



RESEARCH ARTICLE

Transcontinental and Translational High-tech Acupuncture Research Using Computer-based Heart Rate and “Fire of Life” Heart Rate Variability Analysis

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Abstract

A variable heartbeat was considered a sign of good health by ancient Asian physicians. Today, new computer-based methods (e.g., “Fire of Life” analysis) allow quantification of heart rate and heart rate variability during acupuncture. The objective of this article is to compare different acupuncture methods to evaluate the influence of acupuncture on heart rhythm in short-term and long-term measurements. There were four main sections in this study: (A) a randomized controlled study using needle acupuncture and acupressure at Yintang (Ex1); (B) an innovative blue (violet) laser acupuncture randomized controlled study in Asian volunteers; (C) a comparative study using moxibustion methods; and (D) teleacupuncture. A total of 72 patients (mean age \pm SD: 27.9 \pm 8.6 years) were monitored over periods of 20 minutes to 24 hours in Asia and Austria. Acupuncture was performed with metal needles (in sections A, C and D) or blue laser (in section B) on Yintang, Neiguan, Guanyuan or a special acupuncture regimen for stress disorders (in sections A, B, C and D, respectively). Significant decreases in heart rate after *verum* intervention at Yintang, Neiguan and Guanyuan were found. Improvements in state of health following teleacupuncture were also noted. Computer-based heart rate and heart rate variability analysis was demonstrated to be effective in evaluating the status of health during acupuncture.

1. Introduction

Variable heartbeat has been considered a sign of good health since the third century by oriental physicians and the scientist Wang-Shu Ho. Ho stated, “If the pattern of the heartbeat becomes regular as the tapping of woodpecker or the dripping of rain

from the roof, the patient will be dead in four days” [1]. His statements were based on the manual pulse diagnosis.

Today the electrocardiogram (ECG) allows exact quantification of the time-varying electric rhythm of the heart. Abnormal heart rhythms can be identified on the ECG by detecting the QRS complex

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from one cycle to the next. Computer-based analysis of heart rate (HR) and heart rate variability (HRV) is increasingly employed to obtain information on the mechanisms responsible for cardiovascular regulation in different physiological and pathological conditions and also during acupuncture [2].

In recent years, rapid progress has been made in the field of data measurement and analysis, as well as in the physiological and clinical interpretation of results. We therefore have employed a new software procedure, “Fire of Life” analysis, for the quantification of frequency-related HRV distributions in acupuncture research [3]. This analysis allows the dynamic evaluation of the time modulation of spectral powers during different conditions in acupuncture. In this study, we describe the experimental data and the clinical data using this technique respectively.

This publication is divided into four main sections. Section A deals with a controlled study using manual needle acupuncture and acupressure at the acupoint Yintang (Ex1) and at a control point. Section B provides insight into a new acupuncture stimulation method—blue (violet) laser acupuncture—and contains HR and HRV data from a controlled study in Chinese volunteers. Section C presents a comparative study on HR and HRV using two different moxibustion methods. Finally, section D summarizes the potential importance of teleacupuncture including “Fire of Life” analysis by means of clinical results.

2. Materials and Methods

2.1. HR and HRV data acquisition and signal analysis

HRV was determined using ECG; specifically the duration of RR intervals was measured during a specific time period. ECG recording was performed with three adhesive electrodes (Skintact Premier F-55; Leonhard Lang GmbH, Innsbruck, Austria) applied to the chest (3-lead configuration).

For our investigations a medilog AR12 HRV (Huntleigh Healthcare, Cardiff, UK) system was used. This system is designed for a measuring duration of more than 24 hours. By recording 4096 samples per second, the new recorder can detect R-waves extremely accurately.

2.2. Analysis parameters

HRV is measured as the percentage change in sequential chamber complexes. RR intervals in the ECG are controlled by the blood pressure control system, influenced by the hypothalamus and in particular

controlled by the vagal cardiovascular center in the lower brainstem [2]. HRV can be quantified over time using registration of percentage changes in RR intervals over time, as well as the changes in the frequency range. Parameters were recommended by the European Society of Cardiology and the North American Society of Pacing and Electrophysiology [4]. Calculation of ECG power spectra is thought to provide an understanding of the effects of the sympathetic and parasympathetic systems on HRV. Early work indicated bands in the HRV spectrum that could be interpreted as markers of physiological relevance. Associated mechanisms, such as thermoregulation, blood pressure and respiratory effects can be found in the very low frequency band, low frequency (LF) band and high frequency (HF) band, respectively. In addition, total power of the HR spectrum is calculated for total HRV, and the ratio of the LF and HF band has become accepted as an important parameter [4].

Besides power spectral analysis, a new method of visualization of HRV is “Fire of Life” analysis. Within this diagram, frequencies are not shown on the X axis but on the Y axis. Therefore the very low frequency band can be recognized at the bottom of the diagram. A low frequency component at around 0.1 Hz is represented by the LF band between 0.05 Hz and 0.15 Hz. The power output in the LF band is partly dependent on sympathetic tone because of baroreceptor activity. Third-order blood pressure waves prove the connection of this 10-second rhythm [2]. A high frequency component that is represented by the HF band, generally between 0.15 Hz and 0.5 Hz, is associated with breathing frequency and considered an indicator of vagal activity.

HRV related to respiration, defined as the high frequency spectral component, is a marker of vagal modulation. HRV and arterial pressure variability, defined as the low frequency spectral component, is a marker of sympathetic modulation. The ratio of these two bands, as mentioned before, is an important numerical parameter.

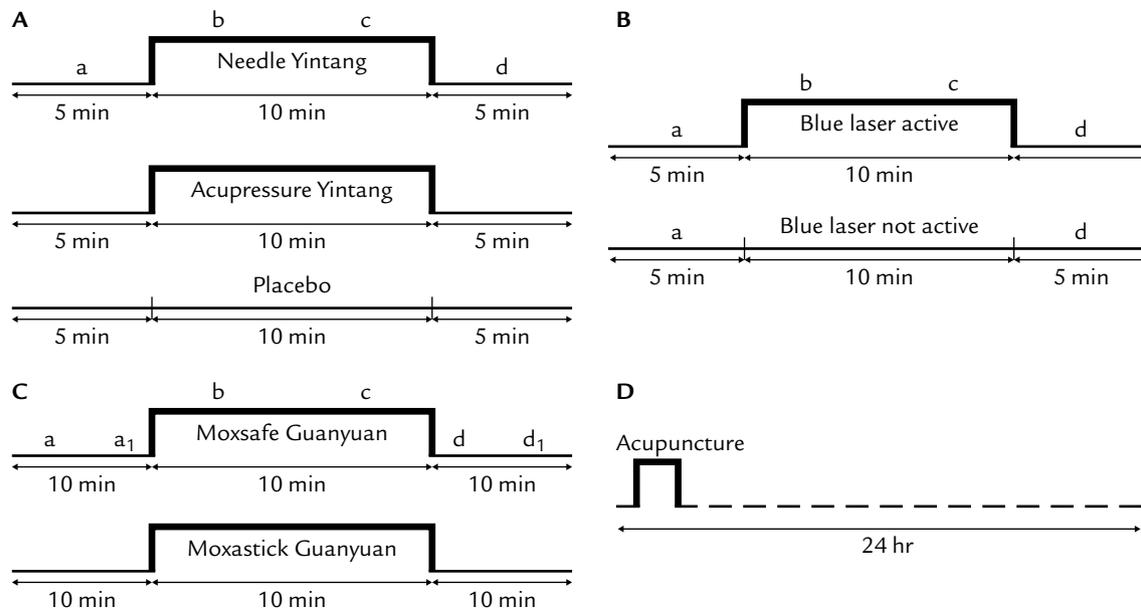
Different methods for calculating HRV spectra exist. Each method has its own advantages and disadvantages. The comparability of different studies is complicated and each study should define their own normal values.

2.3. Healthy volunteers and patients

Altogether 72 participants were investigated. Demographic data can be obtained from Table 1. None of the volunteers was under the influence of medications and all participants were free of neurologic or cardiologic disorders. Participants were informed of the nature of the investigation, as far as the study design allowed. The studies were approved

Table 1 Demographics of study participants

	All	Short-term measurements (healthy volunteers)			Long-term measurements (patients)
		A (Yintang)	B (Neiguan)	C (Guanyuan)	D (24-hr)
Participants (n)	72	25	18	20	9 (22 measurements)
Mean age \pm SD (yr)	27.9 \pm 8.6	26.5 \pm 8.7	30.3 \pm 7.1	23.5 \pm 2.6	36.9 \pm 12.0
Age range (yr)	17–59	17–52	24–50	20–29	24–59
Female (n)	37	12	10	10	5
Male (n)	35	13	8	10	4

**Figure 1** Measurement procedures used in the four different sections of the study. (A) Yintang. (B) Neiguan. (C) Guanyuan. (D) 24-hour heart rate/heart rate variability (HR/HRV) measurements in patients.

by the local ethics committee; all test participants gave written informed consent.

The exact measurement procedures used in the different studies can be seen in Figure 1. All participants in studies A–C were lying relaxed on a bed (10 minutes) to obtain steady-state conditions before stimulation commenced. The volunteers were then monitored over a period of 20 (A, B) or 30 (C) minutes. The data before [measurement phase(s) $a_{(1)}$], during (b,c) and after ($d_{(1)}$) the different stimulation conditions were measured and statistically analyzed. The four main sections of this study are divided into short-term (A–C) and long-term (D) measurements, described in detail below.

2.4. Section A: Yintang study

At the Beijing University of Chinese Medicine, 25 healthy volunteers (for details see Table 1) underwent three procedures consisting of acupuncture at Yintang (Ex1), acupressure at the same point and

placebo acupuncture at a sham point over 10 minutes (Figure 1A). The sequence of the three methods was randomized.

The acupoint Yintang (Ex1; see Figure 2A) is located midway between the medial ends of the eyebrows at the root of the nose. It is one of the main points used for sedation, as demonstrated in previous studies [5]. Acupressure on the acupoint (mean force about 3×10^5 Pa) [6] and acupuncture were always performed by the same person experienced in Traditional Chinese Medicine (TCM). Manual needle acupuncture was performed using single-use sterile needles 0.30 mm \times 30 mm (Huan Qiu, Suzhou, China). After disinfection of the skin, needling was performed in an oblique, caudal direction (0.5 cm). Stimulation for a duration of 20 seconds at intervals of 2 minutes consisted of a combination of rotating and thrusting movements using a special manual acupuncture stimulation technique (sedation method). The needle was removed after 10 minutes. The sham point was located 1.5 cun above and 1 cun

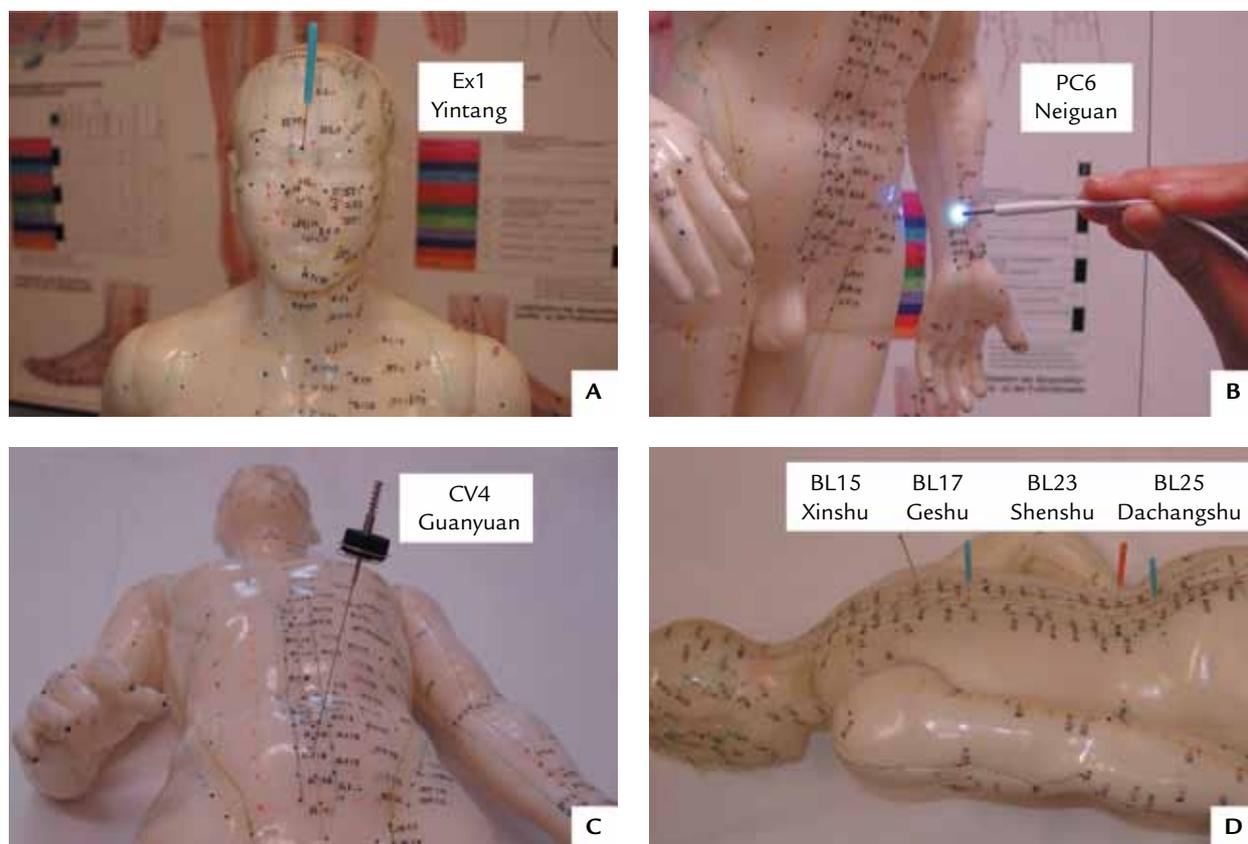


Figure 2 (A–D) Acupuncture points used in the four sections of the study.

medial to the Sizhukong acupoint (SJ23). The width of the interphalangeal joint of the patient's thumb is taken as 1 cun.

2.5. Section B: Neiguan study

At the TCM Research Center, Graz, Austria, investigations were performed in 18 healthy Asian volunteers (see Table 1B). Blue laser stimulation was applied at the Neiguan (PC6) acupoint on both arms for 10 minutes. A placebo measurement with deactivated laser served as negative control (Figure 1B). Performance of initial test procedures was selected at random, whereby the volunteers were not informed of the mode being used. The resting period between both tests was at least 10 minutes.

Neiguan is located between the tendons of palmaris longus and flexor carpi radialis, 2 cun proximal to the transverse crease of the wrist (Figure 2B). The acupoint Neiguan is indicated in heart disorders and disorders of the chest area, especially angina pectoris [7].

For this part of the investigations, the new, optical blue laser acupuncture was used. This new optical method continuously and simultaneously stimulates different acupoints and has as yet only been used by our research group, in two acupuncture studies [8,9]. Blue laser light with a wavelength of

405 nm (which is in fact violet but commonly called blue), an output power of 110 mW and a diameter of 500 μ m was used for these investigations. These blue “optical needles” are special light conductors that are placed vertically at the skin (Figure 2B) and trigger painless but perceptible stimulation at the acupoint. Although the blue laser does not have the same penetration depth in human skin as the red and infrared laser (blue: approximately 2 mm vs. red/infrared: 2–3 cm) [8,10,11], the evoked *De Qi* sensation, which is a prerequisite for effective acupuncture stimulation, warrants the scientific investigation of blue laser stimulation.

2.6. Section C: Guanyuan study

Twenty healthy Chinese volunteers (Table 1C) were evaluated at the Beijing University of Chinese Medicine. Two different kinds of moxibustion were performed at the acupoint Guanyuan (CV4; compare Figures 1C and 2C). Ten volunteers received a new form of needle moxibustion [12]. The new needle-moxa-system (Moxsafe; Seirin Co., Shizuoka, Japan) used in this study consists of an acupuncture needle (0.30 mm \times 50 mm) with a 25-mm-long metal grip. The basic part of the system consists of a metallic holder that is directly applied to the needle. This holder contains a hollow cylinder with an outer diameter

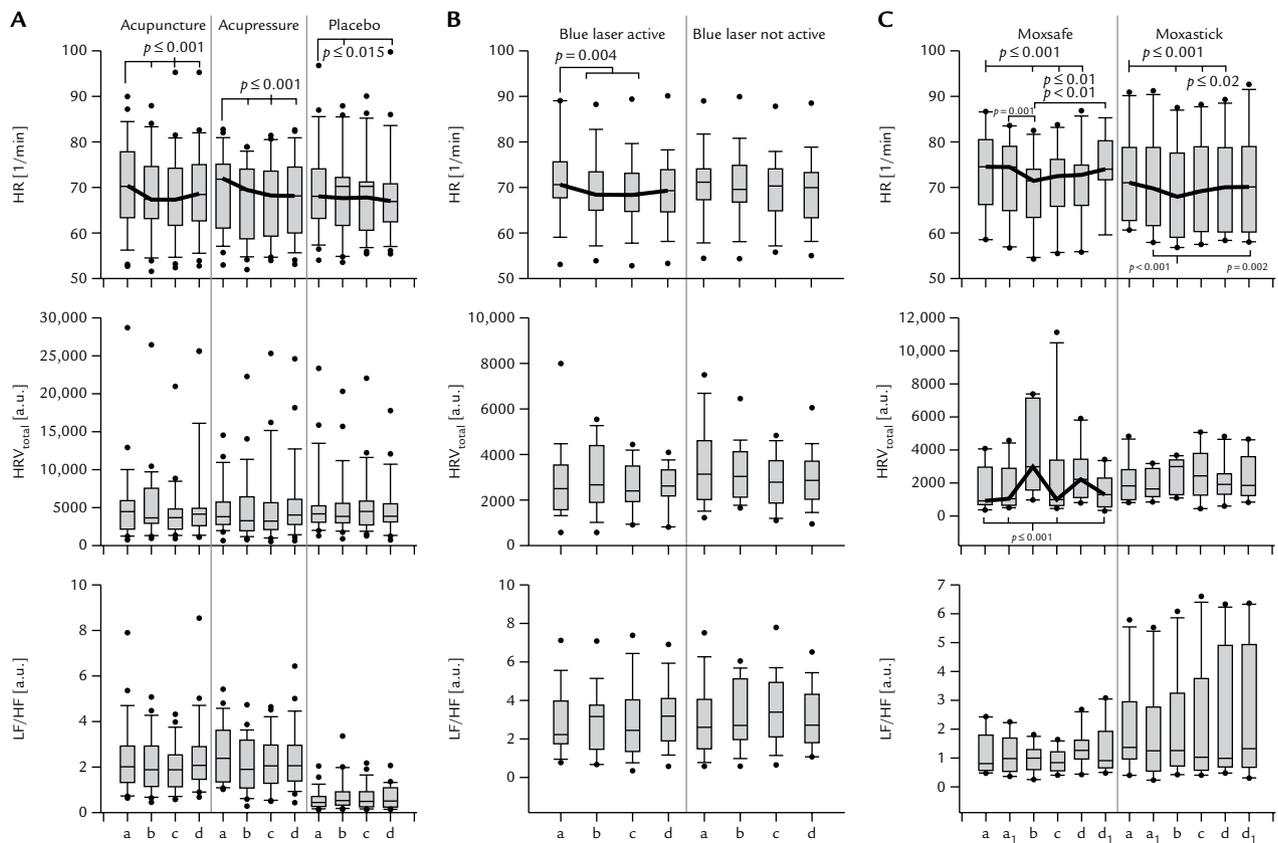


Figure 3 (A) Box plot illustration of heart rate (HR), total heart rate variability (HRV_{total}) and the evaluation parameter low frequency/high frequency ratio before (a), during (b,c) and after stimulation (d). Note the significant decrease of HR during acupuncture and acupressure ($p < 0.001$). (B) Significant changes of HR during blue laser acupuncture at Neiguan ($p = 0.004$). Data are presented as box plot illustrations. (C) Quantification of significant decreases in HR during different moxibustion methods (Moxsafe: new acupuncture moxibustion; Moxastick: traditional moxibustion). Significant changes in total HRV were only found using the new needle acupuncture moxibustion system.

and height of 0.5 cm and is mainly filled with pressed “mugwort coal” (main ingredient: *Artemisia vulgaris*). The entire system (Figure 2C) consists of single-use products. The other 10 volunteers were stimulated with a moxa stick made of mugwort (length 20 cm, diameter 1.5 cm; Hua Tuo, Suzhou, China). The area of the acupoint Guanyuan was stimulated at a distance of about 5–10 cm for 10 minutes (Figure 1C).

The acupoint Guanyuan is located in the midline, 3 cun below the umbilicus. It is indicated in urogenital disorders and is, in general, a very important point for moxibustion in deficiency conditions [7].

2.7. Section D: 24-hour measurements

Twenty-two 24-hour recordings in nine patients (Table 1D) suffering from chronic fatigue or burnout syndrome were performed at the China Academy of Chinese Medical Sciences in Beijing. Data were transferred via the internet to the TCM Research Center, Graz, Austria, directly following the acupuncture

treatment and recording session (Figure 1D). The “Fire of Life” spectral analysis was performed in Graz, and the acupuncturists in Asia were immediately informed of the results. Altogether two or three 24-hour measurements during a whole acupuncture treatment (10 sessions) were performed for each patient; the first at the beginning, the second after the fourth acupuncture session and the third after the final (10th) acupuncture session. In five patients, only two measurements were performed. Each 24-hour recording session began 10 minutes before acupuncture treatment. A typical example is presented in Results section. In this patient, the following acupuncture scheme was used (Figure 3D): Xinshu (BL15; located 1.5 cun lateral to the lower border of the spinous process of T5; needling: oblique, 1–2 cm); Geshu (BL17; located 1.5 cun lateral to the spinous process of T7; needling: oblique, 1–2 cm); Shenshu (BL23; located 1.5 cun lateral to the lower border of the spinous process of L2; needling: perpendicular, 1–2 cm); and Dachangshu (BL25; located 1.5 cun lateral to the lower border of the spinous process of

L4; needling: perpendicular, 1–2 cm) [7]. According to TCM, these points may have a positive influence in cases of chronic fatigue and burnout syndrome (kidney deficiency and blood stagnation).

2.8. Statistical analyses

Data are represented using box plot illustrations (SigmaPlot 11.0; Systat Software Inc., Chicago, IL, USA). The horizontal line represents the median. The ends of the box define the 25th and 75th percentile and error bars show the 10th and 90th percentile. The data were tested with one-way repeated measures analysis of variance on ranks and Tukey test. The criterion for significance was $p < 0.05$.

3. Results

3.1. Section A: Yintang study

Figure 3A shows HR and HRV data from 25 volunteers during a 10-minute stimulation of the Yintang and sham acupoints. Mean HR values decreased significantly during *verum* acupuncture and acupressure on Yintang ($p < 0.001$). The changes in HR during acupuncture on the sham point were also significant ($p < 0.015$); however, the extent of this reduction was smaller. No significant changes in total HRV were observed in any of the three conditions. Acupressure noticeably reduced the LF/HF ratio in all volunteers. When results were analyzed for gender, the LF/HF ratio tended to decrease in both groups, but females showed an obvious reduction in the LF/HF ratio during and after acupressure (females, mean reduction from 1.9 to 1.2; males, from 2.15 to 1.7).

3.2. Section B: Neiguan study

Results of the controlled blue laser acupuncture investigations are shown in Figure 3B. The negative control (blue laser not active) did not lead to any significant changes in HR or HRV in the 18 Asian volunteers. However, HR decreased significantly ($p = 0.004$) during bilateral blue laser acupuncture at the Neiguan acupoint. Even after stimulation, HR values were still markedly (although not significantly) lower compared to baseline values. No significant changes were found in the analysis of total HRV and in the LF/HF ratio.

3.3. Section C: Guanyuan study

A comparison between moxibustion using the new Moxsafe system and a traditional moxa stick showed that there was a significant decrease in HR in both methods ($p < 0.001$). The effect was slightly more

pronounced using the new needle-moxa-system (see Figure 3C, upper panel). Total HRV was significantly increased only when Moxsafe was used ($p < 0.001$; Figure 3C, middle panel). LF/HF ratio was insignificantly altered using both methods.

3.4. Section D: 24-hour measurements

An illustrative example of the 24-hour HRV tele-acupuncture measurements and the new “Fire of Life” computer-based power spectral analysis is provided in the following case report.

A 29-year-old man from Beijing presented to the Tong Ren Tang Outpatient Health Care Center in Beijing complaining of lack of energy, chronic fatigue and mental and physical exhaustion. Furthermore, he reported recurring headaches, diffuse lower back pain and difficulty concentrating at work. In addition he had trouble falling asleep and/or sleeping through the night. His condition had developed and progressed steadily due to the potential loss of his job and personal problems (high-demand and long-term care of his father). Based on various symptoms, e.g., increased sensitivity to cold, grayish-white skin, pale and swollen tongue with a white coating, and a deep and weak pulse (markedly weak at the kidney positions), the TCM diagnosis was determined to be kidney-*Qj* deficiency. The corresponding Western diagnosis could be described as chronic fatigue syndrome or burnout.

His first acupuncture session took place on March 14, 2009. In addition to the points described in the methods section (see Figure 2D), ear acupuncture was applied at Shenmen (ear point 55), liver (97) and an antidepressant point (psychotropic point 3), and laser acupuncture (dichromatic red 685 nm and infrared 785 nm; 30–40 mW, diameter 500 μ m, duration 10 minutes) were performed at the acupoints Hegu (LI4) and Zusanli (ST36).

Examples of the new “Fire of Life” analysis of HRV during acupuncture treatment of this patient are presented in Figure 4 [3,13]. The improvement of the state of health (sleep-wake cycle) of the patient can be clearly seen in this figure. At the beginning of the acupuncture treatment, no distinct sleep-wake cycle could be found (Figure 4A). The respiratory sinus arrhythmia (frequency range 0.2–0.3 Hz) is barely recognizable. After the fourth acupuncture session, the state of health improved, and a clear sleep-wake cycle could be seen (Figure 4B). After the 10th acupuncture session (about 10 weeks after the beginning of treatment), the original symptoms had subsided and clinical status had improved. This is in accordance with the measurement data in Figure 4C. The patient wishes to continue acupuncture treatment in order to stabilize his current condition.

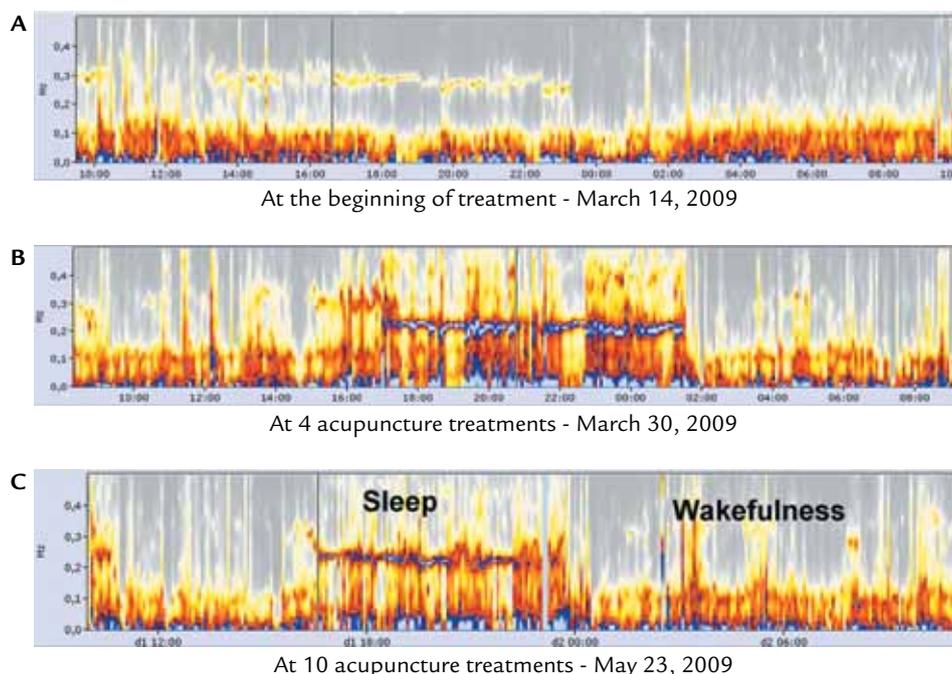


Figure 4 Improvement of the state of health of the 29-year-old patient suffering from chronic fatigue syndrome (kidney-*qi* deficiency). Follow-up investigations during a total of 10 acupuncture sessions are presented (A–C). Note the appearance of an obvious sleep-wake cycle in the “Fire of Life” analysis soon following the fourth acupuncture session (modified from [3,13]).

4. Discussion

ECG is one of the oldest instrument-bound measurements in medicine that has faithfully followed the progression of instrumentation technology. The most recent progression in ECG has allowed patients to wear computer monitors and has provided an enhanced, high-resolution ECG that has opened new vistas in ECG analysis and interpretation.

The scope of HRV is not yet completely clear, but it is known that there are intra- and interindividual variances and that HR variation depends on age [1,4,14,15]. HR variation becomes less random with the aging process and the appearance of age-related diseases. Apart from age, circadian variations (sleep-wake cycle), physical condition and mental and physical exertion are important influencing factors [1,4]. HRV can also be affected by diverse conditions such as diabetic neuropathy, renal failure, essential hypertension, cardiac disorders, coronary artery disease or intracranial lesions. In all cases, medications affecting HR need to be taken into account [4].

HRV can be used as a reliable indicator of the state of health. One can counteract special circumstances, such as stress, using preventive methods like acupuncture. Recent investigations in Asia and Austria concerning patients with burnout syndrome have shown stress alleviation following common teleacupuncture [3,13]. There have been

few studies looking at acupuncture and HR and/or HRV. A review from 2007 can be found in the literature [2].

The influence of acupuncture at the acupoint Yintang (Ex.1) on the bispectral index and spectral entropy of the electroencephalogram (EEG) and the LF/HF ratio of HRV has recently been demonstrated [5,6,16]. The results of the first section of this article show that mean HR also decreased significantly during acupressure and *verum* acupuncture on Yintang [17]. In the present pilot study, there were significant but not clinically important changes with acupressure and needle acupuncture. We have previously found significant and relevant reductions in the EEG bispectral index due to acupressure, while needle acupuncture, laser acupuncture and acupressure at a control point resulted in statistically significant but clinically unimportant reductions [5,6]. Altogether, the results highlight the electroencephalographic and electrocardiographic similarities of acupressure/acupuncture-induced sedation and anesthesia.

Blue lasers are utilized in a few special areas in medicine [18], as they are still a new and expensive invention. In acupuncture research in particular, blue laser has only been applied in two scientific investigations, which were published by our group in 2009 [8,9].

According to TCM, one must first obtain *De Qi* for acupuncture to be effective. Patients and volunteers

describe this feeling as heaviness or like an electrical current running along the treated meridians. *De Qi* sensation is also achieved with blue laser light of sufficient intensity (for technical parameters, see Methods). It is important to understand that laser light may be concentrated to achieve high intensities yet still be given at relatively low average output powers. This is accomplished by reducing the area of the laser beam. If red (685 nm) or infrared (785 nm) lasers are used, patients do not normally notice when the laser is started. So at the beginning of the treatment they also do not feel any *De Qi* sensation. Several minutes later (5–10 minutes), many patients report a pleasant, warm and sometimes vibrating feeling in some treated areas [19]. By contrast, using blue laser acupuncture, volunteers described that the blue laser induced feelings similar to an “ant-like bite” followed by a feeling similar to a slight electrical current, which is similar to *De Qi* evoked by a metal needle. Up till now, most studies investigated people from Asian countries as they already have extensive experience with needle acupuncture. In follow-up studies we will compare the data with European volunteers with and without prior acupuncture experience.

In one of our two pilot studies we found that blue laser stimulation promptly and significantly increases temperature and microcirculation (by approximately 1.5°C and 20%) at the acupoint Hegu (LI.4) after stimulation onset [8]. The main interesting finding of the present results concerning blue laser acupuncture was that HR decreases significantly within an interval of 5–10 minutes after blue laser stimulation onset at the acupoint Neiguan (PC.6). HR in this study did not change significantly during and after placebo stimulation with deactivated blue laser (Figure 3B).

Moxibustion is a method of healing originated from Asia that is able to achieve warming effects at specific acupuncture points [20]. Our recent and present investigations using a new Asian moxa system show that besides temperature and microcirculatory changes at the skin [21], significant alterations in HR and HRV can be seen [22]. This system allows moxibustion with a minimum amount of smoke and a high degree of safety (Figure 2C).

Telecommunication technology includes the assisted transmission of signals and biological data over a distance. The first results from the present teleacupuncture pilot study (needle and laser acupuncture) within the Asian-Austrian High-tech Acupuncture Research Network are presented in Figure 4.

For the first time we used a new HRV analysis technique, the “Fire of Life” analysis. The example shows the first follow-up teleacupuncture measurements between Asia and Europe. The raw data were transferred using the internet to the TCM Research

Center in Graz, Austria, from the patients’ computer in Beijing to the control computer in Graz over a distance of 7650 km. Data analysis of different parameters of HR and HRV was performed immediately for control of possible therapeutic effects of acupuncture. The acupuncturists in China were informed of the findings immediately and the success of the therapy could be objectively demonstrated. This technology may be useful under special circumstances, for example for cooperation between experts from different continents, as demonstrated in our Asian-Austrian collaboration [3,8,15,23,24].

Of course, follow-up measurements are possible and can vividly demonstrate the success of different therapies like acupuncture using HRV. In the Asian patient described in Results section, an obvious sleep-wake cycle appeared over 10 acupuncture treatments within a time period of about 9 weeks. His initially reduced “Fire of Life” started to burn more brightly, so to speak, after only the fourth treatment (Figure 4).

Computer-based HR and HRV analysis has been demonstrated to be reliable and effective in evaluating the status of health during acupuncture treatment. The portability and non-invasive nature of short- and long-term recording equipment make it a useful tool to use with volunteers and patients of all ages. As demonstrated, HR and HRV analyses (including “Fire of Life” documentation) have shown sensitivity and specificity to different kinds of acupuncture (needle, blue laser, red laser, Moxsafe) and acupressure stimulation in comparison to placebo methods. These findings provide information that can be used in specific acupuncture regimens. Likewise, teleacupuncture can be performed for the first time using the new methods presented in this study. This can help in optimizing the communication between basic and clinical science.

The technological advances in recent years and the new software procedures currently in development will make HRV-“Fire of Life” analysis an easy-to-use tool for evaluating the health status of patients suffering from various diseases during acupuncture.

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