative rate of 5% for plethysmography compare favourably with other non-invasive methods of diagnosing DVT such as sonovenography (pooled data showing a sensitivity of 95% for this technique).[11]

A previous study using the same technique of computer-assisted venous occlusion plethysmography found a similar level of sensitivity (94.7%) but this study was based on symptomatic subjects in the post-operative period following orthopaedic procedures rather than the general population as in this study.[10] The two false-negative results in this cohort were both small isolated calf DVTs. None of the above-knee DVTs diagnosed by contrast venography were missed using plethysmography.

Although ascending venography is considered the optimal technique for the diagnosis of DVT, it is invasive and requires cannulation of a distal vein in the foot. This is often uncomfortable, occasionally impossible, and may itself lead to thrombosis within the deep veins of the leg.[3] Because of this, other less invasive methods of diagnosing DVT have been developed. The most commonly used is sonovenography, however, the calf veins cannot be evaluated in up to 40% of patients using this technique.[4] As isolated calf DVTs are less likely to lead to pulmonary embolism, it is accepted as an adequate test to exclude clinically significant DVT. We therefore compared plethysmography with a combination of venography or sonovenography. Sonovenography did not diagnose any cases of DVT missed by plethysmography; thus there were no more false negative results.

A significant finding of this study is that although plethysmography is reasonably accurate, as a screening test, 33% of subjects did not have a useable result. There was no difference in the rate or site of DVT between the valid and invalid results. The investigation requires the subject to be able to maintain a position with the leg supported above the level of the heart for a period of at least 6 min and to lie completely still for the 2 min of the test. The major reason for an invalid result is that the subject is unable to keep still for the required period. Movement artefact then invalidates the result. We have shown that older patients were more likely to have an invalid result and it seems likely that this is because they were unable to keep still. Certainly this was the opinion of the nursing staff performing the investigation.

A further reason for the high rate of invalid results may be that too many operators were performing the procedure. The study was designed to validate the use of plethysmography on a busy admissions ward, and the decision was therefore taken not to restrict the investigation to a single operator. Thirty nurses were trained because of the need to have an operator available 24 h per day. If the plethysmography result was invalid, the test was not repeated, as there is a significant wait before the investigation can be done again. The previous studies of this device did not report any invalid results, but did not comment on the number of operators trained in the procedure.[10] A smaller number of trained individuals with regular assessments of technique might significantly reduce the number of invalid results, but this might then lead to practical difficulties in providing a 24-h service. The manufacturer has now altered the software to include a final check that the result is technically correct before the investigation is considered valid and used for diagnosis.

An alternative approach to the non-radiological diagnosis of DVT is the use of haematological measurement of fibrin degradation products using a variety of D-dimer assays. These assays are becoming faster, more reliable and less expensive.[6] A future strategy for the ward-based screening of DVT may include a combination of D-dimer assay and plethysmography before proceeding to radiological investigation.

In summary, strain-gauge plethysmography with computer-assisted diagnosis is a satisfactory first-line investigation for the diagnosis of DVT. If the result is positive the patients must proceed to further investigation. If the result is negative, the patient can safely be discharged. No proximal DVTs were missed using plethysmography. However, valid results were not obtained in a significant number of subjects, thus the technique is less useful in older subjects or subjects unable to lie still. The major advantages over methods currently in use are that the test is objective, non-invasive, and can be performed on an admissions ward or in a casualty department. If a subject with a negative plethysmography result is then discharged from hospital, this would significantly reduce the number of venograms performed and occupancy of hospital beds waiting for radiological investigation.

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