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ORIGINAL ARTICLE

Heart rate and heart rate variability as indirect markers of surgeons' intraoperative stress

Annika Rieger · Regina Stoll · Steffi Kreuzfeld · Kristin Behrens · Matthias Weippert

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Abstract
Objective In a difficult and demanding environment such as the operating room, the individual workload response of physicians is of particular importance. The aim of this study was to examine the specific effects of intraoperative stress on the cardiovascular system by measuring heart rate (HR) and heart rate variability (HRV).
Methods In a cross-sectional study, the effect of intraoperative stress on autonomic balance, measured by HRV, among surgeons differing with respect to their intraoperative stress levels was studied. Based on their perceived stress (State Trait Anxiety Inventory), surgeons were classified into a stressed and a non-stressed sample. Data on HR and HRV were collected by means of ambulatory ECG-recordings. Changes in autonomic nervous system activity were quantified by frequency and time domain analysis of R–R interval variability. Demographic, anthropometric, and surgery-related group differences were assessed by non-parametric Mann–Whitney U test, differences between relative changes of HR and HRV by Wilcoxon signed-ranks test. In multivariate linear analysis of covariance, group differences were adjusted for possible confounding factors.
Results There was a significant difference in intraoperative HR for stressed and non-stressed surgeons (median: 99.3 vs. 63.7; $P < 0.05$). During sleep, HRV indices indicated a reduced autonomic recovery in stressed participants.
Conclusions Our results reveal that higher perceived stress in the operating room is associated with increased intraoperative HR and decreased HRV at night. Non-stressed surgeons show greater relaxation during sleep compared to their stressed colleagues.

Keywords Heart rate · Heart rate variability · State Trait Anxiety Inventory · Surgery · Ambulatory assessment · Intraoperative stress

A. Rieger (✉) · R. Stoll · S. Kreuzfeld · K. Behrens · M. Weippert
Institute for Preventive Medicine, Rostock University Medical Center, Rostock, Germany
e-mail: annika.rieger@uni-rostock.de

Introduction

For years, people have been aware of the connection between stress and the heart. Several studies have shown that chronic stress is associated with significant morbidity and increased risk of mortality (Belkic et al. 2004; Brotman et al. 2007; Diène et al. 2012; Steptoe and Kivimäki 2012). Likewise, enduring occupational stress as well as adverse physical and psychosocial work environments and working conditions have been considered as independent risk factors of coronary heart disease (Kivimaki et al. 2002; Chandola et al. 2008). Also in medical professions, there has been increasing concern about diverse stressors affecting physicians at various stages throughout their careers. A number of studies have shown that chronic stress does not only affect surgical performance (Wetzel et al. 2011), or patient health outcomes including quality of care (Klein et al. 2011), and patient safety (Horner et al. 2012), but also the health of physicians (Buddeberg-Fischer et al. 2008; Hiemisch et al. 2011).

The field of surgery is known to be of a particularly stressful nature (Balch et al. 2010). The operating room (OR) as a very demanding environment is the place where surgeons spent one third of their daily working time

(Schuld et al. in press). Thus, the operating theater as a complex workplace is of special interest regarding stress experience and stress effects. Key stressors in the OR include for instance operating, bleeding, distractions, time pressure, or equipment problems (Arora et al. 2010a). Even though a certain degree of acute stress can ameliorate concentration and performance, high levels of acute and chronic stress may have adverse effects on quality of care, patient safety, health, and well-being of surgeons.

Heart rate variability (HRV), quantified by the analysis of variation of beat-to-beat intervals, has been shown to be a useful tool for revealing adverse effects of lifestyle and psychosocial stressors on the cardiovascular system (Brosschot et al. 2007; Pieper et al. 2007; Thayer 2005; Thayer et al. 2010; Virtanen et al. 2003; Weber et al. 2010; Wennerblom et al. 2001). High HRV is associated with good adaptability and indicates well functioning autonomic control mechanisms (Böckelmann 2012). Beyond that provided by traditional risk factors, HRV offers prognostic information on cardiac events (Tsuji et al. 1996). Associations between HRV and lasting job strain have been presented in many studies. Higher levels of work stress were associated with lower values of HRV. Furthermore, physical and chemical work environments, psychosocial workload, and working time had been identified as having associations with reduced HRV (Borchini and Ferrario 2012; Clays et al. 2011; Malmberg et al. 2011; Togo and Takahashi 2009).

Analysis of autonomic nervous system regulation of the heart in surgeons revealed for instance that working on night call leads to less dynamic HRV (Malmberg et al. 2011) and that stress management training results in increased coping skills and reduced stress reflected in HRV (Wetzel et al. 2011). While a lot of effort has been done analyzing the effects of chronic work stress on the variation of the autonomic nervous system (Borchini and Ferrario 2012; Chandola et al. 2008; Clays et al. 2011; Hintsanen et al. 2007), to date, little is known about the specific effects of acute stress in the hospital setting, especially in surgery. Some researchers analyzed the intraoperative mental strain by interpreting the physiological response of the autonomic nervous system. For instance, authors reported on the increase in tonus of the sympathetic nervous system during different stages of surgery indicating a rise in emotional level (Czyzewska et al. 1983). Other researchers analyzed the intraoperative HRV of surgeons in coronary artery bypass grafting surgery (Song et al. 2009) and during laparoscopic and conventional surgeries (Böhm et al. 2001).

Besides the utilization of physiological parameters for stress purposes, short questionnaires are a practical and feasible tool for measuring occupational strain (Rieger et al. 2012). Self reports which are collected in real time and not retrospectively are a useful means to measure the effects of stress as perceived by the individual. The solely use and interpretation of heart rate (HR) and HRV measures are critical because of confounding factors such as physical activity or breathing behavior. Until now, combined subjective and objective intraoperative stress assessment has not been a matter of concern in most of the studies. However, an important step in intraoperative stress assessment was done recently. The feasible and non-invasive imperial stress assessment tool (ISAT) relied on the evaluation of surgeons' physiological responses on the basis of the subjective stress experience. The authors detected positive correlations between intraoperative stress and HR as well as intraoperative stress and cortisol levels (Arora et al. 2010b).

On the basis of the recommendations of Arora et al., the surgeons of our study were assigned to stress groups according to their individual stress scores, assessed by a widely accepted scale (Marteau and Bekker 1992). We hypothesized that the individual stress experience will be reflected in the corresponding autonomic regulation indices. In this respect, we analyzed whether there were any differences in HR and HRV between intraoperatively stressed and non-stressed surgeons and consequently, if there is a relationship between objective and subjective stress measurements. We supposed that the HR and HRV of intraoperatively stressed surgeons differ significantly from those who are not stressed in the OR.

Methods

Study design, study sample

The study design was cross-sectional, incorporating an ambulatory monitoring over 24 h under everyday life conditions that combined both objective and subjective measurements. The prospective study was carried out in two hospitals of Northern Germany. Eligibility criteria comprised adequate knowledge of German to ensure comprehension of the questionnaire, and well-being, that is, neither acute nor chronic illnesses were tolerated. 20 out of 22 surgeons recruited from four medical disciplines were enrolled as voluntary participants after having given their written informed consent. Two surgeons could not participate because no surgeries were on their schedule the days of monitoring. Thus, the participation rate was 95.2 %. Six residents, five fellows, five attending, and four chiefs of medicine agreed to take part in the study. The day before monitoring, all surgeons had a regular working day without night shifts.

The Equivital sensor system EQ-01 (Hidalgo Ltd., Cambridge), consisting of a chest belt with an integrated sensor, was used to measure physiological data and body movement within the 24 h of continuous monitoring. The ambulatory assessment system further included a smartphone that was worn in the scrub or white coat and used for individual documentation of stress and work occupations. Subjective data were synchronized with the physiological parameters and sent in real time to the institutional server where data were analyzed and stored (Neubert et al. 2010). Each participant was monitored over the course of at least 8 working hours and the following time of leisure and night recovery. Prior to the ambulatory monitoring that was started before regular start of work early in the morning, surgeons were informed in a short briefing about the main features and the questionnaire design.

The study was approved by the Ethics Committee at Rostock University (A 2012-0075).

Ambulatory measures

HR was recorded continuously during the entire investigation (Hidalgo Ltd.). Three dry electrodes located within the monitoring belt enabled 3-channel ECG-recordings. For online transmissions and analysis, secondary data were used. Running average of HR over 30 s period was calculated (time resolution: four values per minute). Signal confidence and quality measures gave information on the accuracy of the data.

Measurement of HRV took place during the whole work day and a resting period at night. Physiological resting values were assessed by the analysis of representative nighttime recordings. These values served as an individual physiological baseline. Measurements were conducted "beat to beat" in an electrocardiography recording mode, detecting each QRS complex and recording every R–R interval. Recordings were analyzed off-line with the software *Kubios HRV*, allowing for a wide variety of analysis, such as time and frequency domain. Analysis was performed according to the guidelines of the HRV Task Force (Task Force of the European Society of Cardiology and North American Society of Pacing and Electrophysiology 1996). Mean values of short-term 5-min recordings that were free of ectopy, missing beats, and noise and made under physiologically stable conditions were calculated and used in subsequent analysis. For both measurements, operative procedure and night, periods of an equal length have been analyzed. For the time domain, we evaluated the following measures: standard deviation of normal to normal intervals (SDNN), square root of the mean normal to normal interval (RMSSD), and percentage of adjacent pairs of normal to normal intervals differing by more than 50 ms in the recording (pNN50). In the frequency domain, the power spectra of high frequency (HF; 0.15–0.4 Hz), very low frequency (VLF; <0.04 Hz), and low frequency (LF; 0.04–0.15 Hz) were examined. Furthermore, the Total power (TP), that is, the sum of all frequency components, was included in the HRV analysis.

Intraoperative stress assessment

The well validated short form of State Trait Anxiety Inventory (STAI) for adults (Marteau and Bekker 1992) was implemented in the developed software to assess aspects of stress experience in the OR. Surgeons evaluated their well-being on a 1–4 Likert scale (1, not at all…4, very much). The mean sum score on STAI state could range between 6 (minimum) and 24 (maximum) with higher values indicating higher levels of stress. All scales were answered immediately before (preceding lustration and disinfection, that is, when the patient has been prepared for surgery) and after the operative procedure. According to the ISAT (Arora et al. 2010b), intraoperative stress was indicated if the score measured postoperatively exceeded the preoperative value. Based on this approach, subjects could be divided into a stressed (Δ STAI >0) and a non-stressed sample (Δ STAI <0).

Statistical analysis

Data were analyzed with the statistical software SPSS Version 15.0 (SPSS, Inc., Chicago, IL, USA) and tested for normality using the Kolmogorov–Smirnov test. Results are expressed as percent, median, and total range. Group differences were analyzed with the non-parametric Mann–Whitney *U* Test. Differences between the two measurements surgery and night were assessed by the Wilcoxon signed-ranks test. In analysis of covariance, possible confounding factors were entered as covariates. Accordingly, HR and HRV measures were adjusted for age and length of surgeries. All statistical tests were two-tailed with the alpha level set at 0.05.

Results

The median age of the surgeons was 39.0 years, the body mass index (calculated as weight in kilograms divided by height in meters squared) was 24.6, and the participants were of good physical fitness, that is, physicians reported a weekly vigorous activity of 120 min. The participants had 10.0 years of practice and worked 57.5 h per week (Table 1). No participant received any medication or had cardiovascular diseases.

Complete physiologic recordings of good data quality existed for all 20 participants. However, one surgeon did not answer the STAI postoperatively. Since subjects were divided into two stress groups on the basis of their STAI

Table 1 Characteristics of the study sample ($n = 20$)

Characteristics	Median (range) or percent (n)
Age (years): median (range)	39.0 (27.0–55.0)
Height (m): median (range)	1.8 (1.6–1.9)
Weight (kg): median (range)	83.5 (53.0–112.0)
Body mass index (kg/m^2): median (range)	24.6 (21.2–32.7)
Physical activity rating[a]: median (range)	6.0 (3.0–9.0)
Position % (n)	
Residents	30.0 (6)
Fellows	25.0 (5)
Attending	25.0 (5)
Chiefs of medicine	20.0 (4)
Years of experience (year): median (range)	10.0 (1.5–28.0)
Working hours per week (h): median (range)	57.5 (50.0–75.0)

[a] Physical activity rating: evaluated on a scale from 0 (no activity) to 10 (vigorous activity more than 8 h per week)

scores, these intraoperative data could not be considered for group analysis. Descriptive statistics for the two groups are shown in Table 2. Seven physicians felt intraoperatively stressed (mean STAI increase of 2.4 from pre- to postoperative rating), whereas twelve did not experience stress in the OR (mean STAI decrease of 2.8 from pre- to postoperative rating).

The demographic and anthropometric data were similar in both groups. No statistically significant differences in height, weight, body mass index, weekly physical activity, or position were found, and the physicians also reported comparable working hours per week. Even though no significant difference in age was found, this variable was considered as a potential source of confounding in later analysis (Table 3).

The operative procedures of the two stress groups did not differ with regard to complexity and complication rate. However, length of procedures tended to be higher in stressed surgeons. Therefore, it was adjusted for in the statistical analyses.

Heart rate and heart rate variability

Table 4 summarizes the results of the frequency domain analysis by non-parametric method, based on Fast Fourier Transformation (FFT), and the time domain analysis. Irrespective of statistical significance, age and length of surgeries were entered as covariates in the analysis of variance, where STAI level was the independent factor and HR and HRV measures were the dependent measures.

There were main effects of group for intraoperative HR as well as nighttime HRV measures. Intraoperative HR differed significantly between stressed and non-stressed surgeons. Furthermore, intraoperative median R–R interval was significantly shorter for stressed compared to non-stressed surgeons, and VLF power tended to be lower in stressed participants. No differences were found for LF and HF power during surgery. Even though time domain measures were lower for the stressed surgeons, implying decreased relaxation, they did not reach the level of statistical significance. Since results remained the same after exclusion of data of the sole female surgeon, these data were included in the final analysis.

At night, differences in both frequency and time domain measures of HRV were found. While HR at night did not differ between the two groups, from Table 4, it can be seen that LF power, VLF power, and Total power of non-stressed surgeons were significantly higher than those of stressed surgeons, that is, at night, a considerably reduced overall HRV was found for intraoperatively stressed surgeons. As a time domain measure, baseline SDNN values also tended to differ between the two groups.

The Wilcoxon signed-ranks test was conducted to compare relative changes in HR and HRV values for the two measurements surgery and night in both stress

Table 2 Descriptive statistics of surgeons with intraoperative stress ($n = 7$) and without intraoperative stress ($n = 12$)

Characteristics	Non-stressed physicians	Stressed physicians	P value
Age (year): median (range)	34.5 (27.0–43.0)	39.0 (33.0–55.0)	0.14
Height (m): median (range)	1.8 (1.6–1.9)	1.8 (1.8–1.9)	1.00
Weight (kg): median (range)	78.5 (53.0–102.0)	87.0 (76.0–101.0)	0.26
Body mass index (kg/m^2): median (range)	24.3 (21.2–27.1)	24.7 (24.0–26.3)	0.23
Physical activity rating[a]: median (range)	6.0 (4.0–8.0)	7.0 (3.0–9.0)	0.90
Position: median (range)	3.0 (2.0–5.0)	3.5 (2.0–5.0)	0.34
Residents % (n)	41.5 (5)	14.3 (1)	
Fellows % (n)	16.7 (2)	28.6 (2)	
Attending % (n)	25.0 (3)	28.6 (2)	
Chiefs of medicine % (n)	16.7 (2)	28.6 (2)	
Years of experience (year): median (range)	7.0 (1.5–15.5)	11.5 (6.0–28.0)	0.15
Working hours per week (h): median (range)	56.3 (50.0–70.0)	58.0 (52.0–70.0)	0.89

Results based on non-parametric Mann–Whitney U test

[a] Physical activity rating: evaluated on a scale from 0 (no activity) to 10 (vigorous activity more than 8 h per week)

Table 3 Characteristics of surgeries for non-stressed ($n = 12$) and stressed physicians ($n = 7$)

Characteristics	Non-stressed physicians	Stressed physicians	P value
Length of surgeries (h): median (range)	1.0 (0.5–1.6)	1.7 (0.4–2.2)	0.10
Complexity of surgeries[a]: median (range)	2.0 (1.0–3.0)	2.5 (1.0–5.0)	0.90
Complication rate[b] (%): median (range)	5.0 (0.0–50.0)	10.0 (0.0–50.0)	0.84

Results based on non-parametric Mann–Whitney U test

[a] Rated on a Likert scale from 1 (joint aspiration, appendix surgery) to 5 (open craniotomy, heart surgeries)

[b] Visual analog scale scores could range from 0 (no complication) to 100 (highest complication rate)

Table 4 Nighttime and intraoperative HR and HRV measures for non-stressed ($n = 12$) and stressed physicians ($n = 7$), adjusted for age and length of surgeries

Characteristics	Intraoperatively non-stressed physicians	Intraoperatively stressed physicians	P value
Nighttime HR and HRV	($n = 12$)	($n = 7$)	
HR (bpm): median (range)	60.2 (38.7–73.5)	63.7 (46.7–83.9)	0.46
R–R intervals (ms): median (range)	1,006.8 (820.1–1,560.4)	944.6 (720.4–1,286.2)	0.46
HF (ms^2): median (range)	1,335.0 (116.0–3,257.0)	606.0 (223.0–1,188.0)	0.09
LF (ms^2): median (range)	3,096.5 (160.0–8,917.0)	643.0 (285.0–1,599.0)	<0.05
VLF (ms^2): median (range)	238.0 (26.0–913.0)	56.0 (24.0–252.0)	<0.05
Total (ms^2): median (range)	4,464.5 (419.0–10,236.0)	1,386.0 (1,090.0–2,127.0)	<0.05
SDNN (ms): median (range)	59.4 (21.5–99.8)	41.6 (38.3–45.7)	0.08
RMSSD (ms): median (range)	71.3 (20.3–124.7)	45.4 (32.9–63.3)	0.18
pNN50 (%): median (range)	45.2 (1.2–68.4)	26.6 (12.9–47.8)	0.47
Intraoperative HR and HRV	($n = 12$)	($n = 7$)	
HR (bpm): median (range)	79.0 (68.3–110.9)	99.3 (82.0–145.8)	<0.05
R–R intervals (ms): median (range)	768.1 (542.4–882.5)	609.4 (411.9–733.9)	<0.05
HF (ms^2): median (range)	172.0 (24.0–558.0)	101.0 (4.0–285.0)	0.48
LF (ms^2): median (range)	1,203.5 (316.0–6,712.0)	480.0 (27.0–2,012.0)	0.23
VLF (ms^2): median (range)	114.5 (31.0–770.0)	17.0 (1.0–167.0)	0.06
Total (ms^2): median (range)	1,578.5 (419.0–8,006.0)	591.0 (37.0–2,424.0)	0.20
SDNN (ms): median (range)	39.3 (19.9–76.2)	27.5 (7.6–53.6)	0.31
RMSSD (ms): median (range)	25.4 (10.0–42.6)	20.1 (4.7–35.3)	0.43
pNN50 (%): median (range)	4.9 (0.0–18.8)	2.9 (0.0–14.8)	0.63

Results based on analysis of covariance with age and length of surgeries as possible confounding factors

groups (Table 5). The analysis revealed significant differences between HR at night and HR in the OR for both the intraoperatively non-stressed and stressed surgeons. Further, RR-intervals, HF power, RMSSD, and pNN50 were significantly different between the two measurements in both groups. Non-stressed participants also showed significant differences in relative changes of total power and SDNN, whereas stressed physicians did not. Likewise, the analysis revealed a considerable difference in the LF behavior of non-stressed and stressed surgeons. Whereas LF power tended to differ between surgeries and night in non-stressed physicians ($P = 0.12$), it remained fairly stable in stressed participants ($P = 1.00$).

In the tachogram, the HR behavior of a surgeon conducting three consecutive surgeries during psychophysiological monitoring is depicted exemplarily. In the figure, mean HR, length of surgery, complexity, and complication rate are illustrated (Fig. 1).

Discussion

In the present study, the association of perceived stress at work and cardiac autonomic control in surgeons, as a particularly burdened work group, was investigated. Regarding the outcome variables, the two groups, divided according to their perceived stress levels, showed significant differences in intraoperative HR and nighttime HRV.

Nighttime HR

Our analysis revealed that nighttime HR did not differ significantly between stress groups. Nighttime HR and

HRV have prognostic value in diseased as well as in apparently healthy individuals, and especially elevated resting heart rate is a confirmed independent risk factor (Bigger et al. 1992; Binici et al. 2011; Cooney et al. 2010; Gillman et al. 1993). In an ambulatory monitoring study performed over 24 h, it was shown that nighttime HR predicted total, cardiovascular, and non-cardiovascular mortality, whereas daytime HR did not predict any of these outcomes (Hansen et al. 2008). In the international study with more than 6,900 participants randomly recruited, the authors demonstrated that even a nighttime HR increase from 63 to 78 beats per minute (bpm) raised cardiovascular events by 24 % (133–166 events). Although median nighttime HR in our study sample was within the cited normal range of resting HR (60–80 bpm) in healthy individuals (Cook et al. 2006; Snyder et al. 1964), according to the findings of Hansen et al., some of the participants can be considered at a significantly higher risk.

HR reactivity

Relative HR changes between surgery and nighttime showed significant differences between intraoperatively stressed and non-stressed physicians. In stressed physicians HR increased by 63.6 %, whereas in the non-stressed group HR raised by only 34.6 %. While the median absolute HR increase of stressed surgeons (+35.6 bpm compared to nighttime values) was in the range of a 35 bpm HR increase which is considered to be just acceptable during long-term occupational load (Grandjean 1991), the median intraoperative HR increase of the non-stressed group was considerably below this cutoff (+18.8 bpm compared to the group-related nighttime values).

Nighttime HRV

In contrast to nighttime HR, nighttime HRV indices were significantly different between stress groups. Beyond the prognostic value of HRV after myocardial infarction and other diseases, reduced HRV has proven its association with mortality risk in apparently healthy individuals (Araujo et al. 2006; Bigger et al. 1992; Brunner et al. 2002; Camm and Fei 1995; Dietrich et al. 2006; Gianaros et al. 2005; Hayano et al. 1990; Vanoli et al. 1995). Moreover, HRV analysis has gained much importance in the past years by elucidating the possible link between stress and autonomic nervous system activity. It was shown that stressors, worries, and traits were related to higher HR and lower HRV during wakening and that the effects of stressors and worries were extended into the night recovery (Brosschot et al. 2007). These findings are in accordance with our results that revealed that stressed surgeons exhibit lower HRV power spectra during the preceding night. Since no reference values for nighttime HRV of healthy individuals exist and studies are mostly based on quartiles and not absolute values (Binici et al. 2011), it is difficult to make a general statement for our sample. However, the reduced HRV in the stressed participants might be seen as a significant indicator of a reduced autonomic adaptability during recovery.

HRV reactivity

The mode of heart rate modulation in response to occupational stress differed as revealed by HRV analysis. While the non-stressed surgeons showed greater adaptability (Total power doubled from surgery to recovery), HRV of stressed surgeons remained fairly stable, indicating a worse recovery after stressful events. Compared to the non-stressed surgeons, the stress group showed no intraoperative decrease of LF power. The lack of significant total power reduction in the

Table 5 Relative HR and HRV changes between night and operative procedure for non-stressed ($n = 12$) and stressed physicians ($n = 7$)

Characteristics	Non-stressed participants		Stressed participants	
	Relative change (%) median (range)	P value	Relative change (%) median (range)	P value
HR (bpm)	34.6 (17.5–105.3)	<0.01	63.6 (18.5–212.0)	<0.05
R–R intervals (ms)	−25.8 (−50.8 to −14.7)	<0.01	−39.0 (−68.0 to −15.4)	<0.05
HF power (ms^2)	−77.5 (−97.6 to −1.7)	<0.01	−68.2 (−99.5–3.3)	<0.05
LF power (ms^2)	−16.3 (−94.4–508.1)	0.12	−54.2 (−94.3–169.7)	1.00
VLF power (ms^2)	−31.3 (−95.6–353.9)	0.64	−46.2 (−99.6–302.9)	0.18
Total power (ms^2)	−54.2 (−95.1–214.8)	<0.01	−55.9 (−97.1–72.9)	0.18
SDNN (ms)	−26.1 (−77.6–48.4)	<0.01	−33.9 (−81.6–20.5)	0.13
RMSSD (ms)	−57.2 (−76.4–17.9)	<0.01	−52.4 (−91.8 to −6.1)	<0.05
pNN50 (%)	−82.6 (−100.0–416.7)	<0.01	−82.9 (−100.0 to −13.5)	<0.05

Results based on Wilcoxon signed-ranks test

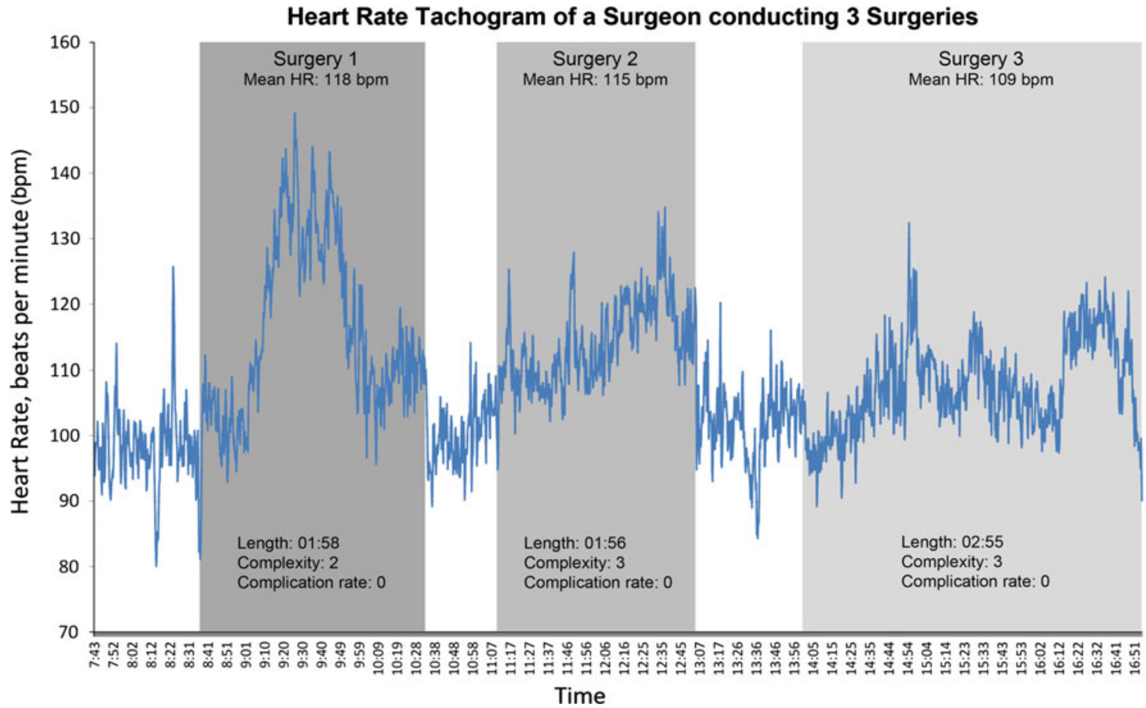

Fig. 1 HR tachogram of a surgeon conducting three consecutive surgeries

stressed sample might be due to these marginal fluctuations in the LF power. Although not exclusively, fluctuations in this band are strongly modulated by the vagus as they reflect baroreflex transferred blood pressure fluctuations. These blood pressure fluctuations are not only caused by respiration but also by changes of regional vasomotor tone, modulated by sympathetic efferent's to the vessels. Thus, baroreflex mediated fluctuations in the LF power of heart rate are at least partly indirectly influenced by sympathetic activity (Bernardi et al. 1997; Grasso et al. 1997). The persisting LF power during surgery might be due to an elevated sympathetic activation, which corresponds to the stressed surgeons' higher heart rate. In comparison, the intraoperative heart rate of the non-stressed surgeons is predominantly achieved by a reduction of vagal activity and lies within the range of the intrinsic heart rate (Jose and Collins 1970). Our results are in line with psychophysiological research linking, for example, aerobic fitness or resting blood pressure levels with different autonomic responses and implicating that the sympathetic and not the vagally mediated response to stress differs between different risk groups (Balanos et al. 2010; Boutcher et al. 1998; Cacioppo et al. 1995; Spalding et al. 2000).

Possible confounders on HR and HRV

An advantage of the study was that measurements were performed during authentic work and recovery periods without external control of the investigator, that is, surgeons could move freely and did not feel disturbed by the system, as identified after the monitoring. This evaluation was in line with the results of a previous study where the feasibility and practicability of the developed monitoring system was analyzed (Rieger et al. 2012). Nevertheless, real-world studies are subject to multiple confounders which have to be considered in the investigation and discussed in detail.

Physical fitness of the surgeons, as a potential confounder, was not only comparable but also at a high level in both groups. Thus, higher intraoperative HR of stressed surgeons cannot be due to poor fitness, which has been shown to be associated with increased cardiovascular and coronary mortality rates (Kannel et al. 1985).

Likewise, both groups worked under almost similar working conditions in the OR, that is, complexities and complication rates of operative procedures did not differ significantly. The length of surgery, entered as covariate in the statistical analysis, was not associated with the physiological workload measures in our sample.

Other possible confounders to be discussed are the intraoperative posture and musculoskeletal strain. Studies on cardiovascular response to isometric exercise support the conclusion that HR increases during surgery, especially within the stressed, but also in the non-stressed group, can hardly be result of orthostatic and metabolic variances alone, but can rather be due to the combination of muscular and mental strain (Fontana et al. 1993; Iellamo et al. 1997; Lind 1970; Mathiassen 1993; Smolander et al. 1998). Some authors found HR increases of about 20 bpm in response to continuous isometric shoulder–neck exercise at an intensity of 15–20 % maximal voluntary contraction force (MVC; Mathiassen 1993). The median times to exhaustion were only 13 min for continuous exercise and 23 min for the intermittent (5 min exercise followed by 1 min rest) exercise. Even if the subjects in the Mathiassen study were not trained, as they took sedentary occupations, it can be concluded that HR increases due to isometric shoulder–neck exercise at 15–20 % MVC cannot be sustained—even if intermittent—much more than half an hour. Given isometric "exercise" intensity below 15–20 % MVC in our study group, HR increases above an average of 20 bpm are most likely due to other non-metabolic factors. Thus, the elevated HR in the stress group seems to reflect psychomental stress, expressed in STAI ratings.

There remain some potential biases that have to be mentioned. Studies have shown that HRV measures of healthy subjects decline with aging (Acharya et al. 2004; Agelink et al. 2001; Stein et al. 2009; Umetani et al. 1998). In our study group, age differed not significantly between the groups but showed a tendency in so far as the stressed surgeons were older. After adjustment, results revealed that HRV differences between the two groups cannot be attributed to age. Furthermore, literature has shown significant, but low correlation coefficients between age and HRV measures. Kuo et al. have demonstrated that even thought absolute values of HRV decreased with age, no significant change in relative measurements, especially in men, was found until 60 years of age (Kuo et al. 1999).

Moreover, in general, young physicians are thought to experience more stress than veteran surgeons who are used to different working conditions and follow their daily routine (Böhm et al. 2001; Wong 2008). In our study, this finding could not be confirmed. We suppose that older and more experienced physicians are confronted with many other work stressors such as higher intraoperative responsibility (teach and do the job at the same time), more time pressure as a result of greater throughput and productivity pressures, or diverse administrative duties that might also have an influence on stress experience in the OR. Another serious problem is the often registered lack of staff that leads to vast overtime, excessively long shifts and managerial problems, especially in the operating room.

Conclusion and perspectives

Based on our findings, it can be concluded that higher intraoperative HR in the stressed sample was not a result of confounders like age and different intraoperative work requirements, but rather due to individual coping with occupational conditions, for example, pressure of time and to perform, psychosocial stressors, or lack of recovery. Furthermore, on average, occupational stressed surgeons do not exhibit elevated nighttime HR, but significantly reduced HRV, which can be an indicator of poor recovery.

It can be summarized that HR and HRV provide useful measures in the study of physiological effects during and after acute occupational stress. The results support the idea that there is a link between occupational stress and HRV and that consequently, research into autonomic nervous system activity should be focused on to protect cardiovascular health.

Conflict of interest The authors declare that there is no conflict of interest in the present study.

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