Study on fat measurement by near infrared spectroscopy

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Abstract: In recent years, with the improvement of people′s living standard, the rate of obesity was on the rise, and the dangers of obesity to health was rising too, therefore the monitoring of obesity became particularly important. Firstly, the propagation mechanism of near infrared light in the fat tissue was discussed, and the interactions between near infrared light and the fat, muscle tissues such as absorption, scattering and reflection were studied in this research. Then the near infrared spectroscopy information of the fat tissue was gotten by the experiments, whose results demonstrated that 930 nm was the best candidate for measuring the fat tissue thickness, and the intensity of light at this wavelength was strongly correlated with the fat tissue thickness on a large scale. Because of the interference of the muscle tissue and the small dynamic range of light intensity varied with the fat tissue thickness at 1 040 nm, the wavelength of 1 040 nm was not suitable for measuring the fat tissue thickness. It laid a foundation for further and better realization of optical noninvasive fat measurement through this study.

Key words: fat; near infrared; spectroscopy; absorbance

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脂肪测量的近红外光谱研究

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摘　要: 近年来,随着居民生活水平的日益提高,肥胖率呈上升趋势,肥胖对健康的危害也在不断扩大,因此对肥胖的监控已显得尤为重要。首先,从近红外光在脂肪组织内的传播机理入手,研究了近红外光与脂肪及肌肉组织的吸收、散射、反射等相互作用。然后通过实验获取了脂肪组织的近红外光谱信息,实验结果分析表明,930 nm 是最适合用于进行脂肪组织厚度测量的波长,该波长处的光强与脂肪组织的厚度具有大范围较强的关联性。由于肌肉组织的干扰作用,及该处光强随脂肪组织厚度变化的动态范围较小,波长 1 040 nm 不适合用于脂肪组织厚度的测量。通过此项研究,为进一步更好地实现光学无损脂肪测量奠定了基础。

关键词: 脂肪; 近红外; 光谱; 吸收率

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0 Introduction

Obesity has been listed as a global public health problem by World Health Organization (WHO) since 1997, which is the same as smoking, and has been listed as one of the top ten threats to human health[1]. Scientific research shows that obesity is not only an independent disease, but also leads to a variety of diseases, such as diabetes, hypertension, stroke and various other types of cancers. In recent years, the rate of obesity is on the rise with the development of improvement of living in China[2]. In order to prevent obesity, the primary task is monitoring body fat content, which means that we should measure body fat content accurately and conveniently. At present, there are many obesity clinical diagnosis methods, such as hydrostatic weighing[3], bioelectrical impedance analysis[4], ultrasound measurement[5], skinfolds and anthropometry[6], deuterium oxide dilution (D_2O)[7], total body potassium determinations[8], computed tomography (CT)[9], magnetic resonance imaging (MRI)[10], dual-energy X-ray absorptiometry (DEXA)[11]. Hydrostatic weighing achieves a high accuracy but is not convenient; bioelectrical impedance analysis requires rigorous measurement conditions and it's not suitable for women who is pregnant or in the menstrual period; ultrasound measurement precision over-relies on operating proficiency; skinfolds and anthropometry has a bigger deviation [12]; D_2O and total body potassium determinations will both cause wounds on human's body; CT, MRI and DEXA measurement are expensive and have radiation, so they can not be widely used. And generally speaking, most of the measurements mentioned above will provide injury to humans. Therefore, a convenient, easy to operate, accurate and noninvasive method to measure the body fat is needed urgently. In recent years, an optical method for fat measurement named near infrared interactance has been paid more attention, and to date for this method, both wavelengths of 930 nm and 1 040 nm have been determined as the optimum wavelengths to measure body fat tissue thickness[13-14]. However, in this research, after investigation, we can prove that 930 nm is the best candidate wavelength to measure body fat tissue thickness instead of 1 040 nm.

1 Theory

As shown in Fig.1, when incident light goes through the fat tissue, one part of the incident light spreads horizontally along the fat tissue in the form of scattering, and is absorbed by the fat tissue constantly during scattering [15]. Therefore, the absorption and scattering will increase with the fat tissue thickness increasing. The rest part of the incident light will spread longitudinally to the interface between the fat tissue and the muscle tissue, and also is accompanied by the absorption during the propagation. The refractive index of the fat tissue, which is mainly composed of oil, is smaller than the refractive index of the muscle that is the main component of the water. So the total reflection can happen at the interface, where the incident light will be reflected back to the fat tissue with the absorption information of the muscle tissue. Then the reflected light spreads horizontally along the fat tissue with the absorption in the form of scattering. This is why the reflection will decrease with fat tissue thickness increasing. In general, the light propagation in the fat tissue includes absorption, scattering and reflection. In this way, there will be a difference of the intensity between the incident and output light, and there is definitely some connection between the difference and the fat thickness.

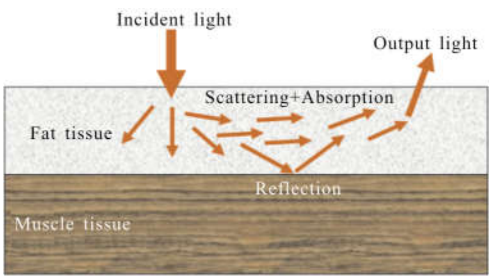

Fig.1 Light propagation diagram in the fat tissue

How to define this difference? In this study, we use absorbance to quantize this difference of the intensity between the incident and output light. According to Lambert′s law [16], the calculation formula of absorbance may be:

$$A=\lg\frac{I_o}{I} \quad (1)$$

where I_o is the intensity of incident light and I is the intensity of the output light.

2 Method and device

We use the pork fat tissue bought in the supermarket as our sample to carry out the experiments, and we cut the fat tissue from thick to thin with a blade. The pork fat tissue thickness can be measured directly with vernier caliper. And we can measure the corresponding near infrared absorption spectroscopy under different thickness of the pork fat tissue.

Figure 2 illustrates the schematic diagram of the measuring device. The light from Tungsten halogen lamp is employed as the incident light and enters the pork tissue through the optical fiber. After interaction with the fat tissue, the output light is detected by the spectrometer (usb2000, Ocean Optics) through the optical fiber and the computer can get its spectral distribution. The interaction information between light and fat tissue can be calculated from the spectral distribution. We can calculate the fat thickness based on the intensity of output light that the probe accepted.

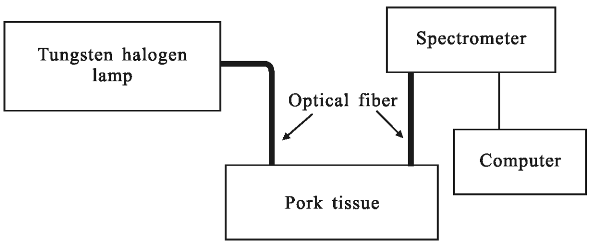

Fig.2 Schematic diagram of the measuring device

3 Results and discussion

Figure 3 illustrates the absorption spectrogram of different fat tissue thickness, where 1 to 11 respectively represent fat tissue thickness of 0.5, 1, 2, 3, 5, 7, 10, 13, 15, 18, 20 mm. The inset shows the curve peak at about 930 nm. What must be mentioned is that all the spectral data measured by the spectrometer had already been pretreated by smoothing for the purpose of cleaning the noise data [17]. Absorbance shows the similar spectral features to those all wavelengths, with one narrow peak at 930 nm and a broad peak above 1 000 nm. At 930 nm, it′s obvious that the absorbance increases with the fat tissue thickness increasing from the absorption spectrogram because of the highest light absorption of fat here. Generally speaking, the interaction will become stronger with the fat tissue thickness increasing, and the stronger absorption can be detected by the probe. However, the absorbance stops increasing and almost approaches saturation when thickness is larger than 15 mm. Because the fat tissue is thick enough, the longitudinally propagating light is almost completely absorbed by the fat tissue before reaching the interface of the muscle tissue, and there is nearly no light reflected to the fat tissue. Thus the horizontally propagating light is also close to saturation.

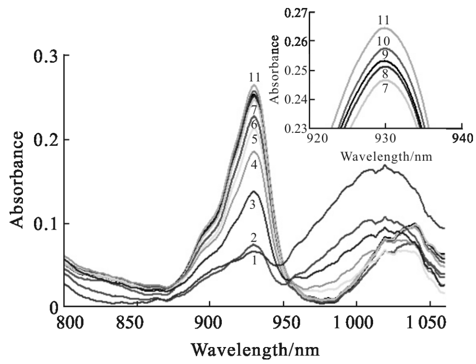

Fig.3 Absorption spectrogram of the fat tissue with different thickness

Figure 3 also shows that when the wavelength is larger than 1 000 nm, there are two curve peaks which are related to the fat tissue thickness. One peak is around 1 020 nm when the fat tissue is thinner than 7 mm, and another peak is around 1 040 nm when the fat tissue thickness is larger than or equal to 7 mm. And the former exactly coincides with the absorption peak of the muscle tissue as shown in Fig.4. Thus we think that the peak at 1 020 nm recorded in Fig. 3 contains the absorption information of the muscle tissue when the fat tissue is thin. And this is because when the fat tissue is thin, the longitudinally propagating light of the incident light is in the majority compared with the horizontally propagating

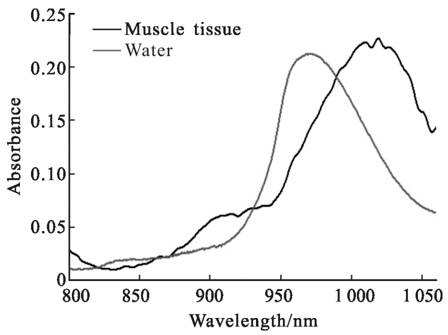

Fig.4 Absorption spectrogram of the muscle and water

light, thus the incident light at the interface will be reflected back to the fat tissue with the absorption information of the muscle tissue and as well as in the output light detected by the probe. With the increase of the fat tissue thickness, the longitudinally propagating light is gradually decreasing, which causes the total reflection at the interface to decrease with less absorption information of the muscle tissue in the output light. Therefore, the absorption peak of 1 020 nm decreases with the fat tissue thickness increasing, which further confirmed that the peak of 1 020 nm recorded in Fig.3 is the absorption peak of the muscle tissue. And then with the further growth of the fat tissue thickness, the horizontally propagating light of the incident light becomes the main form instead of the longitudinally propagating light. So the absorption peak we detected reverts to the absorption peak of the fat tissue itself, namely, 1 040 nm, which is confirmed in many studies [13-14]. After that the absorbance is also increasing with the increase of the fat tissue thickness, and finally approaches a saturated value for the same reason of the situation of 930 nm. However, we notice that the absorbance is close to saturation when the fat thickness is only 7 mm, which means the dynamic range is very small. As a result, we consider that the wavelength of 1 040 nm is not suitable for measuring the fat tissue thickness because of the interference of the muscle absorption information at this wavelength and the small dynamic range of absorbance varies with the fat tissue thickness.

In addition, the samples used in this study are skinless, but it's impossible to remove the skin of people during the measurement. Because of the high water content of skin, we should avoid the absorption of light by water. According to Fig.4, we find that the light absorbance of water reaches maximum at about 970 nm, and it doesn't coincide with 930 nm. Therefore, 930 nm is suitable for measuring the fat tissue thickness of a human body.

Figure 5 illustrates the absorbance of different fat thickness at 930 nm. It shows that the absorbance is increasing with the increase of the fat tissue thickness, and reaches saturation above the thickness of 15 mm. And then we can use the representative wavelength of 930 nm to build the relationship or regression equation for the fat tissue thickness according to Fig.5. Then some modifications are made for the relationship or regression equation which is gotten above by adding human's individualization parameters. After that we can calculate the human fat tissue thickness by measuring the difference of the light intensity at the wavelength of 930 nm.

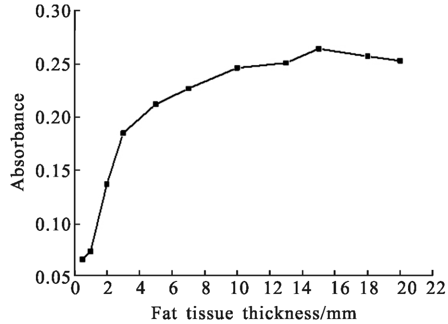

Fig.5 Absorbance diagram corresponding to different fat thickness at 930 nm

4 Conclusion

The mechanism of interaction between light and the fat tissue has been discussed, and we get the near infrared spectroscopy information of the fat tissue through the experiments whose results demonstrate that 930 nm is the best candidate for measuring the fat tissue thickness. The light intensity of 930 nm is strongly correlated with the thickness of the fat tissue on a large scale. Because of the interference of the muscle tissue, and the small dynamic range of light intensity varies with the fat tissue thickness at 1 040 nm, so 1 040 nm is not suitable for measuring the fat tissue thickness. It lays a foundation for further and better realization of optical noninvasive fat measurement through this study.

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