RENAL FISTULA ASSESSMENT USING AUTOMATED THERMAL IMAGING

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Abstract: Arterio-venous fistulae (AVF) enable the long-term treatment of end stage renal disease using haemodialysis. Poor AVF blood flow can result from fistula narrowing or occlusion while at the other extreme vascular steal from the hand can result from very high fistula blood flow rates. Previous work, based on manual-based image processing techniques of thermal images, has shown that bilateral differences in arm temperature about the region of the fistula can objectively assess fistula function. In this study we describe an automatic image processing technique for this type of assessment. Initial experimental results found no differences between manual and automatic bilateral temperature differences derived from the thermal images.

Introduction

Arterio-venous fistulae (AVF) are important for the long-term treatment of end stage renal disease using haemodialysis [1, 2]. A fistula enables access to high volume blood flow rates, usually at an arm site. Ongoing assessments are therefore important to determine if they are likely to be viable for routine haemodialysis [3, 4]. Clinical problems can arise under the two extremes of fistula blood flow; very poor flow due to fistula narrowing or occlusion, or excessively high flow resulting in vascular steal from the hands [3, 5, 6, 7].

AVF function can be assessed by clinical examination and by various objective measurement techniques, including thermal dilution, angiography, magnetic resonance imaging, and diagnostic ultrasound [8, 9, 10, 11, 12]. None of these techniques is perfect for this application. Ideally, AVF function should be evaluated using simple, safe, non-invasive and accessible techniques. Colour duplex ultrasound is used in various centres, and more recently medical thermal imaging has shown promise for this application [13, 14, 15].

The fistula essentially results in the high pressure arterial and lower pressure venous systems being short-circuited, with the relatively warm blood from the heart flowing through the fistula and transferring heat to the surrounding tissues. Since healthy subjects are known to show thermal symmetry between between right and left body sites [13] then it is possible for thermography to quantify the thermal asymmetry arising from AVF blood flow. Allen *et al.* [15] have demonstrated, using temperature measurements which were manually extracted from regions of interest on the thermogram, that the differences between arm temperatures (fistula side - non-fistula side) are significantly and positively correlated with fistula blood flow.

The aim of the work was to develop an automated technique based on thermal imaging to estimate AVF blood flow.

Methods

Patients

Adult renal patients were studied.

Infrared thermography measurement

Patient preparation

Patients followed the Freeman Hospital thermal imaging preparation protocol, requiring that in the 3 hours before their study they refrain from smoking, coffee, tea, caffeinated soft drinks, alcoholic beverages, taking stimulating drugs or substances not prescribed by their doctor, to avoid physical exertion, and to avoid using skin creams or talc. They were also asked to eat only a light meal and drink water or juice prior to their study, and to continue taking any prescribed medication as usual. On arrival at the measurement facility the patient was seated and relaxed with measurement sites exposed to air whilst acclimatising for at least 20 minutes in the thermo-neutral temperature-controlled room (23±1°C).

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Collection of thermograms

Thermography measurements were made using a FLIR SC300 infrared thermal imaging system in a dedicated medical thermal imaging facility. Thermograms were taken of the dorsal aspect of both arms to allow bilateral comparisons of skin temperature in the region of the AVF. The patient remained comfortably seated throughout the measurement session.

Manual thermogram image analysis

Thermograms were analysed manually using dedicated image processing software (FLIR ThermaCAM Researcher) by using specific temperature measurement areas manually outlined on the arms of each patient. For brachial AVFs these areas were carefully drawn symmetrically on each arm from just proximal to the elbow then through the elbow region to the forearm. For forearm and radial AVFs these areas were drawn from just distal to the elbow to the wrist. Skin emissivity was assumed to be 0.97. The maximum regional temperatures and their bilateral differences (fistula side - non-fistula side) were calculated by the FLIR ThermaCAM Researcher software for each patient.

Automated thermogram image analysis

Clearly, the manual extraction technique relies on interactive intervention of the clinician and can take up valuable time. Computerised image processing and pattern recognition techniques have been used in acquiring and evaluating medical thermal images [16, 17] and proved to be important tools for clinical diagnostics. Therefore an automated technique that extracts the regions of interest on both the fistula and non-fistula side was developed. The algorithm uses the same images of the patients' arms as for the manual analysis technique described above.

Firstly, the background, i.e. all non-body parts in the thermogram, were removed. In the image processing literature thresholding algorithms are commonly employed to divide the intensities in an image into two ranges, below and above a certain threshold value which is ideally adaptively selected based on the image so as to account for variation in the intensity distribution due to image capture, contrast etc. The threshold is derived based on the algorithm by Otsu [18] which is based on maximising the between-class variance. Areas with intensities (i.e. temperatures) below the threshold are deemed as background and hence discarded.

Secondly, morphological image processing [19] is applied to fill small holes and merge them with larger corresponding areas. The two largest regions left after this should then be those of the arms of the patients. In cases where those areas are merged into one, e.g. if some other parts of the body are visible in the thermogram, the regions are split at the point that produces the shortest boundary between the areas.

Finally, extracted arm regions are labelled according to their side (i.e. ”fistula arm” and ”non-fistula arm”) and the maximum regional temperatures and their bilateral differences (fistula side - non-fistula side) calculated.

Ultrasound assessment of fistula blood flow

AVF blood flow was measured using an ATL HDI 5000 colour duplex ultrasound scanner [20].

Results

Infrared thermography AVF measurements

Upper limb thermograms from patients with arterio-venous fistulae are shown in Figure 1, giving a representative example of a healthy fistula and a failed fistula. Here, patient A had a clearly defined fistula in which the regions relating to warmer superficial AVF blood flow can be seen, and with their hands demonstrating bilateral similarity in temperature. For patient B fistula flow was 60 ml/min, consistent with fistula failure; note there is no clear temperature difference between the arms.

Automatically extracted arm regions

Results of the automatic image analysis algorithm are given in Figure 2 which show the arm regions extracted from the thermograms of Figure 1.

Summary of thermography measurements

The mean difference in bilateral temperatures for manual - automatic extraction techniques was +0.02 °C. No significant difference was found between the two techniques.

Relationships between thermography and fistula blood flow

Initial results showed a relationship between bilateral differences in maximum arm temperatures and AVF blood flow.

Discussion

The significant correlation between the bilateral arm temperature differences and fistula blood flow is proposed as a useful indicator for renal fistula assessment. Furthermore, thermography combined with the automated image extraction technique described shows promise for an efficient and effective tool for use in the clinical environment. In this pilot study the automated image analysis technique has been successfully validated against the manual technique of regional temperature extraction from the arms in this patient group.

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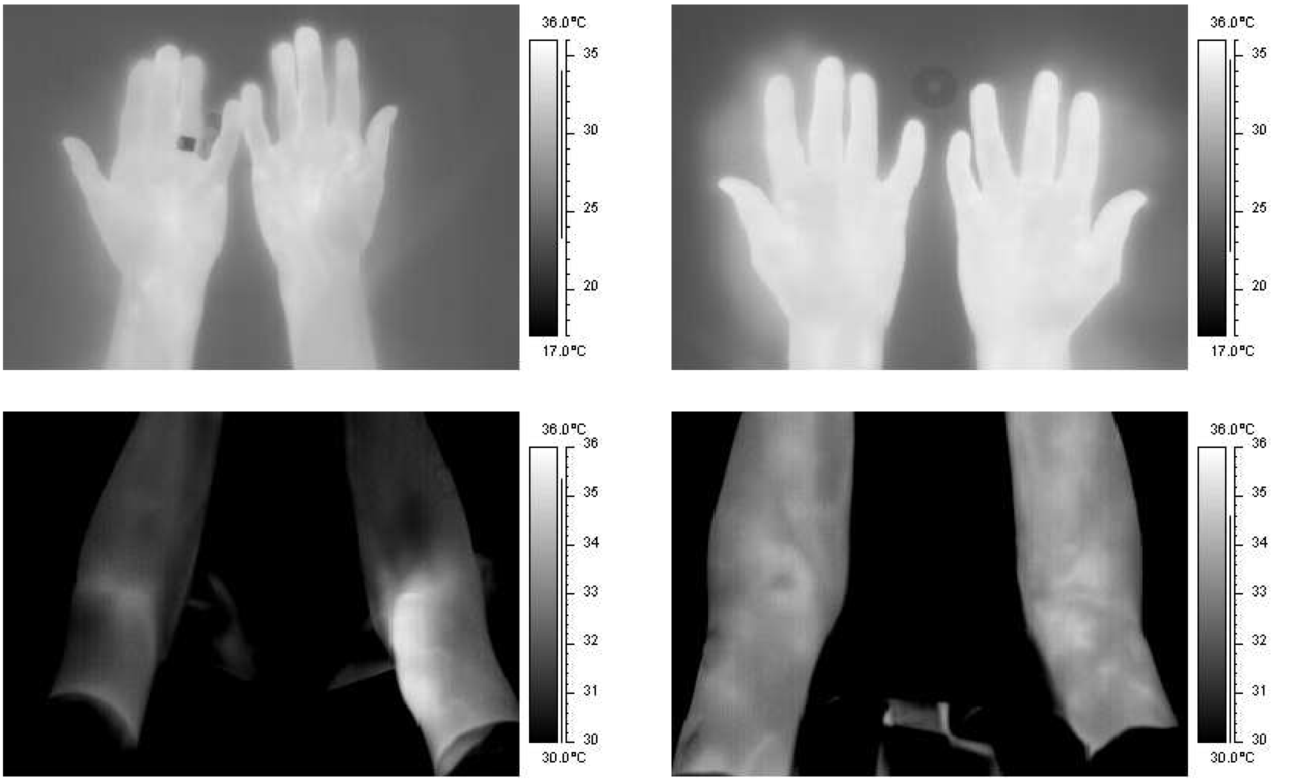

Figure 1: Example thermograms from two renal patients: patient A (left) with a clearly defined fistula, patient B (right) with a failed fistula. The arm and hand thermograms are displayed using grayscale temperature scale, with white representing the warmest and black the coolest regions in the image.

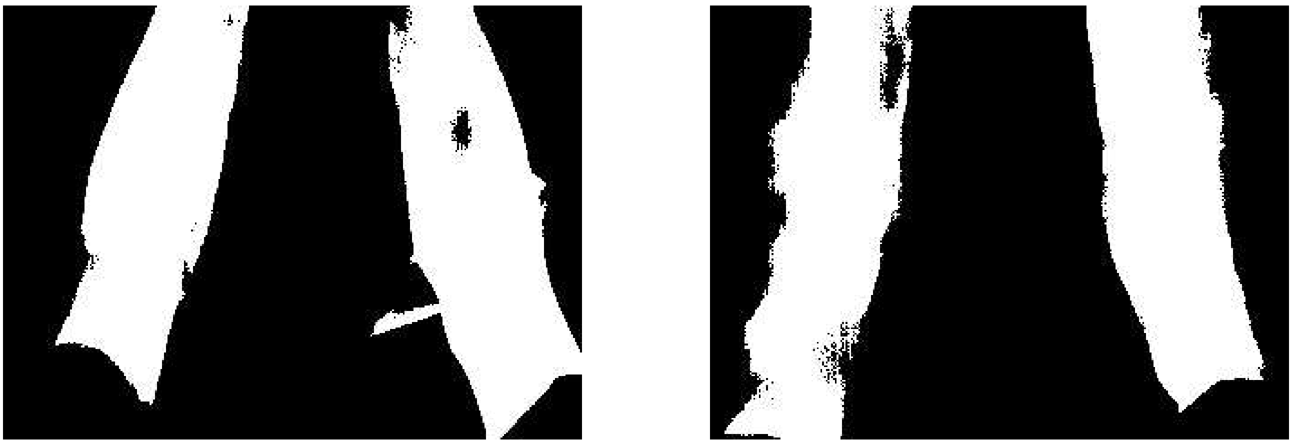

Figure 2: Regions of interest extracted using the automated image analysis technique. The white areas correspond to the study regions of the patients' arms.

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Conclusions

An automated image processing approach for the assessment of renal fistulae was developed and promising initial results presented. The study of the relationship between bilateral differences in arm temperature and arterio-venous fistula blood flow should now be extended. Further work is now needed to refine the automated algorithm to ensure the full arm regions are always identified and that the algorithm is sufficiently robust for routine clinical use. The research group also aim to undertake the study of a larger homogeneous group of renal patients with arterio-venous fistulae.

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