Rheumatology 2001;40:1384–1387

The use of portable radiometry to assess Raynaud's phenomenon: a practical alternative to thermal imaging

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Abstract

Objectives. To compare the performance of a portable radiometer with thermal imaging and to assess the potential for radiometry to provide a practical alternative for assessing vascular responsiveness in Raynaud's phenomenon (RP).

Methods. Subjects comprised 18 patients with diagnosed RP and 19 non-RP subjects. A thermal imager (Starsight) and a portable radiometer (Cyclops) measured digital temperature at baseline and the subsequent drop and rise in temperature following a cold challenge test.

Results. The intra-class correlations between the two instruments for all three measures exceeded 80%. The overall performance of each instrument was almost the same, the Starsight thermal imager correctly classifying 84% of subjects as RP or non-RP and the Cyclops portable radiometer correctly classifying 86% of subjects. The sensitivity of the thermal imager was 83%, compared with 89% for the portable radiometer; the specificity of both instruments was 84%. The positive and negative predictive values of the thermal imager were 83 and 84% respectively, and those for the portable radiometer were 84 and 89%.

Conclusions. The two instruments performed equally well and the differences between them in their absolute measurements did not influence their ability to detect RP. Portable radiometry provides a practical, cheap, accurate and reliable alternative to thermal imaging and has the potential to be used in range of clinical and epidemiological settings.

KEY WORDS: Thermography, Radiometry, Raynaud's phenomenon, Classification, Cold challenge test.

The uses of thermography in medicine are wide-ranging [1] and include the detection of breast disease [2], lumbar disc herniation [3] and deep venous thrombosis [4]. In rheumatology, thermography can be used to quantify the degree of synovitis in patients with inflammatory joint disease [5]. Thermography also shows promise as a diagnostic tool for Raynaud's phenomenon (RP), in which disturbances of vasomotor control produce abnormal surface temperature patterns, when performed in conjunction with a cold challenge of the hands or feet [6, 7]. However, the technique has limited practical application outside specialist centres because of the requirement for costly thermal imaging equipment and its lack of portability.

Recent advances in technology have led to the development of inexpensive hand-held radiometers that might offer an alternative to thermography. However, whilst portable radiometers can be used outside the specialized setting of a vascular laboratory, it is unclear if the radiometric technique is an effective substitute for established thermographic methods. In this study we compared the performance of two instruments—a pyroelectric thermal imager and a portable radiometer—in discriminating the cold challenge responses of RP patients from those of normal subjects.

Method

Subjects

Measurements were taken from 18 female subjects classified as having RP and from 19 healthy female controls. The 18 RP subjects included 16 identified from a hospital database of primary RP and two identified from a healthy volunteer population (hospital workers). A nurse trained in the assessment of the disease classified RP following an interview. The interview questions

Submitted 2 November 2000; revised version accepted 4 June 2001.

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related to the subject's history of sensitivity to cold and digital colour changes, including white. All RP subjects satisfied the clinical criteria for definite RP validated by Brennan *et al*. [8].

Instruments

The instruments used by independent trained operators were (i) the Starsight pyroelectric vidicon thermal imager (Insight Vision Systems, Great Malvern, UK) [9], with image capture and analysis software by Thermosoft (EIC, Jenison, MI, USA) and running on a 486-66 PC-compatible computer under Windows 3.11; and (ii) the Cyclops 330S Portable Radiometer (Land Instruments, Dronfield, UK). Both the Cyclops 330S hand-held thermometer and the Starsight thermal imager use the pyroelectric method to detect infrared radiation within a similar spectral range (7–15 μm). The Starsight uses a staring array detector to produce an image of the target, whereas the Cyclops simply records spot temperature. Consequently, in comparison with the Starsight, the Cyclops is a considerably less sophisticated instrument and costs less than one-tenth of the price.

Procedure

All subjects underwent a cold challenge test. This test has been used extensively (with only minor differences in protocol) for the thermographic assessment of RP [6, 7, 10, 11]. Hot or caffeinated drinks were avoided on the study day and subjects were clothed lightly. Prior to the cold challenge, there was an initial equilibration phase during which subjects were seated and exposed to an ambient temperature of 23°C for 15 min. This temperature was achieved by the use of a ceiling-mounted air-conditioning unit set to slow airflow. The cold challenge was conducted by immersing the subjects' gloved hands in water at 15°C for 60 s.

Two operators then took temperature measurements independently on the same subject. Subjects were seated and held their hands at chest height, palms forward. The Starsight thermal imager was mounted on a tripod and took an instantaneous image of both hands. The thermograms were analysed with the Thermosoft program by using the freeform shape facility to define regions of interest and measure their temperature. In this study, the operator measured the temperature of all fingertips (excluding thumbs) in an area bordered by the fingertip and the distal finger crease.

The Cyclops was held by an operator who sat close to and opposite the subject and took sequential measurements of all eight fingertips immediately after each thermal image had been taken. The Cyclops operator aimed to measure the temperature at the centre of the whorl visible on the palmar aspect of each fingertip.

Measurements were taken by both operators at baseline (T_{pre}) and at three further time points during a 10-min period after cold challenge: T_{post} = immediately after immersion; $T_5 = 5$ min after immersion; $T_{10} = 10$ min after immersion. This allowed computation of baseline (T_{pre}), drop ($T_{pre} - T_{post}$) and rise ($T_{10} - T_{post}$). The measurements were taken independently by the two operators, who were blinded to each other's observations.

Analysis

The analysis first assessed the level of agreement between the two instruments and, secondly, addressed the question of whether the differences between the two instruments affected their ability to distinguish between RP and non-RP subjects in the clinical setting.

The agreement between the instruments was assessed using the method of Bland and Altman [12]. Their ability to detect RP was assessed by using the data from the Starsight camera to construct a rule to discriminate between RP and non-RP subjects, which was then applied to the Cyclops data. This rule was derived from a logistic regression model that contained all three variables (baseline, drop and rise); patients were classified as having RP if the probability of disease on the basis of their measurements was >0.5. For the purpose of analysis, the average temperature of all eight digits at each time point was taken.

All analyses were carried out using STATA (StataCorp, College Station, TX, USA).

Results

Subjects

The mean age of the patients with RP was 6 yr older than that of the normal volunteers (Table 1). None of the patients with RP had associated connective disease.

TABLE 1. Characteristics of subjects

	RP ($n=18$)		Non-RP ($n=19$)	
	Mean	Range	Mean	Range
Age (yr)	37	17–61	31	18–53
Starsight				
Baseline temperature (°C)	26.17	23.12 to 29.96	30.66	24.89 to 35.11
Drop (°C)	4.89	2.53 to 7.34	7.86	4.63 to 11.50
Rise (°C)	0.83	0.26 to 2.71	4.78	0 to 8.43
Cyclops				
Baseline temperature (°C)	23.78	20.89 to 27.24	29.91	23.06 to 33.88
Drop (°C)	3.93	2.64 to 6.14	7.46	3.95 to 10.46
Rise (°C)	1.55	0.32 to 3.58	5.73	−0.37 to 10.25

One was taking vasodilators at the time of the study, but still showed the overall pattern of lower baseline temperature, 'blunted' drop and slower rise following the cold challenge typical of the RP subjects compared with normal subjects (Table 1). All the normal volunteers were healthy.

Agreement between instruments

The intra-class correlations, mean difference, standard deviation of the difference between the instruments (s_{diff}, Starsight − Cyclops) and the range of values defining the 95% limits of agreement (mean difference $\pm 2s_{diff}$) for the two instruments for each of the three key measures are given in Table 2.

All the intraclass correlations exceeded 80%, indicating good agreement between the instruments. There was no consistent bias of either instrument and the limits of agreement were acceptable. The variance of the difference was not affected by the mean. As expected, the limits of agreement were wider for baseline measurements (which were absolute measures and would have been influenced by calibration differences between the two instruments) compared with measurements of drop and rise (which were relative measures and were less influenced by calibration differences).

Classification of RP

The performance of Starsight in correctly classifying subjects as having RP or not and how well the Cyclops measures compared are shown in Table 3. The clinical definition of RP was used as the gold standard. The sensitivity of the Starsight thermal imager was 83% compared with 89% for the Cyclops portable radiometer. The specificity of both instruments was 84%. The positive and negative predictive values of the Starsight were 83 and 84% respectively, and those of the Cyclops radiometer were 84 and 89% respectively. The overall proportion of subjects correctly classified by each camera was almost the same: 84% for Starsight (31/37) and 86% for Cyclops (32/37).

TABLE 2. Agreement between instruments

	ICC	Mean difference (°C)	S.D. of difference (°C)	Limits of agreement (°C)
Baseline	0.82	1.55	1.70	−1.85 to 4.95
Drop	0.82	0.68	1.18	−1.68 to 3.04
Rise	0.94	−0.84	0.72	−2.28 to 0.60

ICC, intraclass correlation.

TABLE 3. Classification of RP

		Clinical disease: RP		
Instrument	Classification of RP	Positive	Negative	Total
Starsight	Positive	15	3	18
	Negative	3	16	19
Cyclops	Positive	16	3	19
	Negative	2	16	18
	Total	18	19	37

Discussion

We have investigated the performance of two methods of skin temperature measurement in subjects with RP and in healthy individuals: a thermal imaging system, which has been in common use in clinical vascular assessment, and a portable radiometer, which is better suited to taking measurements in wider clinical settings. Our analysis shows that there was close agreement between the instruments in absolute terms and any differences between the instruments in their absolute measurements did not influence their ability to detect RP in a clinical setting. These findings indicate that a portable radiometer can reliably replace thermography for the assessment of RP in non-specialized settings.

Portable radiometry does have a number of limitations, and this technique has not been used widely in the assessment of RP. Unlike thermography, it does not take an instantaneous measurement of all digits at one point in time, as the digits can only be measured sequentially by the operator. Therefore, part of the variation in temperature between fingers will be due to the unavoidable time lag in taking the measurement. The technique is labour-intensive. Recognition of the pattern of skin temperature changes is also more difficult.

However, our results indicate that the lack of real-time measurement by the Cyclops is of no practical significance. Data sampling rates using the radiometer were sufficiently fast to keep pace with the rewarming process, even in the control subjects. The cold challenge test is sufficiently standardized for the assessment of RP to allow data collection to be restricted to a few key measures and time points that can be readily captured using the radiometer.

It should be stressed, however, that a thermally controlled environment, careful patient equilibration and the rigorous application of the test protocol are essential elements of any successful technique for the measurement of human body temperature [13]. We have demonstrated that these criteria are met when a trained nurse uses a radiometer in an air-conditioned, dedicated room.

This study was motivated by a desire to extend objective measurements of RP outside specialist settings for use in epidemiological surveys. It is therefore of importance to demonstrate similar accuracy in classifying RP subjects. We accept that neither the thermal imager nor the radiometer currently offers the most accurate method for skin surface temperature assessment. Modern focal plane array (FPA) imagers [14] now offer greater temperature sensitivity and image resolution than the Starsight pyroelectric system, although the accuracy of carefully calibrated FPA systems typically remains no better than ± 1°C. Neither pyroelectric vidicon thermography nor radiometry should be considered the tool of choice where high sensitivity to temperature is essential. FPA thermal imagers will continue to dominate the market for medical temperature measurement in specialist units. At such centres, the thermographic work carried out is often multidisciplinary, encompassing such fields as rheumatology, dermatology and neurology for both routine clinical practice and research. Much of this work will necessarily require high imaging performance, and for such applications the versatility of modern imagers justifies the cost.

The temperature changes provoked by cold challenge of the hands in studies of RP are large compared with the temperature changes known to be of diagnostic significance in other medical conditions [15]. Hence cold challenge studies are not particularly reliant on high thermographic imaging performance. Our results suggest that the radiometric technique has utility equal to that of more sensitive techniques designed to detect peripheral vasospasm. We believe that the technique can be transported to any dedicated temperature-controlled environment, and thus may be widely used in a range of clinical and epidemiological settings.

Acknowledgements

We should like to thank the subjects who volunteered for this study, the RP patients from the Royal Free Hospital and the hospital workers who were the healthy subjects. This work was supported by the Arthritis Research Campaign. AJM is an ARC Senior Fellow.

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