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The use of infrared thermal imaging in the diagnosis of deep vein thrombosis

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HIGHLIGHTS

- The sigma difference between two legs is relatively high in each of patients with DVT.
- CAD is developed in the diagnosis of DVT by using IRT as a pre-screening test.
- A novel combination is proposed to utilize EMC to perform diagnosis and treatment of DVT.

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ABSTRACT

The diagnosis of Deep Vein Thrombosis is of vital importance, especially in emergency situations where there is a lack of time and the patient's condition is critical. Late diagnosis causes cost increase, long waiting time, and improper treatment. Today, with the rapidly developing technology, the cost of thermal cameras is gradually decreasing day by day. Studies have shown that many diseases are associated with heat. As a result, infrared images are thought to be a tool for diagnosing various diseases. In this study, it has been shown that infrared thermal imaging can be used as a pre-screening test in the diagnosis of Deep Vein Thrombosis with the developed computer aided software. In addition, a sample combination is shown for applications that utilize emergency services to perform diagnosis and treatment of Deep Vein Thrombosis as soon as possible.

1. Introduction

Venous thrombosis is the name given to the formation of blood clots (thrombosis) in the veins. This clot prevents blood flow in the vein, leading to regional swelling and pain. Venous thrombosis is often referred to as deep vein thrombosis because it most commonly occurs in veins found in the legs, calves and hips.

Deep venous thrombosis (DVT) is often painless, but the most important aspect is that it dislodges from the site of the clot, causing death by clogging the lung vessels through blood circulation. It is an emergency situation and can lead to death if not treated immediately. In DVT, the clot is often not completely dissolved, or even if dissolved over time, it causes obstruction, narrowing, and deterioration of the lids inside the vein. In this case, after years of clotting, the flow of venous blood, which should return from the legs gradually, is blocked and the blood starts to accumulate in the veins and the pressure starts to increase. Then, high blood pressure in the veins can damage the tissues, resulting in swelling of the legs, pain, color change, and venous insufficiency with wrist wounds (venous ulcer). Also, as a result of blood pooling in the leg due to blocked veins, the leg swells gradually and eventually the circulation of the artery is disturbed and gangrene develops in the leg and may cause loss of the leg. DVT is a pathology with high complications of mortality and morbidity in both acute and chronic stages. Immediate initiation of treatment with deep vein thrombosis diagnosis will significantly prevent these possible complications.

Venography is accepted as the most reliable test. Although venography is a reliable imaging method for DVT, it can only be performed by the related branch physician, which restricts the accessibility of this examination. However, due to concerns such as an invasive procedure, exposure to radiation and developments in alternative methods, it is much less frequent nowadays. The method used for the laboratory test is the D-dimer measurement.

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If the D-dimer is normal, it most likely indicates that there is no DVT. On the other hand, the steady increase of D-dimer does not always point to DVT. The most widely used and reliable method currently available for DVT is Color Doppler Ultrasonography (CDUSG). With CDUSG, DVT diagnosis can be painless, easy, cheap and accurate. Although there are not many of these risks in this method, reaching a radiologist at any time in emergency situations and waiting for the reporting process can lead to a clinical concern such as delayed treatment and the patient to wait for a long time in the emergency service. In the study carried out by Caronia et al., 19 medical assistants performed CDUSG in 75 patients and patients were then directed to radiology for confirmation. The radiologist reported an average of 14.7 h of CDUSG [1]. In a similar study, the required CDUSG reporting from radiology caused an average delay of 13.8 h [2].

The use of a thermography to diagnose a DVT disease has been suggested to alleviate these problems. Previously, many equipment that had already been worked on but had not gained practical use due to the disadvantages such as the high cost of the devices, the size and the cumbersome, has come back again with the reduction in cost and the development of more compact designs. Especially with the development of computer software and the progress of artificial intelligence work, the devices become suitable for use.

2. Thermography

Throughout history, it has been proven that temperature is a very good indicator of health and disease discrimination [3,4]. Since 400 BCE, the temperature has been used for clinical diagnosis in different forms [5]. As a homotherm, a person can maintain his body at a constant temperature, regardless of environmental temperature [6]. The body of the homotherms is divided into two parts as the core temperature and the outer wall temperature [7]. The core temperature is constantly maintained in a narrow range of about 33–42 °C [7]. Regulation of the inner core temperature is one of the most basic features of the normal human body. A few degrees of change in the core temperature are considered a clear indicator of possible disease [6].

Abnormal thermal patterns, which can be easily recognized by infrared imaging, can allow early diagnosis. Thermographic findings are generally correlated with other clinical findings. Although it is often not specific and largely due to environmental factors, there is a range of reasons why this technique has been widely accepted in the medical world. Above all, infrared imaging is a remote, non-contact, non-invasive technique. It is possible to monitor a large area simultaneously and quickly. Also, it is easy and fast to interpret colored thermograms. In addition, this technique only records the natural radiation from skin surfaces and so does not have any harmful radiation effects. Therefore, it is suitable for long-term and continuous use. Finally, infrared imaging is a real-time imaging technique that can monitor dynamic changes in temperature. Because of these advantages, thermography is used as an effective alternative diagnostic tool. Table 1 shows contralateral temperature differences in various body parts (left and right sides) in normal individuals [6,8].

In 1963, Barnes showed that thermograms can provide information on physical anomalies and thus may be useful for physical disease diagnosis [9]. Sherman and colleagues have shown that thermal imaging can evaluate skin temperature symmetries between the identical extremities in humans. Thus, they concluded that the simplest method of scanning symmetry throughout the whole body [10]. Ring et al. revealed that thermography could have different possibilities in the field of medicine [11]. Jung [12], Ammer and Ring [13] also demonstrated various medical applications. Thermography are commonly used for diabetic neuropathy [14–16], vascular disorders [14,17,18], breast cancer detection [19,20], thermoregulation studies [6,7], fever monitoring [21,22], brain imaging (thermoencephaloscopy) [23], dentistry and dermatology [24,25], muscle pain and shoulder impingement syndrome [26], diagnosis of rheumatic diseases [27,28], dry eye syndrome [29], parasitic liver disease treatment [30], metastatic liver disease detection [31], intestinal ischemia [32], kidney transplantation [33,34], heart therapy [35], and gynecology [36,37]. It is also used for the treatment of acupuncture [38,39], cryotherapy [40], forensic medicine [41,42] and assessment of radiation damage to the human body [43]. Lahiri et al. has published a comprehensive literature summary of various medical applications and related developments related to thermography in 2012 [44].

Table 1
Contralateral temperature differences in various body parts (left and right sides) in normal subjects.

Body parts	Average temperature difference (°C)
Forehead	0.12
Cheek	0.18
Chest	0.14
Abdomen	0.18
Neck (Posterior)	0.15
Lumber (Back)	0.25
Body Average	0.17
Arm (Biceps)	0.13
Palm	0.23
Thigh (Front)	0.11
Thigh (Rear)	0.15
Foot (Dorsal)	0.30
Average Fingertips	0.38
Average Foot Toe-Fingertips	0.50

In patients with DVT, it is seen in the literature that the complaining leg was found to be warmer than the normal leg [45–48]. Harding et al. in 1997 found that that thermal imaging has many advantages when compared with Ultrasonography (USG) and Venography. According to study, when thermography is used as the first test, the USG and Venography requirements are reduced by a factor of 33 percent. In this study, it is seen that none of the patients who excluded DVT by thermal imaging developed pulmonary emboli later. As a result of this, both unnecessary diagnostic tests and unnecessary anticoagulation therapy are not performed. This study is the pioneering work of thermography in this field [45].

In a study conducted by Deng et al. on New Zealand rabbits in 2012, it was found that subjects with experimental thrombosis generated in femoral vein had significant asymmetric heat distribution when comparing the heat differences between the legs before and after the study, and significant temperature increase on the side where thrombus was formed [46]. Another study by Kalodiki and colleagues has been performed with liquid crystal thermography, duplex USG and venography on 100 patients with clinical suspicion of DVT. A negative predictive value of 97% was found for the thermography performed within one week from the onset of symptoms. Based on these results, unnecessary USG and venography in 39 of 100 patients were prevented. USG alone was sufficient in 56 of the remaining 61 patients, but USG was not performed due to strained and sensitive legs in 6 patients and venography was required. When this method is used, 1 thrombus is bypassed and 3 patients are given unnecessary treatment. The algorithm in this study alone reduced costs even though it was not fully effective [47]. In a study conducted by Holmgren et al. in 1990 with 102 patients; thermography, thermal profile and impedance plethysmography, venography are compared, the sensitivity of the thermal imager measurements was 83% and the specificity was 55% [48]. In recent years, according to the study