Increase in Operator's Sympathetic Nerve Activity during Complicated Hepatobiliary Surgery: Evidence for Surgeons' Mental Stress

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Surgeons often experience stress during operations. The heart rate variability (HRV) is the variability in the beat-to-beat interval, which has been used as parameters of stress. The purpose of this study was to evaluate mental stress of surgeons before, during and after operations, especially during pancreaticoduodenectomy (PD) and living donor liver transplantation (LDLT). Additionally, the parameters were compared in various procedures during the operations. By frequency domain method using electrocardiograph, we measured the high frequency (HF) component, representing the parasympathetic activity, and the low frequency (LF)/HF ratio, representing the sympathetic activity. In all 5 cases of PD, the surgeon showed significantly lower HF component and higher LF/HF during operation, indicating predominance of sympathetic nervous system and increased stress, than those before the operation ($p < 0.01$) and these did not return to the baseline level one hour after the operation. Out of the 4 LDLT cases, the value of HF was decreased in two and the LF/HF increased in three cases ($p < 0.01$) during the operation compared to those before the operation. In all cases, the value of HF was decreased and/or the LF/HF increased significantly during the reconstruction of the vessels or bile ducts than during the removal of the liver. Thus, sympathetic nerve activity increased during hepatobiliary surgery compared with the level before the operation, and various procedures during the operations induced diverse changes in the autonomic nervous activities. The HRV analysis could assess the chronological changes of mental stress by measuring the autonomic nervous balances.

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Introduction

Surgeons often experience stress for long periods of time when performing operations. Stress has a direct impact on performance (Wetzel et al. 2011) and decision-making (Flin et al. 2008); namely, an appropriate amount of stress may improve performance, but an excess amount of stress leads to poor performance and decision-making. Thus, we wanted to evaluate mental stress objectively in various situations. The heart rate is regulated by balance between the sympathetic and parasympathetic nervous systems (Shaffer et al. 2014). The heart rate variability (HRV) is the beat-to-beat fluctuation of the R-to-R interval between adjacent heartbeats on an electrocardiogram, which is controlled by the sympathetic and parasympathetic nervous systems. The sympathetic and parasympathetic nervous activities can be evaluated by analyzing the HRV. The HRV is commonly analyzed using frequency domain methods, which convert such beat-to-beat variations to specific band frequencies (Prichard et al. 2012). The frequency domain components are obtained from two main components, i.e., the high frequency (HF; with a frequency ranging from 0.15 to 0.4 Hz) component, which is indicative of parasympathetic activity, and the low frequency (LF; with a frequency

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ranging from 0.04 to 0.15 Hz) component of sympathetic and parasympathetic origins. The LF to HF ratio (LF/HF) indicates the sympathetic nerve activity. Thus, the HRV has been reported to be useful for evaluating mental stress as well as the cardiovascular status, for instance, to assess pilots' stress levels during flight (Roscoe 1992). Recently, there have been reports regarding HRV analyses during surgical operations (Song et al. 2009; Prichard et al. 2012). In low anterior resection of the rectum, experienced surgeons showed a significant increase in the sympathetic tone, which represented the increased stress, and moreover, significant correlation was demonstrated between the HRV measurements and perceived amount of stress (Jones et al. 2015).

To the best of our knowledge, there have been no reports on HRV analysis of operators during hepatobiliary surgeries. Therefore, the aim of this study was to evaluate the mental workload of surgeons before, during, and after pancreaticoduodenectomy (PD) and during various procedures of living donor liver transplantation (LDLT), both of which include various complex operations that generally take a long time to complete.

Materials and Methods

Study participants

Two male surgeons (T.K. and S.E.), who each had more than 20 years of experience and experienced more than 150 cases of PD or LDLT as operators, participated in this study. At the time of study, neither of the surgeons was taking any medications that would affect the heart rate, nor did they have any cardiac disease including arrhythmias.

Ethical approval was obtained from the ethical committee of Nagasaki University and informed consent was obtained from the participants.

Collection of the data and the heart rate variability analysis by frequency domain methods

We used a small monitoring device to collect the data, weighing 10 g, which included tri-axial accelerometer, thermometer, electrocardiograph (ECG), central processing unit, memory integrated circuit and lithium cell battery (Orita et al. 2012). The two surgeons wore the device from one hour before operation to one hour after operation (Fig. 1). The device monitored data every minute. After monitoring, we transferred the data to a computer with a dedicated software program to analyze the data. By using the frequency domain method with ECG, we analyzed the HF component (milliseconds squared (ms^2)), which represents the parasympathetic activity, and the LF/HF frequency ratio, which represents the sympathetic activity between the sympathetic and parasympathetic activities.

Statistical analysis

Results are expressed as the median (25th to 75th quartiles). In the HRV components, such as the HF and LF/HF values, which were recorded at every minute, a one-way analysis of variance (ANOVA) was performed to compare the values among the three phases (i.e., "before", "during", and "after" surgery). For p values < 0.05, the Tukey-Kramer test was applied for multiple comparisons. The statistical analyses were performed using the StatMate III software program for Macintosh (ATMS Co., Ltd., Tokyo, Japan).

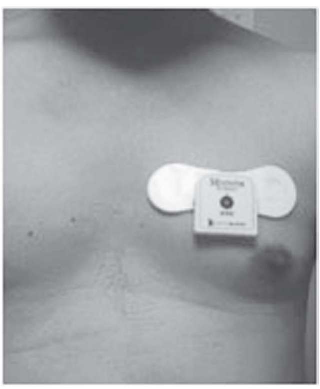

Fig. 1. A small monitoring device for the collection of data.

Results

Fluctuation in the heart rate variability before, during, and after surgery

In this study, surgeon T.K. carried out PD for patients with biliary or pancreatic neoplasms (Table 1). Fig. 2 shows the changes in the parasympathetic nervous system activity in the representative example. Each dot indicates the value of the HF at every minute. The value of the HF was suppressed during operation, compared with that before operation, and increased mildly after operation. There were significant differences in the value of the HF before and during operation, indicating that the parasympathetic activity was suppressed during operation. The value of the HF

Table 1. Operations of surgeon T.K.

Patients	Diseases	Operative methods	Duration of operation (minutes)	Blood loss (gram)
1	IPMC	lap-assist PpPD	453	360
2	BDC	lap-assist PpPD	507	1,000
3	BDC	PD	350	750
4	BDC	PD	351	810
5	IPMC	PpPD	270	450

IPMC, intraductal papillary-mucinous carcinoma of pancreas; BDC, bile duct carcinoma; lap-assist, laparoscopic-assisted; PpPD, pylorus preserving pancreaticoduodenectomy; PD, pancreaticoduodenectomy.

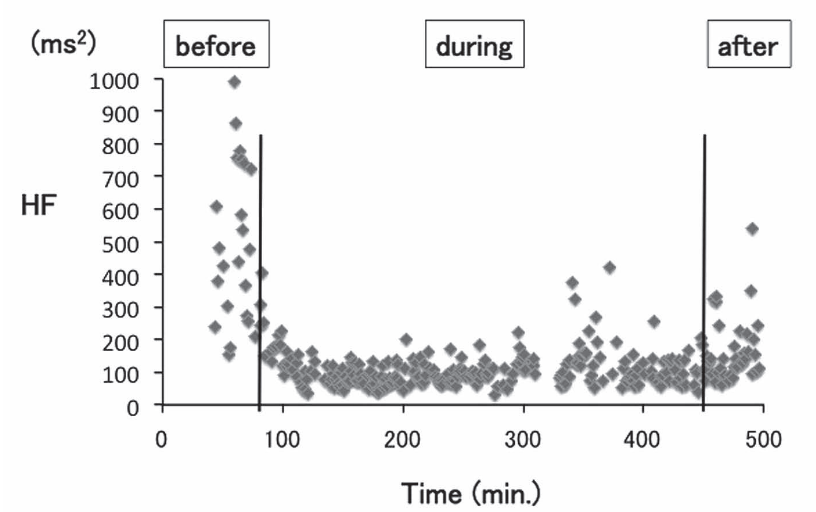

Fig. 2. Fluctuation in the HF before, during, and after pancreaticoduodenectomy.
Each dot represents the HF value at every minute, with higher value indicating parasympathetic nervous being activated more.

Table 2. Heart rate variability of surgeon T.K.

	Patients	Operation		
		Before	during	after
HF	1	639.0 (431.0-854.2)	239.5 (161.8-329.4)*	312.6 (234.2-427.1)*
	2	362.6 (344.1-483.3)	151.8 (103.4-211.9)*	64.6 (37.6-108.4)*,†
	3	479.5 (301.6-750.8)	96.9 (74.2-131.4)*	130.5 (94.2-165.9)*
	4	353.3 (184.7-506.2)	181.4 (140.7-248.5)*	148.9 (101.4-219.5)*,†
	5	497.2 (347.7-766.4)	186.4 (136.0-244.5)*	175.5 (97.5-311.0)*
LF/HF	1	1.1 (0.7-2.0)	6.0 (3.9-9.1)*	3.4 (2.0-6.4)*,†
	2	3.5 (1.5-4.5)	10.6 (7.9-15.2)*	9.0 (6.3-13.9)*
	3	2.7 (1.8-3.3)	9.8 (6.0-14.4)*	8.0 (5.1-13.6)*
	4	3.0 (2.1-4.3)	8.0 (5.5-11.4)*	7.9 (4.7-12.9)*
	5	2.9 (1.9-4.1)	9.1 (5.7-13.0)*	4.5 (2.5-7.5)†

Values median (25th to 75th).
*$p < 0.01$ vs. before operation, †$p < 0.01$ vs. during operation.

did not return to the level before operation for at least one hour after operation. Table 2 shows all 5 datasets for surgeon T.K. Changes in the sympathetic activity was inversed to that of the parasympathetic nervous system, namely, it increased significantly during operation and decreased mildly after operation. The data indicated that in all operations, the sympathetic nervous system was dominant during operation compared to before operation, suggesting an increase in mental stress. Moreover, the autonomic nervous activity did not return to the baseline level and maintained a dominant sympathetic nervous activity for at least one hour after operation.

Fluctuation in the heart rate variability during various procedures of LDLT

Table 3 shows the operative data for surgeon S.E. LDLT is associated with risks of bleeding due to liver failure or portal hypertension, and consists of various fatal procedures, i.e., removal of the whole liver, reconstruction of the hepatic veins and portal veins, reperfusion of the implanted liver, reconstruction of the hepatic artery and reconstruction of the bile duct. Fig. 3 shows the fluctuation in the parasympathetic nervous system activity during various procedures of LDLT. The value of the HF appeared to be decreased during the removal of the whole liver. In subsequent reconstruction of the veins, it appeared to drop further and increase after the start of reperfusion of the liver. It dropped again in reconstruction of the bile duct and increased after operation. When comparing the value of the HF among various procedures during operation, the HF during reconstruction of the bile duct was significantly lower than that in the removal of the liver and reperfusion of the liver. Table 4 shows all 4 datasets of surgeon S.E. during three critical procedures of liver transplantation.

Table 3. Operations of surgeon S.E.

Patients	Diseases	Operative methods	Duration of operation (minutes)	Blood loss (gram)
1	LDLT donor/B-LC	LDLT donor→LDLT recipient	674	3,700
2	alcoholic LC	LDLT recipient (emergency)	577	4,150
3	C-LC, HCC	LDLT recipient	802	4,200
4	B-LC	LDLT recipient	597	4,700

LDLT, living donor liver transplantation; B-, hepatitis B virus-related; LC, liver cirrhosis; C-, hepatitis C virus-related; HCC, hepatocellular carcinoma.

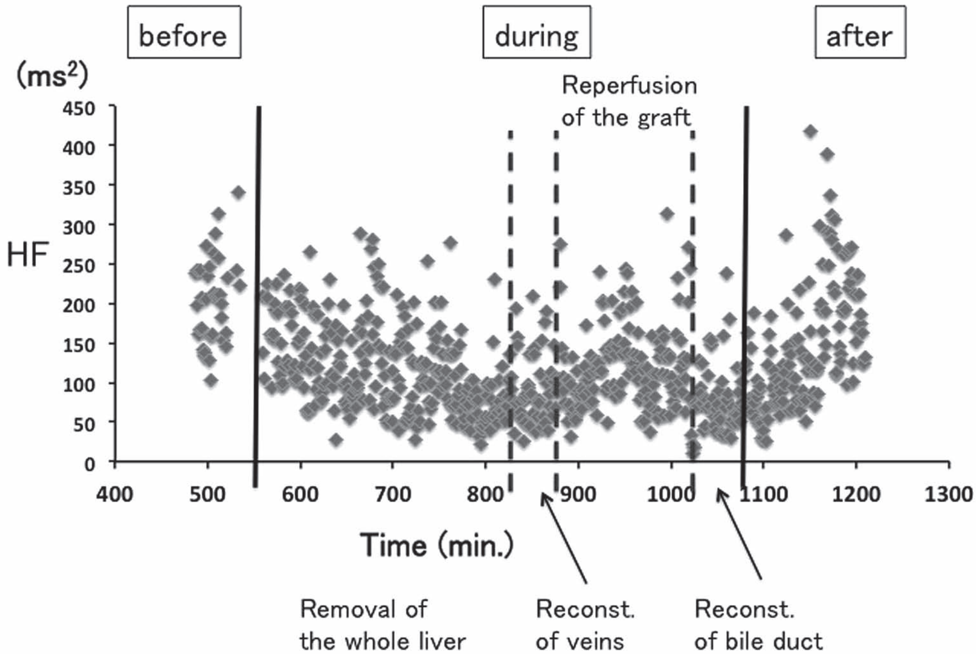

Fig. 3. Fluctuation in the HF during various procedures of living donor liver transplantation. Each dot represents the HF value at every minute, with higher value indicating parasympathetic nervous being activated more.

Table 4. Heart rate variability of surgeon S.E.

	Patients	Operation		
		Removal of liver	Reconstruction of hepatic and portal veins	Reconstruction of bile duct
HF	1	222.3 (169.5-298.7)	133.4 (105.2-171.2)**	58.6 (39.4-84.0)**,††
	2	179.8 (107.9-283.9)	101.1 (79.4-166.6)**	279.3 (192.8-348.5)††
	3	84.7 (62.1-125.1)	57.3 (40.2-78.8)*	86.5 (54.2-121.5)
	4	104.3 (76.2-154.0)	84.6 (57.3-110.4)	72.0 (54.3-103.4)**
LF/HF	1	3.7 (2.3-5.6)	3.8 (2.5-7.0)	7 (4.4-10.8)**,††
	2	5 (3.2-8.8)	3.7 (2.9-5.5)*	4.5 (2.7-5.7)
	3	9.5 (6.9-13.6)	9.5 (5.9-14.5)	11.1 (7.3-15.9)
	4	10.1 (7.1-14.2)	10.6 (7.5-15.9)	7.1 (4.8-10.4)**,†

Values are median (25th to 75th).
*$p < 0.05$ vs. removal of liver, **$p < 0.01$ vs. removal of liver, †$p < 0.05$ vs. reconst. of veins, ††$p < 0.01$ vs. reconst. of veins.

The fluctuation in the value of the HF was relatively consistent. Namely, compared to the value of the HF in the removal of the liver, it decreased significantly during reconstruction of the veins in 3 out of 4 operations and in reconstruction of the bile duct in 2 out of 4 operations. On the other hand, the fluctuation in the LF/HF was variable. Compared with the LF/HF during the removal of the liver, the LF/HF decreased in reconstruction of the veins only in 1 operation, and increased and decreased in 1 operation, respectively, in reconstruction of the bile duct.

Discussion

Our results showed a fluctuation in the autonomic nervous activity, in which the sympathetic activity was dominant during operation, i.e., PD, compared with before operation, as reported previously in other kinds of surgery (Bohm et al. 2001; Song et al. 2009; Prichard et al. 2012). Furthermore, in the same surgeon, the autonomic nervous status did not return to the baseline level for quite a while after surgery. A HRV analysis in a previous study showed that stressed surgeons during operation, in whom the magnitude of stress was measured using the State Trait Anxiety Inventory (STAI), demonstrated less relaxation during sleep compared with non-stressed surgeons (Rieger et al. 2014). Out of the surgical setting, stressors were related to a higher heart rate and lower HRV during waking as well as the sleeping period (Brosschot et al. 2007). Excessive stress was reported to have negative impacts on not only decision-making (Flin et al. 2008), surgical performance (Wetzel et al. 2011), and patient safety (Horner et al. 2012), but also the physicians' health (Buddeberg-Fischer et al. 2008).

Various procedures during LDLT induced diverse autonomic nervous changes in the surgeon. Patients with liver failure have the tendency of being bled and surgeons are under extreme mental stress during the removal of the liver. In subsequent reconstruction of the hepatic and portal veins, the sympathetic nervous system appeared to be the predominant feature. Quick as well as precise technique is required to reconstruct the veins because a too long ischemic situation or faulty anastomoses can result in graft failure. After reperfusion of the liver, the value of the HF was obviously increased, that is, the sympathetic nervous activity subsided and this may be compatible with subjective relief from mental strain. A previous study demonstrated a significant correlation between the HRV measurement and perceived stress, evaluated using the STAI, in various steps during colorectal surgery (Jones et al. 2015). In our study, the changes in the HF or the LF/HF were not always consistent among the cases of LDLT, possibly due to various situations regarding the surgeon himself or assistants or patients' condition such as constitution or stage of disease progression, and possibly the environment regarding operation. The limitation of our study is that only one surgeon in each operation was enrolled. Further investigation of such inconsistencies could help to elucidate the optimal conditions for surgeons to perform such difficult operations.

Although the HRV measurement has been reported to be an objective method for evaluating mental strains, there are some potential flaws associated with this method. HRV changes as well as perceived stress varies according to individuals even in the same situation, such as surgical operation (Brosschot et al. 2007). Furthermore, there are no cut-off values, and appropriate stress evaluated by the HRV that would give positive or negative effects on surgeon should vary according to the individual. Thus, it appears to be essential to compare the HRV and perceived stress in each individual before applying this method as a tool for stress-measurement.

According to our observation, the HF and the LF/HF did not always change reciprocally. While it is generally accepted that the vagal activity mainly contributes to the HF component, controversy exists regarding the LF (Malik 1996). Furthermore, both the sympathetic and parasympathetic nervous systems can be simultaneously active (Berntson and Cacioppo 1999), especially psychological stress may induce independent changes in the sympathetic and parasympathetic activity (Shaffer et al. 2014).

In this study, we focused on assessing experienced surgeons. The HRV may widely differ in trainees or with the accumulation of experience. We speculate that a surgeon-in-training would show sympathetic nervous system activity dominantly during operation compared with experienced surgeons, although each would exhibit a different autonomic nervous status, representing his/her mental strain. Moreover, excess stress might impair the acquisition of surgical technique. In future studies, we intend to elucidate the relevance of HRV and accumulated experience, in addition to the learning curve of operations.

Our study has some limitations. We analyzed the HRV in only two surgeons for a short period of time (i.e., one hour) after operation. Further studies are necessary with an increased number of surgeons and longer duration of follow-up to elucidate the influence of stress during surgery on the autonomic nervous system.

In summary, in experienced surgeons, while the sympathetic nerve activity increased during hepatobiliary surgery compared with the level before the operation, the autonomic nervous status did not return to the baseline level for quite a while after surgery. Moreover, various procedures during the operations induce diverse changes in the autonomic nervous activities. Therefore, monitoring the changes in the autonomic nervous activities could be useful as a powerful tool for the objective evaluation of the mental workload of operations for surgeons.

Conflict of Interest

The authors declare no conflict of interest.

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