Available online at http://www.journalcra.com

INTERNATIONAL JOURNAL OF CURRENT RESEARCH

International Journal of Current Research
Vol.3, Issue, 3, pp.077-083, March, 2011

ISSN: 0975-833X

RESEARCH ARTICLE

ASSESSMENT OF SICKLED ERYTHROCYTE DISEASE USING THERMOGRAPHY AND ENERGY EXCHANGE PROCESSES

[#1]Aweda M. A. [1]Edi A. A. and [2]Kehinde M. O.

[1]Department of Radiation Biology and Radiotherapy, College of Medicine/Lagos University Teaching Hospital, Idi-Araba. PMB 12003, Lagos.
[2]Department of Medicine, College of Medicine/Lagos University Teaching Hospital, Idi-Araba. PMB 12003, Lagos.

ARTICLE INFO

Article History:

Received 19th January, 2011
Received in revised form
8th February, 2011
Accepted 27th February, 2011
Published online 13th March, 2011

Key words:

Thermography,
Skin temperature,
Energy exchange processes,
Sickled erythrocyte patient,

ABSTRACT

Thermography for determination of mean weighted skin temperature and physiological energy exchange processes in sickled erythrocyte patients (SS) were studied in order to determine relevance in the management of the disease. The mean skin temperature for SS patients was 35.45 ± 0.402 °C while for non-sickled erythrocyte subjects (AA), it was 35.06 ± 0.128 °C (101.11 % of AA). The mean oxygen consumption rate (VO_2) in SS patients (130.99 ± 21.17 $ml.s^{-1}$) was much higher than AA subjects (50.88 ± 4.69 $ml.s^{-1}$), (SS mean value was 257.45 % of AA). The mean metabolic energy exchange rate (M) in SS was 2294.87 ± 330.95 Jh^{-1} while in AA subjects, it was 916.88 ± 111.31 Jh^{-1} (ie. 250.29 % of AA). The mean evaporative heat loss (E) was 10414.70 ± 116.105 Jh^{-1} in SS patients and 10566.90 ± 36.45 Jh^{-1} for AA (98.56 % of AA). The mean convective rate of heat exchange (C) in SS was 11044.60 ± 425.52 Jh^{-1} while it was 10646.20 ± 134.92 Jh^{-1} in AA (103.74 % of AA). The radiative rate of heat exchange (R_r) in SS was 199175 ± 11145.10 Jh^{-1} while it was 134689 ± 3533.54 Jh^{-1} for AA (147.88 % of AA). The total energy balance (ΔH) in SS was 225491 ± 12729.78 Jh^{-1} while it was 155003 ± 3638.68 Jh^{-1} for AA (145.48 % of AA). The results showed that sickled erythrocyte patients consume more oxygen and have much higher metabolic, radiative and total energy change rates than the AA subjects.

*Corresponding author: maaweda@cmul.edu.ng

INTRODUCTION

The correlation of body temperature and diseases has been known for several decades, but due to recent inventions and new technologies, it is possible to use skin temperature as a convenient and effective diagnosis. The first documented application of thermography was for early preclinical diagnosis of breast cancer [1]. Infrared thermography is a non-contact, non-invasive tool which maps the skin temperature. Physiological temperature distribution depends on complex relationships between the skin, inner tissues, local vasculature and metabolic and hormonal activities. Hence, the use of thermography as a diagnostic tool is based on the fact that pathologies would raise skin temperature due to increased metabolic activities. Thermal images have been used to quantify sensitive changes in skin temperature in relation to certain diseases [2]. Blood flow can be assessed by many methods including the washout technique, laser Doppler flowmetry and medical infrared imaging. Of all these, infrared thermography has the advantage of being non-invasive, non-traumatic, fast, reliable, non-contact, capable of producing multiple recordings at short time intervals and absolutely safe for patients and physicians. Modern techniques allow the use of multispectral imaging in which the infected regions are well delineated.

SS disease conditions are commonly associated with regional vasodilation, hyperthermia, hyperperfusion, hypermetabolism, and hypervascularization which generate a higher-temperature heat source. The heat emanating from the skin and the surrounding blood flow can be quantified by using the Pennes' bio-heat equation [3],

$$k\Delta^2 T - c_b w_b (T - T_a) + q_m = 0$$

where k is the conductivity, q_m is volumetric metabolic rate of tissue, T is the unknown tissue temperature, and T_a is the arterial temperature. Energy exchange processes take place through conduction, convection and radiation while the physiological factors influencing the net heat metabolic heat production, radiation balance, convective transfer via sensible and latent heat, conduction and the heat loss through respiration. The curved, crescent-shaped or sickle-shaped erythrocyte is a genetic disorder that strikes the black race far more than any other population group. It is caused by a defective gene and anaemia results from abnormal hemoglobin, the oxygen-carrying component of red blood cells. The disease is often accompanied by intense pain and serious deficiencies of oxygen and other blood nutrients throughout the body. Sickle cell infection may affect skin temperature as a result of energy changes. The disease is therefore of economic and social importance. The aim of this study is to investigate the correlation of skin temperature and physiological energy exchange processes in the management of sickled erythrocyte (SS) patients. We have employed the various standard methods in the Man-ENvironment heat EXchange models as developed by Blazejczyk [4] and modified in 2005 [5] for the energy balance and transfer processes. These models and their applications are based on the first fundamental law of thermodynamics. We have correlated the thermographic information with physiological parameter modifications resulting from SS infection in order to apply the results for the disease management.

MATERIALS AND METHOD

20 subjects were recruited for this study comprising of 10 SS patients and 10 non-sickled erythrocyte (AA) subjects as control. The patients were randomly selected from the outpatient clinics, Lagos State University Teaching Hospital (LUTH), Lagos, Nigeria, following the study approval granted by the Lagos University Teaching Hospital Ethics and Research Committee. The consent of the patients was obtained after a detailed explanation of the procedure and its potential benefits. The (1) anthropometric data obtained from each subject were age, weight, height and body mass index (BMI) was determined. The blood pressure and oxygen consumption rate were also measured. The control subjects were randomly selected among the volunteers of the staff and students of the College of Medicine of the

ranged from 15 to 33 with a mean of 24 years, while those of the control ranged from 19 to 26 with a mean of 22.5 years. All the subjects were allowed to rest in the consulting room for about 15 min, where the relative humidity and room temperature were controlled in order to achieve equilibrium of the body with the environment. Not more than three persons at a time were allowed inside the room in order to minimize the parameters that might influence temperature while the other parameters that may influence thermographic imaging were fixed. The wall-mounted air-conditioning split unit provided the required stable temperature. The skin temperatures at some specific points on the patients were obtained using the FLIR digital infrared camera model INFRACAM 1124520 (from FLIR Systems, USA). The camera is a compact light weight focal plane array-based system with a temperature resolution of 0.1 ^oC. A high-resolution real time image was provided on the LCD colour display on which the skin temperature is also displayed. The mean skin temperatures at specific points on the patients were determined and used to calculate the various energy exchange rates.

Skin temperatures were taken at the forehead, neck, arms, hands, feet, legs, thighs and trunk. The values were used to calculate the mean weighted skin temperature (T_{sk}) with the equation below according to Blazejezyk (1997) [6]

$T_{sk} = 0.071t_{fh} + 0.14\ t_a + 0.05\ t_{ha} + 0.07\ t_f + 0.13\ t_l + 0.19\ t_{th} + 0.35t_t)$ …….………………… 3

where t_{fh} = the skin temperature of the forehead

t_a = the skin temperature of the arm

t_{ha} = the skin temperature of the hand

t_f = the skin temperature of the foot

t_l = the skin temperature of the leg

t_{th} = the skin temperature of the thigh

t_t = the skin temperature of the trunk

The mean weighted skin temperature is used to calculate the radiative heat exchange R and the convective heat exchange C using the formulae

$R = 6.6\ (T_w - T_{sk})$ …………………. 4

where T_w = mean radiant temperature (^oC) of the surrounding walls and

$C = 7.0 \times V_a \times 0.6\ (t_a - T_{sk}$…………... 5

where V_a = velocity of air (in m/s).

The measured oxygen consumption rate was used to calculate the metabolic heat gain, the methods of conductive C, radiative R, respirative R_{es} and total energy balance ΔH have been describe elsewhere [7]. The results obtained for this study was analyzed statistically and summarized as in the table 2, and compared with those of AA participants using the paired sample student T- test [8,9]

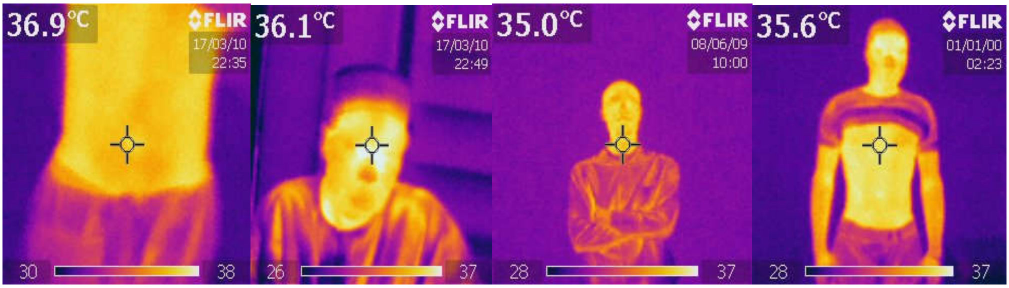
RESULTS AND DISCUSSION

Table 1 shows the anthropometric parameters of the patients from where the BMI was calculated. There were no significant differences in the patient (SS) parameters compared with control (AA). Typical thermographs of the studied SS patients are presented in figure 1, indicated on them are the skin temperatures at (a) abdomen, (b) forehead, (c) neck and (d) chest. The T_{sk} of the SS patients was only slightly higher than that of AA, and did not vary much from patient to patient as seen figure 2. T_{sk} for AA varied from 34.28 ^oC to 35.60 with a mean value of 35.06 ± 0.128 ^oC. The values varied from 34.14 ^oC to a maximum of 37.64 ^oC in SS subjects, giving a mean value of 35.45 ± 0.402 ^oC (101.11 % of AA). Variation in T_{sk} was not significant (p-value = 0.455). The slight differences in T_{sk} indicate that SS produce a little more heat than AA. This might be due to the presence of young the erythrocytes which use the metabolic energy to maintain their structural and functional integrity.

Figures 3 indicate that the average oxygen consumption rate (VO_2) in SS is much higher than in AA. The VO_2 among the AA subjects varied from 25.71 to 69.38 $ml.s^{-1}$ with a mean value of 50.88 ± 4.69 $ml.s^{-1}$. Those of SS varied from 74.81 $ml.s^{-1}$ to 276.43 $ml.s^{-1}$ with a mean much higher than that of AA (130.99 ± 21.17 $ml.s^{-1}$, i.e. 257.45 % of AA). VO_2 is much higher in SS subjects (p-value = 0.005). This could result from the abnormal conformational changes in the molecular structures of the sickled hemoglobin [10] which causes abnormal energy expenditure of erythropoietic hyperplasia when carrying oxygen [11].

The metabolic heat production rate (M) for AA varied from 450.42 Jh^{-1} to 1666.76 Jh^{-1} with a mean value of 916.88 ± 111.31 Jh^{-1} as depicted in figure maximum of 4842.72 Jh^{-1} in SS subjects, giving a mean value of 2294.87 ± 330.95 Jh^{-1} (250.29 % of AA). The difference in the mean M values for the SS compared with AA is very significant with p-value = 0.007.

Figure 5 shows the evaporative heat production rate (E) for AA which varied from 10414.66 Jh^{-1} to 10791.83 Jh^{-1} with a mean value of 10566.90 ± 36.45 Jh^{-1}. The values in SS subjects varied from 9777.49 Jh^{-1} to a maximum of 10952.32 Jh^{-1},



a b c d

Figure 1 Typical thermographs of patients showing points of temperature measurement

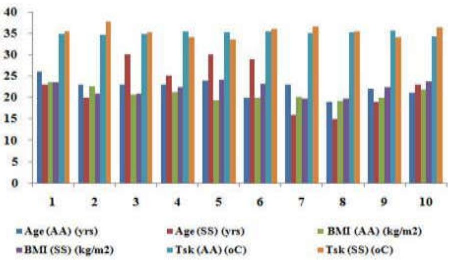


Figure 2. Mean weighted skin temperature (T_{sk}) in SS compared with AA subjects

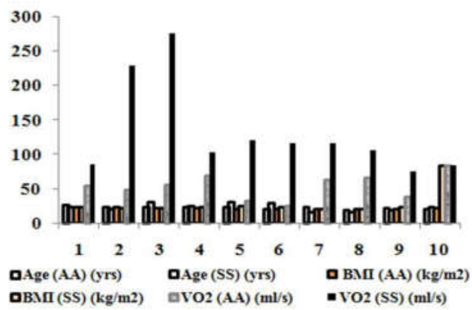


Figure 3. Mean oxygen consumption rates (VO_2) in SS compared with AA subjects

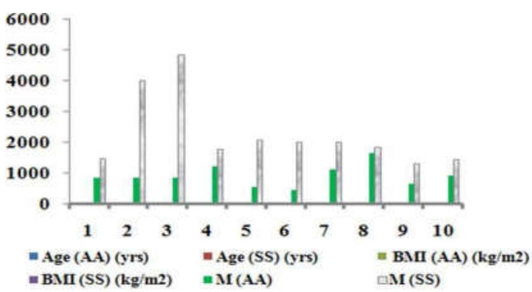


Figure 4. Mean metabolic energy change rates (M) in SS compared with AA subjects

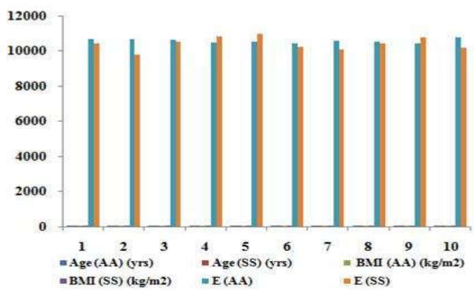


Figure 5. Mean evaporative energy change rates (E) in SS compared with AA subjects

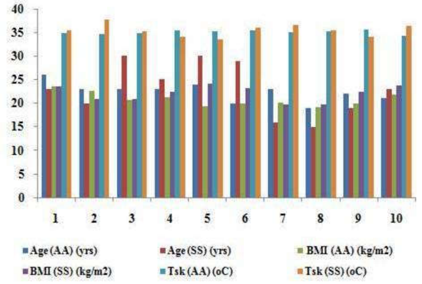


Figure 6. Mean convective energy change rates (C) in SS compared with AA subjects

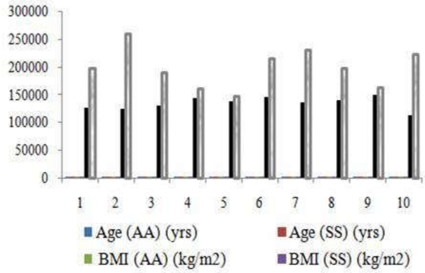


Figure 7. Mean Radiative energy change rates (L_r) in SS compared with AA subjects

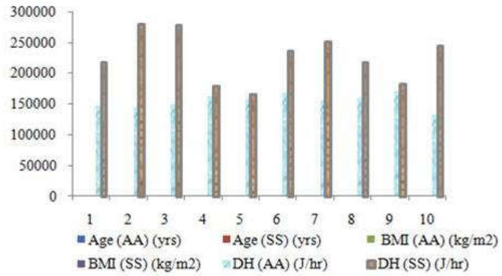


Figure 8. Mean total energy change rates (ΔH) in SS compared with AA subjects

Table 1. Homozygous (AA) non- sickle cell anemia subjects as control (a) and Homozygous (SS) sickle cell anemia subjects (b)

Ages (yr)	Weigh t (kg)	Height (cm)	Body mass index (kg/m²)	Body surface area (m²)	Age s (yr)	Weight (kg)	Height (cm)	Body mass index (kg/m²)	Body surface area (m²)
26	69	171	23.59	1.81	23	69	171	23.59	1.81
23	70	176	22.59	1.85	20	53	159	20.96	1.53
23	60	170	20.76	1.69	30	60.5	170	20.93	1.70
23	60	168	21.25	1.68	25	58	161	22.38	1.61
24	62	179	19.35	1.78	30	65	164	24.17	1.71
20	55	166	19.96	1.61	29	67	170	23.18	1.78
23	70	178	20.09	1.87	16	50.3	160	19.65	1.51
19	45	153	19.22	1.39	15	50	159	19.78	1.49
22	54	165	19.84	1.59	19	58	161	22.38	1.61
21	53	156	21.78	1.51	23	63	158	25.24	1.64

a b

Table 2. Summary of the heat exchange parameters of homozygous sickle (SS) compared with non-sickle (AA) cell subjects

Physiological parameters	Non-sickle cell (AA) (Mean ± SEM)	Homozygous sickle cell (SS) Mean ± SEM	p-value
Oxygen consumption rate (VO_2) (ml/s)	50.88 ± 4.69	130.99 ± 21.17	0.005
Metabolic heat production (M) (J/h)	916.88 ± 111.31	2294.87 ± 330.95	0.007
Mean skin temperature (T_{sk}) (^oC)	35.06 ± 0.128	35.45 ± 0.402	0.455
Evaporative heat loss (E) (J/h)	-10566.90 ± 36.45	-10414.70 ± 116.105	0.300
Convective heat exchange (C) (J/h)	-10646.20 ± 134.92	-11044.60 ± 425.52	0.455
Long wave radiative heat exchange (L_r) (J/h)	-134689 ± 3533.54	-199175 ± 11145.10	0.001
Respiratory heat loss (R_{es}) (J/h)	-22.54 ± 0.0	-22.54 ± 0.0	N/A
Total energy production rate (ΔH) (J/h)	155003 ± 3638.68	225491 ± 12729.78	0.001

giving a mean value of 10414.70 ± 116.105 Jh^{-1} (98.56 % of AA). The p-value for the variation was 0.300.nThe convective heat production rate (C) for AA varied from 9821.95 Jh^{-1} to 11219.04 Jh^{-1} with a mean value of 10646.20 ± 134.92 Jh^{-1}. In figure 6, the values varied from 9070.49 Jh^{-1} to a maximum of 13378.18 Jh^{-1} in SS subjects, giving a mean value of 11044.60 ± 425.52 Jh^{-1} (103.74 % of AA). Similar to T_{sk}, the variation was not significant; p-value was 0.455. Lee [12] in his theoretical model which assumed a wind velocity of 0.2 $m.s^{-1}$, predicted the ratio of convective to radiative heat loss as 1: 0.7 at a temperature of 20 °C. Zhang et al. [13] have also published the work of simulation of Convective and Respiratory heat losses. The different methods developed to evaluate the heat exchange have recently been described by Buchlin [14]. de Dear et al. [15] measured radiative and convective heat loss rates and found the rates to be 16,200 Jh^{-1} and 11880 Jh^{-1} respectively. Even in the absence of wind, convection is an important mechanism in cooling human body. Convection accounts for about 33 % of the thermal loss of the human body in cool and still air. As other thermal loss mechanisms like forced convection and perspiration become more significant, radiation becomes less significant in human thermal balance [16]. The long wave radiative energy production rate (L_r) for AA varied from 113097.60 Jh^{-1} to 149688.00 Jh^{-1} with a mean value of 134689 ± SS subjects, giving a mean value of 199175 ± 11145.10 Jh^{-1} (147.88 % of AA). This variation was significant with a p-value of 0.001. The respirative heat loss (R_{es}) for AA did not vary from patient to patient. There was no difference in the value for both SS and AA, and the determined value was 22.54 Jh^{-1}. The total energy production rate (ΔH) for AA varied from 132802.26 Jh^{-1} to 170680.35 Jh^{-1} with a mean value of 155003 ± 3638.68 Jh^{-1}. Figure 8 shows that the values varied from 165415.75 Jh^{-1} to a maximum of 279456.86 Jh^{-1} in SS subjects, giving a mean value of 225491 ± 12729.78 Jh^{-1} (145.48 % of AA). The variation here was significant with p-value = 0.001. Numerous energy balance and anthropometric studies have been reported in the literature. Some of these investigated the interrelationship between energy expenditure and energy intake as they affect development of cancers [17-21]. Deficiency in energy balance is an indication of risk of developing diseases.

CONCLUSION

The result of this study shows that the mean weighted skin temperature derived from thermography may be used to quantify various energy changes and hence for determining the variations in the different energy exchange rates between SS patients and AA subjects.

thermographically provided the required parameter for calculating the various energy exchange rates. Significant differences in the VO_2, M, L_r and ΔH values are useful in delineating patients with sickled erythrocyte from others. Age, sex and BMI seem not to play significant role in this SS assessment method. This method provides a quick and non-invasive method of assessing the status of SS individuals based on the differences in the energy exchange rates.

REFERENCES

1. Lawson .R, Implications of surface temperatures in the diagnosis of breast cancer. Canadian medical association journal (1956) 75; 309 – 310.
2. Canadian Medical Association Journal. Thermography, a Canadian invention finding wider applications. (1977) 117(17); 680 - 685.
3. Bagavathiappan S, Saravanan T, John Philip, Jayakumar T, Baldev Raj, Karunanithi R, Panicker T.M.R, Paul Korath M, Jagadeesan K. Infrared thermal imaging for detection of peripheral vascular disorders. Journal of Medical Physics (2009) 34(1); 43-47.
4. Błazejczyk K, Krawczyk B. New climatological-and-physiological model of the human heat balance outdoor (MENEX) and its applications in bioclimatological studies in different scales. In: Bioclimatic research of the human heat balance. Zesz. IGiPZ PAN. (1994) 28; 27-58.
5. Blazejczyk K. (MENEX 2005): The updated version of man-environment heat exchange model. Available at www.igipz.pan.pl/geoekoklimat/blaz/bioklima.htm
6. Błazejczyk K, Dry heat exchange and skin temperature in subjects outdoors at fluctuated cloud cover. In B. Nielsen-Jahannsen, R. Nielsen (eds.), Thermal Physiology 1997, Proc. of The Intern. Symp on Thermal Physiology, Copenhagen 8-12 July 1997: 115-118.
7. Aweda MA, Ketiku KK, Ajekigbe AT Edi AA. Potential role of thermography in cancer management. Archives of Applied Science Research. (2010), 2(6); 300-312 Available at http://scholarsresearchlibrary.com/archive.html
8. Rosner. B. Fundamentals of biostatistics. (1982) Duxbury.
9. Dawson B and Trapp. R.G. Basic and clinical biostatistics, 4th edition, (2004) McGraw- Hill
10. Boyo A.E and Ikomi-Kumm.J.A. Increased metabolic heat production by erythrocytes in Sickle cell disease. Lancet, June 3 (1972), 1 (7762); 1215 – 1216
11. Singhal, A., Davies .P, Sahota .A, Thomas P.W. and Serjeeant G.R. Resting metabolic rate in homozygous sickle cell disease. American Journal of Clinical Nutrition, (1993), 57; 32 – 34.
12. Lee B. Theoretical Prediction and Measurement of the Fabric Surface Apparent Temperature in a Simulated Man/Fabric/Environment System (DSTO Aeronautical and Maritime Research Laboratory), (1999) Available at: http://www.dsto.defence.gov.au/publications/2135/DSTO-TR-0849.pdf
13. Zhang Y, Novieto D, Ji Y. Human environmental heat transfer simulation with CFD – the advances and challenges. Eleventh International IBPSA Conference. 2009; July 27-30, Glasgow, Scotland.
14. Buchlin J. M. Convective heat transfer and infrared thermography. Journal of Applied Fluid Mechanics. (2010) 3(1); 55-62. Available online at www.jafmonline.net
15. de Dear R. J. Brager G. S. Cooper D. J. Developing an adaptive model of thermal comfort and preference. Final Report on ASHRAE RP-884. Sydney MRL. (1997)
16. Ingrid Warnold, Kent Lundholm, Tore ScherstÃ. Energy Balance and Body Composition in Cancer Patients. Cancer research. (1978) 38; 1801-1807.
17. Kaaks R. Lukanova A. Energy balance and cancer: the role of insulin and insulin-like growth factor-I. Proc. Nutr. Soc. (2001) 60; 91–106.
18. Dirx M. J. Zeegers M. P, Dagnelie P. C, van Den B. T, van den Brandt P.A. Energy restriction and the risk of spontaneous mammary tumors in mice: a meta-analysis. Int. J. Cancer. {2003) 106; 766–770.
19. Malin A, Matthews C. E. Shu X. O. Cai H. Dai Q. Jin F. Gao Y. T. Zheng W. Energy Balance and Breast Cancer Risk. *Cancer Epidemiology, Biomarkers and Prevention*. (2005), *14;* 1496.
20. Lin J. J. Wang J. Greisinger A. J, Grossman H. B. Forman M. R. Dinney C. P. Hawk E. T. Wu X. Energy Balance, the PI3K-AKT-mTOR Pathway Genes, and the Risk of Bladder Cancer**.** *Cancer Prevention Research.* (2010) 3; 505.
21. Gonzalez F. J. Infrared Imager Requirements for Breast Cancer Detection Engineering in Medicine and Biology Society, 2007. EMBS 2007. 29th Annual International Conference of the IEEE Lyon

****