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Ultra-weak photon emission in healthy subjects and patients with type 2 diabetes: evidence for a non-invasive diagnostic tool

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Background: Spontaneous ultra-weak photon emission (UPE) is a common phenomenon in biological systems and has been linked to pathological states. Researchers have always considered ultra-weak photon emission a potential non-invasive diagnostic tool, but its application in the medical field is stagnant due to the lack of relevant data for pathological states. *Methods*: Ultra-weak photon signals from five body sites (forehead, neck, heart, stomach, and navel) in fifty patients with type 2 diabetes and sixty age-matched healthy subjects were measured using a moveable whole-body biophoton detection system. Photon signal is measured for 10 min and detected in bins of 50 ms by a photomultiplier with a range of 290–630 nm. Each signal is a time series of 12 000 elements. Various parameters including photon intensity, Q value, squeezed state parameters ($|\alpha|$, θ, $\varnothing$, r) and SSI were analyzed. *Results and conclusion*: we found significant differences in the abovementioned parameters between groups, and all subjects could be clustered into two groups according to the results obtained by principal component analysis. Methods and results from this study could be useful for constructing a UPE database for a range of diseases, which would promote the application of UPE in clinical diagnosis in the future.

1. Introduction

All biological systems, including human beings, can spontaneously emit photons to their surroundings, and this phenomenon is called spontaneous ultra-weak photon emission (UPE).[1–5] UPE is a common phenomenon and exists in all types of animals, plants, algae and microorganisms; its spectral range is 200–800 nm, and the intensity is very weak, about a few to hundreds of photons per s per cm^2.[2,6–11] Spontaneous ultra-weak photons are emitted *via* transitions from a high-energy state to a low-energy state of electronically excited species formed during oxidative metabolic processes.[12–14] UPE is a vital phenomenon that occurs at the "molecular level", and contains information about the molecular composition and structure of biological systems.[1] This information is encoded in the signal intensity, spectral distribution and photon count distribution.[15–17] Measurement and analysis of these parameters could reveal changes in the biological systems in detail.

It has been reported that UPE is linked to physiological and pathological states.[18–20] Biological rhythms, age, gender, and consciousness state can affect the photon emission intensity, and the UPE intensity and left-right symmetry of photon emission differed in a human in his diseased and healthy conditions.[21–27] Several research groups presented data on changes in the intensity of photon emission for chronic diseases where patients have no skin injury or disease. Results demonstrated that the photon emission intensity of the index and middle fingers was lower in patients with hypothyroidism and patients whose thyroid glands had been removed.[28] Cohen and Popp reported that UPE intensity was higher in multiple sclerosis patients than that in healthy subjects.[29] The left-right symmetry of photon emission would become worse in the patients suffering from cold and in hemiparesis patients.[20,30] Furthermore, Yang reported a significant difference in the maximum peak of the spectral distribution between healthy subjects and patients suffering from cold.[31] The spectral peak

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for some body sites of patients with essential hypertension exhibited a red-shift during the attack state and returned to the original wavelength during the remission state.[32] There existed a significant difference in spectral parameters, such as frequency, intensity, and band shape between cancer patients and healthy subjects.[33] Chen distinguished serum samples of patients with acute lymphoblastic leukemia from those of healthy volunteers.[34]

During early research on UPE, the majority of studies would take photon intensity as the main descriptive parameter, and other characteristics of human photon emission were less reported. As research progressed, some scholars introduced other parameters (Q value, Fano factor, squeezed state parameters, SSI, *etc.*) for characterizing the ultra-weak photon emission of human subjects, which greatly enriched the amount of information encoded in the ultra-weak photon emission of human beings. Most of these studies focused on a few healthy subjects, and analyzed the differences in these parameters, besides photon intensity, among different body parts and consciousness states.[17,35,36] The results demonstrated that different UPE parameters contain different types of biological information and may capture some aspects of the psychological state.

However, the differences in the above mentioned parameters between healthy and non-healthy states has been less analyzed. As it is known, ultra-weak photon emission is anticipated to be a promising and non-invasive diagnostic tool by an increasing number of researchers, but its application in the medical field has so far been stagnant due to a lack of more relevant data on the pathological state. Therefore, understanding the characteristics of human biophotons in the healthy and pathological state is of great significance for the application of biophotonic technology in the clinical setting.

In this study, spontaneous ultra-weak photon emission from five body sites in fifty patients with type 2 diabetes and sixty age-matched healthy subjects was measured with a high-sensitivity whole-body biophoton detection system and several parameters (photon intensity, Q value, squeezed state parameters ($|\alpha|$, θ, $\varnothing$, r) and SSI) were analyzed with the aim of understanding their differences. We expected that these differences between healthy subjects and diabetic patients would provide quantitative data that would allow the future application of biophoton detection techniques in clinical diagnosis.

2. Materials and methods

2.1 Experimental setup

In this study, a moveable whole-body biophoton detection system was used. The components that were used in the system are the following: moveable frame, high voltage power supply, photon counting unit, computer with photon count data software and control box. A schematic representation is displayed in Fig. 1. The moveable frame, including a photomultiplier system, was constructed such that the photomultiplier could be positioned at a specific location with respect to a human subject. The position could be electronically regulated in height over a range of 70 cm. In the horizontal plane, it could be moved in two directions with respect to the subject's body. For practical reasons, a bed was positioned under this system. The entire system was located in a specially designated room, which was in complete darkness, and no phosphorescence could be detected from the walls, ceiling or floor. The photomultiplier tube (Electron Tube 9235QA) is sensitive in the spectral range of 290–630 nm and has a 51 mm (2 in.) diameter window seated in the housing for cooling. A 7 cm long cone-shaped extender was attached to the front of the photomultiplier tube, allowing to record photon emission from an anatomic area of 9 cm diameter at a fixed distance. A high-voltage power supply was used for the PMT, which regulated the electronic background. The photons were counted using the photon counting unit (C9744) and the detection time for every photon was recorded and stored digitally by a computer that was equipped with a counter card and photon counting software.

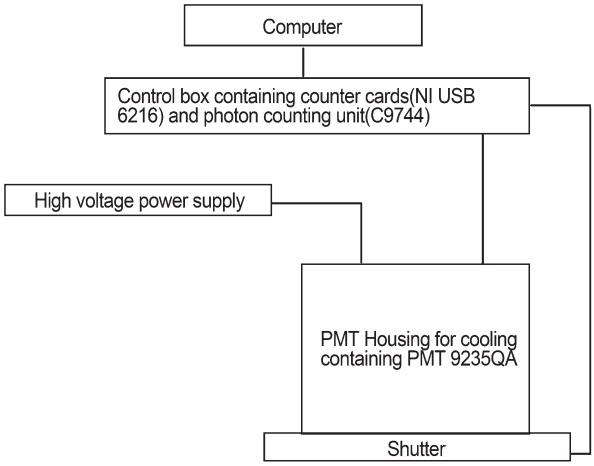

Fig. 1 Schematic of the moveable biophoton detection system.

2.2 Subjects

Fifty patients with type 2 diabetes (29 females and 21 males, age 41–79 years) and sixty age-matched healthy volunteers (35 females and 25 males, age 39–76 years) participated in the UPE measurements voluntarily. Healthy subjects were interviewed to exclude physical or emotional disorders. Type 2 diabetes patients were all recruited from the Diabetes Hospital of the Shandong Province. All these subjects appropriately understood the recording procedure and gave verbal informed consent. Following the Medical Research Involving Human Subjects Act (2006), diabetic patients signed an informed consent form before the experiment. Five body sites located along the frontal middle line of the human body were selected in order to avoid the influence of left-right symmetry, and the sites, namely forehead, throat, heart, abdomen, and navel, are illustrated in Fig. 2.

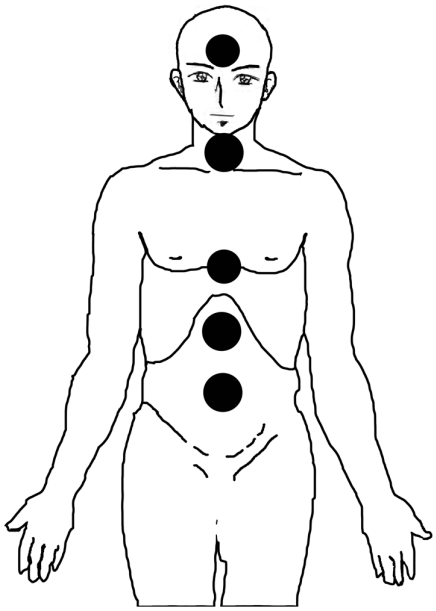

Fig. 2 Anatomic locations from which ultra-weak photon emission was measured.

2.3 Measurement procedure

In order to reduce the effect of diurnal rhythms, UPE in subjects was measured between 15 pm and 17 pm in order to reduce the influence of diurnal rhythms. Before the UPE measurements, the PMT background signal was recorded with the shutter closed for 10 min at intervals of 50 ms. During this period, subjects remained in red dim light in the control room. Then, subjects walked into the dark room with controlled temperature and humidity and were positioned on the bed for at least 5 min. The photomultiplier tube was placed above the body, with the ring at the front port of the photomultiplier barely touching the body. UPE from the navel, stomach, heart, neck, and forehead were measured sequentially. The duration of the recording for each body site was 10 min at intervals of 50 ms, and each signal consisted of a time series of 12 000 elements, with the total measurement time for each person being approximately 1 hour. The temperature in the dark room was maintained at 23 °C, and the background noise was in the range of 10.8–11.5 counts per s.

2.4 Data analysis

Statistical analysis of photon emission data was performed using the SPSS 16.0 software (SPSS, USA). The assumed quantum squeezed state parameters ($|\alpha|$, r, θ, $\varnothing$) were estimated by the minimization program (designed by Bajpai) in Matlab 7.0, and the formulae and detailed computational process can be found in the literatures.[37,38] The sixty subjects were classified by principal component analysis (PCA) according to the obtained data. Calculations and graphs were made using Origin 9.0 (Origin Lab Corporation, Northampton, USA).

3. Results

3.1 Statistical parameters for photon emission in patients with type 2 diabetes and healthy subjects

The statistical parameters (mean, kurtosis and skewness) for photon emission data from five body sites in patients with type 2 diabetes and age-matched healthy subjects, and from background data, are given in Table 1. The data show that in both healthy and diabetic subjects, the average intensity of forehead and throat is clearly higher than that of the other three body sites, and there are little differences in photon intensity among the heart, abdomen, and navel. The skewness is greater than zero, which indicates that the UPE of healthy and diabetic subjects obeys a positively skewed distribution. On the other hand, kurtosis is non-zero, which suggests that the photon count distribution for both healthy and diabetic subjects does not follow a normal distribution.

The average intensities of the background and spontaneous photon emission of five body sites in healthy and diabetic subjects are given in Fig. 3. These data show that the average photon intensity of the navel in the diabetic group is significantly higher than that in the healthy group (independent t-test, $p = 0.018$); the UPE intensity of the forehead in the diabetic group is significantly lower than in the healthy group (independent t-test, $p = 0.014$); and there were no significant differences for the other three body sites between the two groups.

3.2 Q value for photon emission in patients with type 2 diabetes and healthy subjects

The Q value is an indicator of the deviation of the observed signals from a Poisson distribution and is defined as variance per mean.[35] A positive Q value indicates a super-Poisson distri-

Table 1 Statistical parameters for UPE from background and five body sites in healthy subjects and type 2 diabetic patients

	UPE of healthy group (cps)			UPE of diabetes group (cps)		
Body sites	Mean ± std	Kurtosis	Skewness	Mean ± std	Kurtosis	Skewness
BG	11.18 ± 0.46	21.02 ± 5.85	3.49 ± 0.31	11.18 ± 0.43	22.53 ± 4.93	3.49 ± 0.40
Forehead	54.05 ± 4.35	4.12 ± 2.32	1.22 ± 0.33	43.68 ± 4.34	3.99 ± 2.30	1.33 ± 0.32
Throat	56.43 ± 5.35	3.84 ± 3.05	1.23 ± 0.42	50.65 ± 4.46	3.76 ± 2.48	1.24 ± 0.41
Heart	29.85 ± 4.06	7.72 ± 3.77	1.88 ± 0.44	30.53 ± 3.65	7.46 ± 3.90	1.80 ± 0.40
Abdomen	30.16 ± 4.32	7.40 ± 3.70	1.85 ± 0.45	33.07 ± 3.51	7.00 ± 4.07	1.76 ± 0.43
Navel	26.46 ± 3.75	8.22 ± 3.65	1.94 ± 0.40	34.86 ± 4.52	4.65 ± 3.76	1.72 ± 0.41

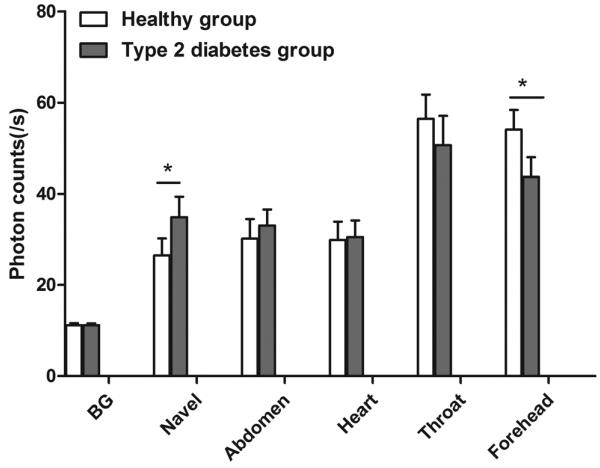

Fig. 3 Photon intensity of the five body sites in type 2 diabetic patients and healthy subjects, *$p < 0.05$.

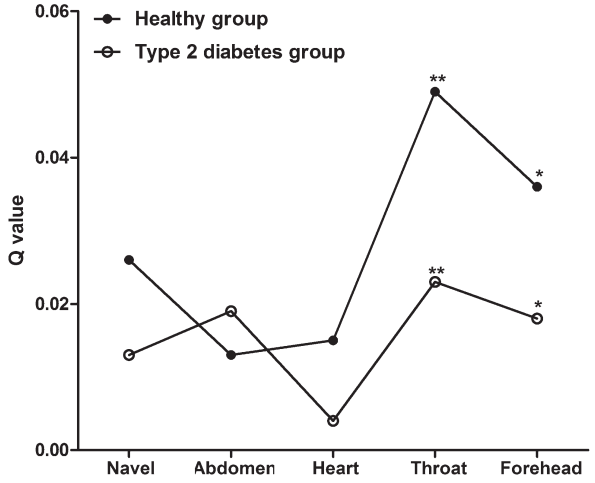

Fig. 4 Q values for the five body sites in type 2 diabetic patients and healthy subjects, **$p < 0.01$, *$p < 0.05$.

bution, and a negative value indicates a sub-Poisson distribution. In our measurements, the Q value for the background was about 1.152, and it was much higher than that for the five body sites (Table 2), which indicates that the photon count distribution of the background certainly follows a super-Poisson distribution, whereas the photon count distribution in subjects differs only slightly from a Poisson distribution. Table 2 also shows that the Q value varied between the different groups for the same body site.

The Q value for the five body sites in the healthy group and the type 2 diabetes group is shown in Fig. 4. Data in Fig. 4 shows that the Q value for the navel, heart, throat and forehead is lower in diabetic patients than that in healthy subjects, whereas the Q value for the abdomen is higher in diabetic patients. There are significant differences for the throat and forehead between diabetic patients and healthy subjects (independent t-test, $p = 0.004$ and $p = 0.026$). The Q value for all five body sites in healthy subjects and patients with type 2 diabetes is greater than zero, which indicated that the photon count distribution follows a super-Poisson distribution. The Q value for throat and forehead in diabetic patients is significantly lower than in healthy subjects, which indicates that the degree of super-Poisson distribution is lower for diabetic patients than that of healthy subjects.

Table 2 Q value for UPE from background and five body sites in healthy subjects and type 2 diabetes

	UPE of healthy subjects		UPE of type 2 diabetes group	
Body sites	Mean ± std	Min–max	Mean ± std	Min–max
Background	1.152 ± 0.127	0.953–1.545	1.151 ± 0.167	0.958–1.415
Forehead	0.036 ± 0.035	−0.122–0.167	0.018 ± 0.032	−0.113–0.141
Throat	0.049 ± 0.033	−0.038–0.330	0.023 ± 0.030	−0.075–0.256
Heart	0.015 ± 0.107	−0.142–0.292	0.004 ± 0.091	−0.214–0.287
Abdomen	0.013 ± 0.089	−0.265–0.301	0.019 ± 0.103	−0.155–0.365
Navel	0.026 ± 0.093	−0.159–0.242	0.013 ± 0.102	−0.201–0.293

3.3 Squeezed state parameters of photon signals in type 2 diabetes and healthy subjects

Squeezed state parameters ($|\alpha|$, r, θ, and φ) were determined from the photon count distribution. They were estimated by the least square minimization of the differences between calculated and observed probabilities. In several previous studies, squeezed state parameters were usually calculated and analyzed in order to reveal the quantum information contained in the photon count distribution.[35,37,38] The equations and calculation methods we used are the same as those from previous reports. The four parameters $|\alpha|$, r, θ, and φ for the photons emitted by the navel, abdomen, heart, throat and forehead of healthy subjects and patients with type 2 diabetes were calculated by the minimization program in Matlab 7.0 encoded by Prof. Bajpai. The parameters $|\alpha|$, r, θ, and φ corresponding to ten different bin sizes (50 ms, 100 ms, 150 ms, ..., 500 ms) for the photons emitted from the navel, abdomen, heart, throat and forehead in a healthy subject and a patient with type 2 diabetes are shown in Fig. 5 and 6, respectively. Both figures show that $|\alpha|$ increases linearly with bin size. This is due to the linear increase in bin size at intervals of 50 ms. Fig. 5 illustrates that the signals from all five body sites in healthy subjects have nearly the same r, θ, and φ values in different bin sizes, namely, $r = 2.72 \times 10^{-10}$, $\theta = 101.91°$, $\varphi = 69.53°$, which is in accordance with the experimental results obtained by other researchers.[39] These values are also considered as normal values for squeezed state parameters in healthy states. Fig. 6 demonstrates that for the signals from the navel, throat and forehead in patients with type 2 diabetes, the number of signals yielding normal values for the squeezed state parameters was significantly lower.

Fig. 5 and 6 clearly depict the squeezed state parameters for five body sites in ten different bin sizes in a healthy subject and in a patient with type 2 diabetes. In order to obtain quan-

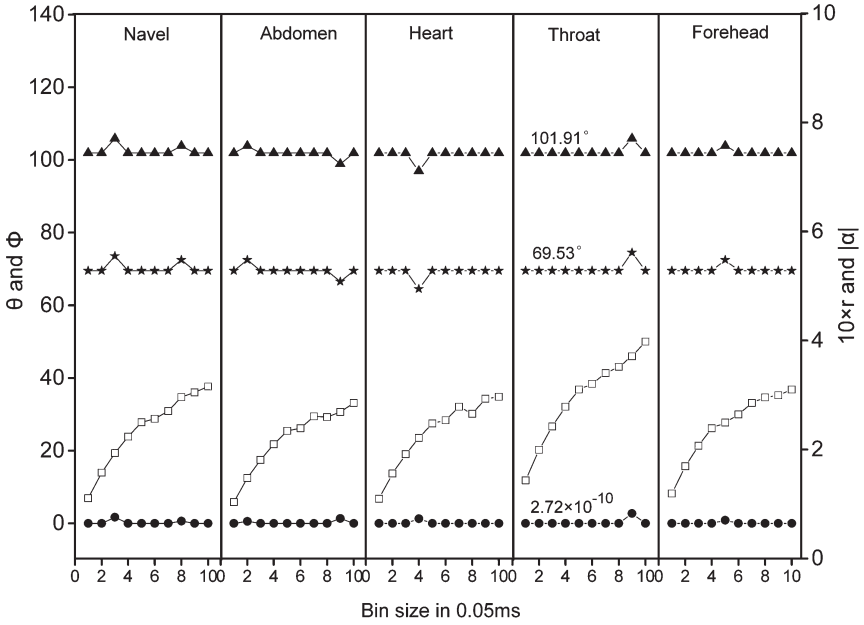

Fig. 5 Squeezed state parameters for the five body sites of a healthy subject: squeezed state parameters against the bin size used for detecting the signal (bin size is denoted in units of 0.05 ms). The symbol for $|\alpha|$ is □, θ is ▲, ⌀ is ★, and r is ●. The graph is divided in five regions, corresponding to a different body site.

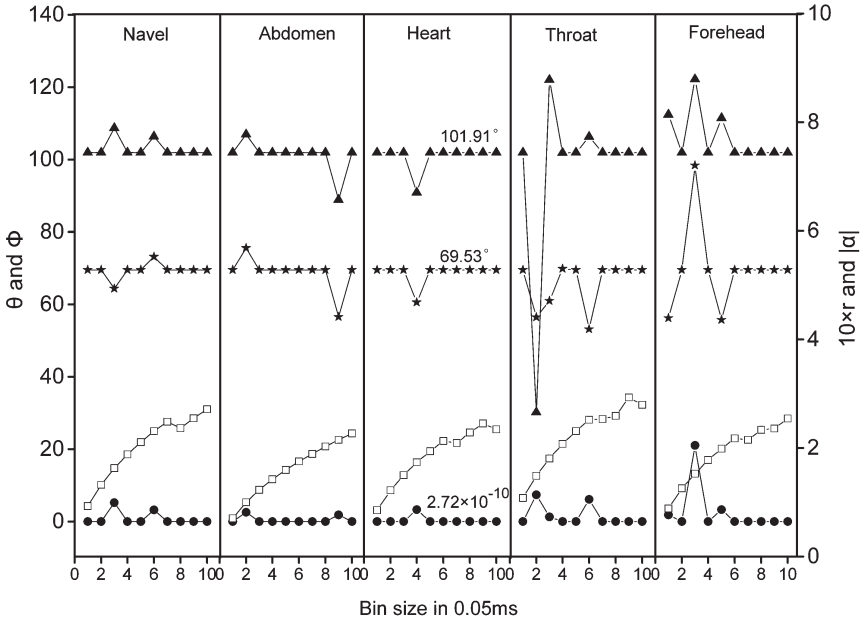

Fig. 6 Squeezed state parameters for the five body sites of a patient with type 2 diabetes: squeezed state parameters against the bin size used for detecting the signal (bin size is denoted in units of 0.05 ms). The symbol for $|\alpha|$ is □, θ is ▲, ⌀ is ★, and r is ●. The graph is divided in five regions, corresponding to a different body site.

titative data for healthy subjects and patients with type 2 diabetes, the percentage of signals yielding normal values for the five body sites in the ten different bin sizes for sixty healthy subjects and fifty patients with type 2 diabetes was calculated. Through our calculations, the percentage of normal values for the navel, abdomen, heart, throat and forehead in thirty healthy subjects in different time series was 80.11%, 79.46%, 82.63%, 95.8% and 95.3%, respectively; and the percentage of

the abovementioned five body sites of the patients with type 2 diabetes was 79.43%, 78.09%, 80.98%, 85.61% and 90.18%, respectively. There was a clear difference for the throat and forehead between healthy subjects and patients with type 2 diabetes according to the Chi-square test ($p < 0.05$).

3.4 Squeezed state index (SSI) of photon signals in type 2 diabetes and healthy subjects

Squeezed state index (SSI) is an indicator to estimate the separation between observed and expected photon count distribution from the signal intensity, it represents a holistic view of biological systems,[39] and its value is usually comprised between 0 and 1. SSI equals 1 in perfect conditions; however, SSI is usually lower than 1 due to the complexity of photon emission in the human body. Squeezed state index (SSI) of spontaneous photon emission for five body sites in patients with type 2 diabetes and healthy subjects is shown in Fig. 7. Fig. 7 shows that the SSI values for the navel, abdomen, heart, throat and forehead in healthy subjects are 0.826, 0.810, 0.795, 0.967 and 0.964, respectively, and the SSI values for patients with type 2 diabetes are 0.810, 0.806, 0.794, 0.846 and 0.863, respectively. The SSI values for throat and forehead in patients with type 2 diabetes are significantly higher than in healthy subjects, according to the independent *t*-test ($p = 0.003$, $p = 0.021$). There was no significant differences for other three body sites between the healthy and diabetes group.

3.5 Identification of the healthy group and type 2 diabetes group by PCA analysis of UPE data

Principal component analysis (PCA) is a statistical procedure that uses an orthogonal transformation to convert a set of observations of possibly correlated variables into a set of values of linearly uncorrelated variables. PCA is generally preferred for data reduction and can be used to find clusters in a set of data. In this study, PCA was used to discriminate among the parameters (signal strength, Q value, $|\alpha|$, θ, $\varnothing$, r, and SSI) for the five body sites in 110 subjects using the tools provided by SPSS 16.0. Two main component scores (PC1 and PC2) in all subjects were obtained by data reduction, which accounted for 57.4% and 32.1% of the whole variation, respectively. Fig. 8 shows a plot with the PCA scores using the obtained data with PC1 and PC2 values of 57.4% and 32.1%, respectively. From this PCA analysis, it is clear that the entire population could be separated into two groups, with the healthy subjects clustered on the right side and the patients with type 2 diabetes grouped on the left part of the plot (Fig. 8).

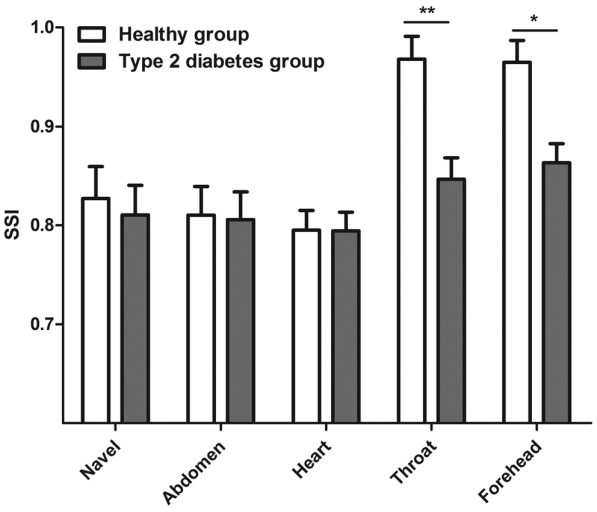

Fig. 7 Squeezed state index (SSI) values for the five body sites in healthy subjects and patients with type 2 diabetes patients (**$p < 0.01$, *$p < 0.05$).

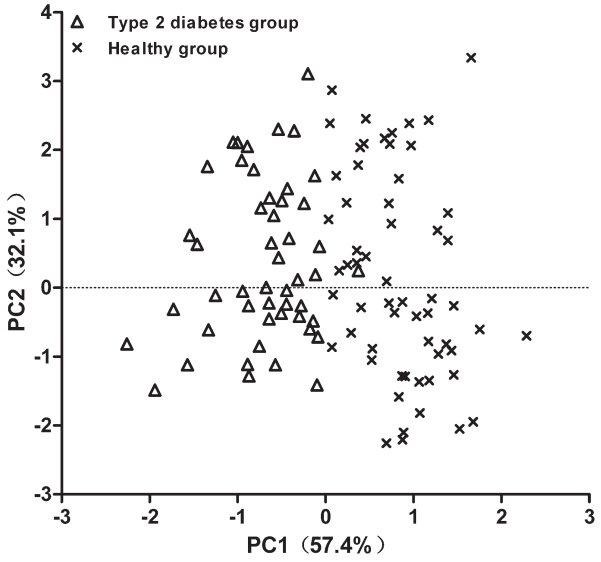

Fig. 8 Principal component analysis (PCA) plot, which is used to separate the subjects. The symbols "×" and "Δ" denote the healthy group and the type 2 diabetes group, respectively. PC1 and PC2 represent the two main component scores for all subjects, and accounted for 57.4% and 32.1% of the total variation, respectively.

4. Discussion

Ultra-weak photon emission is an inherent property of biological systems. UPE is a life phenomenon that occurs at the "molecular level", and contains information about the molecular composition and structure of biological systems.[1] Many studies have been conducted on the correlation of UPE and psychological state. Previous studies demonstrated that UPE intensity could be altered in some disease states,[19,20,29–33] including cold, hypothyroidism, multiple sclerosis, hemiparesis, essential hypertension, cancer, *etc.* However, the majority of the previous studies take UPE intensity as the main parameter, and other characteristics (containing more biological information) of the photon signal in non-healthy states have been less analyzed. Therefore, in this study, we studied UPE in

patients with type 2 diabetes by comparing and analyzing a range of characteristics in addition to the UPE intensity, with the aim to identify more characteristic features of the disease state. Our preliminary results revealed differences between patients with type 2 diabetes and healthy subjects for several parameters. The photon intensity of the navel and forehead in diabetic patients is significantly higher and lower than in the healthy group, respectively, which suggests that the difference in intensity between the healthy and disease state is specific to the body site and shows variability. The Q value is an indicator of the deviation of the observed signals from a Poisson distribution. In our present results, the Q value for the throat and forehead in the diabetic group is clearly lower than in the healthy group, and it demonstrates that the degree of super-Poisson distribution in the diabetes state is probably lower than in the healthy state. This result may indicate that the coherence of the biophotons emitted in the diabetes state changed is worse.

Squeezed state parameters are normally used to reveal the quantum information of the UPE signals; they are holistic and measurable characteristics of the biological systems and are sensitive to many physiological factors.[40] The percentage of signals yielding normal values for these parameters is a good indicator of health.[38,39] For the throat and forehead, the percentage of signals yielding normal values for these parameters was clearly lower in the diabetic group, suggesting that in the disease state, the UPE is probably not in a squeezed state and is likely a mixture of a squeezed state and a classical state. The squeezed state index (SSI) provides a quantitative measure of the coherence of photons in living systems. SSI for the throat and forehead in type 2 diabetes patients is significantly lower than in healthy subjects, which indicates that in patients with diabetes, the coherence of biophoton emission is worse than in healthy subjects. PCA is generally preferred for data reduction and can be used to find clusters in a set of data. In this study, PCA was used to discriminate among the parameters for five body sites in 110 subjects, and the results indicated that all subjects could be clustered into two groups based on the calculated parameters, suggesting that the measurement and analysis of the characteristics of human UPE is a promising non-invasive method for the diagnosis of diabetes.

5. Conclusions

We measured the spontaneous ultra-weak photon emission of five body sites in healthy subjects and in patients with type 2 diabetes using a moveable whole-body biophoton detection system. We found that the characteristics (signal strength, Q, $|\alpha|$, θ, $\varnothing$, r and SSI) of the photon signals in type 2 diabetes are significantly different from those in healthy subjects, and this provides quantitative data that allows to differentiate between healthy and non-healthy states according to biophoton emission. All the subjects could be clustered into two groups (healthy group and diabetes group) based on the different parameters by principal component analysis, which suggested that human UPE could be a promising, non-invasive and assisting method for identifying the healthy and diabetes state. As a continuation of this study, photon signals and the relevant characteristics for other diseases will also be measured and analyzed with the aim of constructing a UPE database that includes a range of diseases, so as to promote the UPE-based technology in medical applications.

Acknowledgements

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References

1 Q. Gu, Ultra-weak photon emission in biological systems, *China Sci.*, 1989, **1**, 35–40.
2 R. Van Wijk and E. P. A. Van Wijk, An introduction to human biophoton emission, *Forsch Komplementarmed Klass Naturheilkd*, 2005, **12**, 77–83.
3 H. Schwabl and H. Klima, Spontaneous ultraweak photon emission from biological systems and the endogenous light field, *Forsch Komplementarmed Klass Naturheilkd*, 2005, **12**, 84–89.
4 S. Cohen and F. A. Popp, Biophoton emission of human body, *Indian J. Exp. Biol.*, 2003, **41**, 440–445.
5 R. Van Wijk, Introduction: biophoton emission, stress and disease, *Experientia*, 1992, **48**, 1029–1030.
6 R. P. Bajpai, Biophoton emission of a lichen species parmelia tinctorum, *Indian J. Exp. Biol.*, 2003, **41**, 403–410.
7 P. Pospisil, Ultra-weak photon emission from living systems–from mechanism to application, *J. Photochem. Photobiol., B*, 2014, **139**, 1.
8 M. Cifra and P. Pospisil, Ultra-weak photon emission from biological samples: definition, mechanisms, properties, detection and applications, *J. Photochem. Photobiol., B*, 2014, **139**, 2–10.
9 A. Prasad and P. Pospisil, Towards the two-dimensional imaging of spontaneous ultra-weak photon emission from microbial, plant and animal cells, *Sci. Rep.*, 2013, **3**, 1211.
10 W. Y. Shi, K. K. Jiao, Y. T. Liang and F. Wang, Efficient detection of internal infestation in wheat based on biophotonics, *J. Photochem. Photobiol., B*, 2016, **155**, 137–143.
11 F. A. Popp, W. Nagl, K. H. Li, W. Scholz, O. Weingartner and R. Wolf, Biophoton emission, *Experientia*, 1988, **44**, 543–544.
12 A. Prasad and P. Pospisil, Two-dimensional imaging of spontaneous ultra-weak photon emission from the human

skin: role of reactive oxygen species, *J. Biophotonics*, 2011, **4**, 840–849.
13 P. Pospisil and A. Prasad, Formation of singlet oxygen and protection against its oxidative damage in Photosystem II under abiotic stress, *J. Photochem. Photobiol., B*, 2014, **137**, 39–48.
14 M. Kobayashi, K. Sasaki, M. Enomoto and Y. Ehara, Highly sensitive determination of transient generation of biophotons during hypersensitive response to cucumber mosaic virus in cowpea, *J. Exp. Bot.*, 2007, **58**, 465–472.
15 J. A. Ives, E. P. A. Van Wijk, N. Bat, C. Crawford, A. Walter, W. B. Jonas, R. Van Wijk and J. Van der Greef, Ultraweak photon mmission as a non-invasive health assessment: a systematic review, *PLoS One*, 2014, **9**, e87401.
16 J. Z. Zhang, Physical properties of biophotons and their functions, *Indian J. Exp. Biol.*, 2008, **46**, 371–377.
17 R. Van Wijk, E. P. A. Van Wijk and R. P. Bajpai, Photocount distribution of photons emitted from three sites of a human body, *J. Photochem. Photobiol., B*, 2006, **84**, 46–55.
18 D. Swinbanks, Body light points to health, *Nature*, 1986, **324**, 203.
19 R. R. Zheng, Studies on the correlation of ultra-weak photon emission of human body and some physiological and pathological state, *Chin. J. Lumin.*, 1986, **7**, 20–26.
20 C. Lee, J. M. Yang, S. H. Yi, H. J. Cho, M. J. Kang, J. S. Yang and K. S. Soh, Biophoton emission from patients with a cold, *J. Int. Soc. Life Inform. Sci.*, 2004, **22**, 362–365.
21 J. M. Yang, C. Choi, W. M. Woo, S. H. Yi, K. S. Soh and J. S. Yang, Left-right and yin-yang balance of biophoton emission from hands, *Acupunct. Electro Res. Int. J.*, 2004, **29**, 197–211.
22 E. P. A. Van Wijk, J. Ackerman and R. Van Wijk, Effect of meditation on ultraweak photon emission from hands and forehead, *Forsch Komplementarmed Klass Naturheilkd*, 2005, **12**, 107–112.
23 H. Nakamura, H. Kokubo, D. V. Parkhomtchouk, W. Z. Chen and T. Zhang, Biophoton and temperature changes of human hand during Qigong, *J. Int. Soc. Life Inform. Sci.*, 2000, **18**, 418–422.
24 F. Laager, J. C. Choi, S. H. Park, J. M. Yang and K. S. Soh, Year long measurement of biophoton emission of hands and feet, *NeuroQuantology*, 2008, **6**, 464–471.
25 R. Van Wijk, E. P. A. Van Wijk and M. Cifra, Spontaneous ultra-weak photon emission from human hands varies diurnally, *Biophotonics*, 2007, **6633**, 1–9.
26 M. Cifra, Dynamics of spontaneous photon emission from human body in 24 hour period, *Poster*, 2007, **5**, 1–5.
27 M. Cifra, E. P. A. Van Wijk, H. Koch, S. Bosman and R. Van Wijk, Spontaneous ultra-weak photon emission from human hands is time dependent, *Radioengineering*, 2007, **16**, 15–19.
28 M. Usa and H. Inaba, Spontaneous photon emission from human body, *Med. Imaging Technol.*, 1995, **13**, 47–54.
29 S. Cohen and F. A. Popp, Biophoton emission of the human body, *J. Photochem. Photobiol., B*, 1997, **40**, 187–189.
30 H. H. Jung, W. M. Woo, J. M. Yang, C. Choi, J. Lee and G. Yoon, Left-right asymmetry of biophoton emission from hemiparesis patients, *Indian J. Exp. Biol.*, 2003, **41**, 452–456.
31 M. N. Yang, J. X. Pang, J. Y. Liu, Y. L. Liu, H. Fan and J. X. Han, Spectral discrimination between healthy subjects and cold patients using spontaneous photon emission, *Biomed. Opt. Express*, 2015, **6**, 1331–1339.
32 W. Y. Yang, D. X. Ni, H. M. Zhang, K. X. Sun and L. Su, Spectral analysis of ultraweak photon emission of acuponits of patients with essential hypertension, *Chin. J. Basic Med. Tradit. Chin. Med.*, 1998, **4**, 49–51.
33 N. Zhu, FTIR spectra of finger nails of normal people and cancer patients, *Res. Explor. Lab.*, 2012, **31**, 246–247.
34 P. Chen, L. Zhang, F. Zhang, J. T. Liu, H. Bai, G. Q. Tang and L. Lin, Spectral discrimination between normal and leukemic human sera using delayed luminescence, *Biomed. Opt. Express*, 2012, **3**, 1787–1792.
35 E. P. A. Van Wijk, R. Van Wijk and R. P. Bajpai, Statistical analysis of the spontaneously emitted photon signals from palm and dorsal sides of both hands in human subjects, *J. Photochem. Photobiol., B*, 2010, **99**, 133–143.
36 E. P. A. Van Wijk, R. Van Wijk and R. P. Bajpai, Quantum squeezed state analysis of spontaneous ultra weak light photon emission of practitioners of meditation and control subjects, *Indian J. Exp. Biol.*, 2008, **46**, 345–352.
37 R. P. Bajpai, Biophoton emission in a squeezed state from a sample of Parmelia tinctorum, *Phys. Lett. A*, 2004, **322**, 131–136.
38 R. P. Bajpai and M. Drexel, Effect of colorpuncture on spontaneous photon emission in a subject suffering from multiple sclerosis, *J. Acupunct. Meridian Stud.*, 2008, **1**, 114–120.
39 R. P. Bajpai, E. P. A. Van Wijk, R. Van Wijk and J. Van der Greef, Attributes characterizing spontaneous ultra-weak photon signals of human subjects, *J. Photochem. Photobiol., B*, 2013, **129**, 6–16.
40 R. P. Bajpai, Squeezed state description of spectral decompositions of a biophoton signal, *Phys. Lett. A*, 2005, **337**, 265–273.