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Advancements in biomedical applications of infrared imaging

Introduction

Infrared imaging permits to map the surface thermal distribution of the human body. A large number of studies has been so far established to assess the contribution that such information may provide to the clinicians. Cutaneous temperature distribution depends on complex relationships defining the heat exchange processes between cutaneous tissue, inner tissue, local vasculature, and metabolic activity. All of these processes are mediated and regulated by the sympathetic and parasympathetic activity to keep the thermal homeostasis. At a local level, diseases and disorders can affect the heat balance or exchange processes resulting in modification of the cutaneous temperature and of its functional with respect to healthy conditions. Therefore, the characteristic parameters modeling the spontaneous activity of the cutaneous thermoregulatory system can be used as quantitative diagnostic parameters. The functional Infrared Imaging (fIRI)– also named Infrared Functional Imaging (IRFI) – is the study for diagnostic purposes, based on the modeling of the bio-heat exchange processes, of the functional properties and alterations of the human thermoregulatory system. In this paper, we will review some of the most important recent clinical applications of the functional infrared imaging.

Quantifying the Relevance and Stage of Disease with the τ Image Technique.

Infrared imaging can provide diagnostic information according different possible approaches. The approach generally followed consists of the detection of significant differences between the cutaneous thermal distributions of the two hemisoma or in the pattern recognition of specific features with respect to average healthy population [1]. More valuable and quantitative information can be obtained from the study of the cutaneous temperature dynamics in the unsteady state, where the processes involved and controlled by the thermoregulatory system can be modeled and described through their characteristic parameters [2-7]. The presence of diseases interfering with the cutaneous thermoregulatory system can be then inferred by the analysis of its functional alterations [8-18]. Merla et al. [7, 17, 20, and 21] proposed a new imaging technique, based on this approach, for the clinical study of a variety of diseases. Starting from a general energy balance equation, they have demonstrated that the recovery time from any kind of thermal stress for a given region of interest depends from the region thermal parameters.

The proposed model accept an exponential solution and suggests to use the time constant τ as a characterizing parameter for the description of the recovery process after any kind of controlled thermal stress, with τ mainly determined by the local blood flow and thermal capacity of the tissue.To pictorially describe the effect of the given disease, an image reporting pixel to pixel the τ recovery time can be used to characterize that disease [7, 17, 20, and 21].

The τ image technique has been first proposed as complementary diagnostic tool for the diagnosis of muscular lesions, Raynaud's phenomenon and Deep Vein Thrombosis [7, 17 20, 21].

Raynaud's Phenomenon and Scleroderma

Raynaud's phenomenon (RP) is defined as a painful vasoconstriction - that may follow cold or emotional stress - of small arteries and arterioles of extremities, like fingers and toes. RP can be primary (PRP) or secondary (SSc) to scleroderma. None of the physiological measurement techniques currently in use, but infrared imaging, are completely satisfactory in focusing primary or secondary RP [3]. Thermography protocols [3-5, 24-28] usually include cold patch testing to evaluate the capability of the patient hands to re-warm. The pattern of the re-warming curves is usually used to depict the underlying structural diseases. Merla et al. [14, 16] proposed study the natural response of the fingertips to exposure to a cold environment through a simple bioheat model to compute the amount of heat produced by the local thermoregulatory system and stored in the fingertip as a possible diagnostic parameter. Such a parameter has been used in [14, 16] to discriminate and classify PRP, SSc and healthy subjects on a set of 40 (20 PRP, 20 SSc) and 18 healthy volunteers.

The sensitivity of the method in order to distinguish patients from normal is 100%. The specificity in distinguishing SSc from PRP is 95%.

Diagnosis of Varicocele and Follow Up of the Treatment

Varicocele is a widely spread male disease consisting into a dilatation of the pampiniform venous plexus and of the internal spermatic vein. Consequences of such a dilatation are an increase of the scrotal temperature and a possible impairment of the potential fertility [36, 37]. fIRI has been used to determine whether altered scrotal thermoregulation is related to subclinical varicocele [15]. In a study conducted in 2001, Merla and Romani enrolled 60 asymptomatic volunteers that underwent to clinical examination, echo color Doppler imaging (the gold standard) and fIRI. The latter technique accurately detected 22 no symptomatic varicocele. The control of the scrotum temperature should improve after varicocelectomy as a complementary effect of the reduction of the blood reflux. Moreover, follow-up of the changes in scrotum thermoregulation after varicocelectomy may provide early indications on possible relapses of the disease. To answer the above questions, Merla et al. [9] used fIRI to study changes in the scrotum thermoregulation of 20 patients that were judged eligible for varicocelectomy on the basis of the combined results of the clinical examination, Echo color Doppler imaging, and spermiogram. fIRI documented the changes in the thermoregulatory control of the scrotum after the treatment and proved that the surgical treatment of the varicocele induces modification in the thermoregulatory properties of the scrotum, reducing the basal temperature of the affected testicle and pampiniform plexus, and slowing down its recovery time after thermal stress.

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Conclusions

fIRI is a biomedical imaging technique that relies on high resolution infrared imaging and on the modeling of the heat exchange and control processes at the cutaneous layer. fIRI is aimed to provide further information about the studied disease to the physicians, like explanation of the possible physics reasons of some thermal behaviors and their relationships with the physiology of the involved processes. One of the great advantages of fIR imaging is the fact that is not invasive and it is a touchless imaging technique. fIR is not a static imaging investigation technique. Therefore, data for fIR imaging need to be processed adequately for movement. Adequate bio heat modeling is also required. The medical fields for possible applications of fIR imaging are numerous, ranging from those described into this chapter, to psychometrics, cutaneous blood flow modeling, peripheral nervous system activity, and some angiopathies. The applications described in this paper show that fIR imaging provides highly effective diagnostic parameters. The method is highly sensitive, but also highly specific into discriminating different conditions of the same disease.

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