A Prospective Randomized Trial on Heart Rate Variability of the Surgical Team During Laparoscopic and Conventional Sigmoid Resection

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Hypothesis: Mental strain measured by heart rate variability differs during laparoscopic and conventional sigmoid resections.

Design: Prospective randomized study.

Setting: University hospital.

Participants: Two surgeons performed 10 conventional and 10 laparoscopic sigmoid resections, alternating roles as primary surgeon and assistant. The kind of technique was randomly chosen each time.

Intervention: Electrocardiograms of the surgeon and assistant were continuously recorded during the procedures and heart rate variability was analyzed off-line. The first 10 procedures (5 laparoscopic and 5 conventional) were performed by the more experienced and the next 10 by the less experienced surgeon.

Main Outcome Measures: Heart rate variability was determined by power spectral analysis as heart rate in beats per minute, high frequency (HF) and low frequency (LF) components in normalized units, and LF/HF ratio.

Results: Results are given for heart rate, HF, LF, and LF/HF ratio for the following variables: laparoscopic surgery: 87.9, 14.7, 90.1, 7.5; conventional surgery: 90.2, 17.1, 87.6, 6.4; surgeon: 94.0, 13.5, 91.4, 8.4; first assistant: 84.1, 17.8, 86.3, 5.6; more experienced surgeon: 93.1, 16.5, 87.8, 6.4; and less experienced surgeon: 85.0, 14.8, 90.0, 7.5. The LF/HF ratio was significantly higher (P<.05) for laparoscopic compared with conventional surgery and for the surgeon compared with the assistant (P<.001), but not between the less and the more experienced surgeons.

Conclusion: Performing laparoscopic colorectal surgery causes higher mental strain in surgeons than performing conventional surgery.

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Laparoscopic techniques have been proven to be beneficial to patients in terms of postoperative lung function, pain, ileus, immunosuppression, and overall convalescence. While these advantages for patients have been investigated in numerous studies, the stress on the surgical team during minimally invasive surgery has not yet been evaluated, although it is well known that advanced laparoscopic surgery is more challenging and time-consuming. Since laparoscopic colorectal surgery seems to be more exhausting than conventional colorectal surgery, we thought it would be worthwhile to determine the heart rate variability (HRV) of the surgical team during prolonged and advanced laparoscopic procedures as an indirect measure of mental strain. The autonomic nervous system is a major determinant of the functional properties of the heart in that it alters spontaneous sinus node depolarization and cardiac rhythm, which can be assessed by the rhythm of the sinus node. It has been very useful in the past to transform HRV into power spectral density to monitor a variety of pathological physical and mental states. In addition, analysis of HRV seems to reflect the sympathovagal balance during surgery, and some studies have found HRV and mental strain to be closely associated with increased sympathetic and decreased parasympathetic activity. Because mental strain has been identified as a risk factor for the development of hypertension and probably coronary heart disease, we investigated whether the surgical team experienced more signs of mental strain during laparoscopic vs conventional sigmoid resection.
PARTICIPANTS AND METHODS

The purpose of the study was to compare HRV of the surgeon and assistant during laparoscopic and conventional sigmoid resection to find out whether laparoscopic surgery is more demanding than conventional surgery. We differentiated between stress and strain. While stress comprises all factors influencing an individual, strain is defined as the physical and psychological effects of stress on an individual. Because individuals may cope differently with identical situations (for example, an experienced surgeon may be more relaxed intraoperatively than an inexperienced one when a major inadvertent bleeding occurs), we have decided to assess strain as an indicator of the individual response to stress.

Since mental strain is difficult to measure, HRV was chosen as the primary end point. Therefore the sympathetic and vagal activities regulating heart rate could be assessed using spectral analysis of HRV. We tested the null hypothesis that laparoscopic surgery does not change HRV compared with conventional surgery. The alternative 2-sided hypothesis was that laparoscopic surgery changes HRV.

MEASURING HRV

The electrocardiogram was run continuously throughout the procedure on a solid-state minimized autonomous recording device that allowed signal reconstruction without amplitude and phase distortion. All digital data were transferred to a personal computer after surgery and analyzed off-line using commercially available software modified for our study.

The electrocardiogram sampled data at a rate of 400/s. With a combined threshold and maximum detection algorithm carefully edited by visual checks and manual corrections of individual R-R intervals and QRS complex classification, an interval tachogram (ie, the series of consecutive R-R intervals) was generated for a period of 5 minutes. The length of the tachogram and the type of analysis were selected according to the recommendations of the Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology.11

The variations in heart rate were evaluated by time and frequency domain measures of this tachogram.11 The mean R-R interval, the SD of the R-R intervals, the mean heart rate, and the difference between the longest and shortest R-R intervals were calculated. In addition, the computer calculated the power spectral density using the fast Fourier transformation. The component near 0 Hz (ie, the direct current component) was not considered. Three main spectral components were distinguished: a very-low-frequency component of less than or equal to 0.04 Hz, which was not analyzed because of dubious interpretation in short-term recordings; a low-frequency (LF) component of 0.04 to 0.15 Hz; and a high-frequency (HF) component of 0.15 to 0.4 Hz (Figure 1). The power and frequency of each spectral component were calculated as absolute units (ie, milliseconds squared) and normalized units. The latter are the relative values of each power component in proportion to the total power minus the very low frequency component. These data are given to emphasize the controlled and balanced behavior of the autonomic nervous system.

It is assumed that when sympathetic activity increases, the power of LF increases; conversely, when vagal activity increases, the power of HF increases.5,10 Thus, it is also important to calculate the LF/HF ratio.5,8,9

STUDY PROTOCOL

Only 2 surgeons participated in the study to avoid interindividual variations. To reduce external influence as much as possible, the preoperative activities were standardized. The surgeons had at least 7 hours of rest the night before surgery, breakfast at 7 AM on the day of surgery, and only minor routine work to do. Neither took any kind of medication. The procedure was always performed as the first case in the morning and with mostly the same nurses. The type of procedure, laparoscopic (n = 10) or conventional sigmoid resection (n = 10), was randomly assigned by block randomization on the day before surgery.

Immediately before surgery, both surgeons were connected to a portable recording unit. The equipment was checked and baseline data obtained for a period of 5 minutes during rest and then continuously throughout the surgical procedure. When the procedure started, 2 observers documented any environmental factors that could influence the surgical team. Sigmoid resection was divided into 10 well-defined steps (Table 1) to evaluate the most demanding parts of the procedure and to allow for a proper comparison between both techniques. The beginning and the end of each phase of the procedure were carefully documented during surgery.

The first 10 procedures (5 conventional and 5 laparoscopic) were accomplished by the more experienced surgeon (B.B.) (>80 laparoscopic colectomies) with the same assistant each time (W.S.). The other 10 procedures (5 conventional and 5 laparoscopic) were then performed by the less experienced surgeon (W.S.) (20 laparoscopic colectomies) with the same assistant each time (B.B.). This study design was chosen to find out whether a more experienced surgeon copes better with the demands of laparoscopic surgery than a beginner.

STATISTICAL ANALYSIS

Heart rate variability during a 5-minute period was analyzed for each of the 10 steps to allow proper comparison between both techniques. The power spectrum analyses of all 10 steps were used to calculate the means of heart rate, HF and LF components, and LF/HF ratio, which were then entered in univariate and multivariate analyses.

Univariate differences between the 2 groups were analyzed by the Mann-Whitney U test. A multivariate repeated-measures analysis of variance was calculated to study the adjusted effects of technique, expert, and function on outcomes of interest. Technique and expert were treated as between-subjects factors. Function was seen as a within-subjects factor. Possible interactions were incorporated into the model. The outcomes of interest were defined as mean values of the log-transformed LF and HF components, the heart rate, and the LF/HF ratio during the surgical procedure. Log-transformed values were analyzed to interpret contrasts in terms of relative changes with respect to the original measurements after back transformation. Because the sphericity assumption was violated, the Greenhouse-Geisser procedure was used.
The indications for sigmoid resection were sigmoid cancer (n=13) and diverticulitis (n=7). The mean operative time for all procedures was 115 minutes (range, 95-205 minutes). Laparoscopic procedures needed much more time (Table 2) than conventional procedures (P<.01). The experienced surgeon resected the sigmoid colon in a shorter period than the inexperienced one (P<.05). Intraoperative complications did not occur. There was no conversion of a laparoscopic sigmoid resection to laparotomy. The postoperative course of all patients was uneventful.

A significant difference in HRV between laparoscopic and conventional surgery was found for the HF and LF components and LF/HF ratio (Table 3, Figures 2, 3, 4, and 5) but not for heart rate. Although the heart rate was slightly higher in conventional surgery, the difference did not reach significance. The HF component was lower, the LF component was higher, and the LF/HF ratio was much higher in laparoscopic surgery (P<.05). Multivariate analysis showed the surgical technique to be a significant independent factor influencing HRV after adjusting for the effects of the factors considered. Therefore, we rejected the null hypothesis.

The differences in strain between the functions (surgeon vs assistant) were even more pronounced. While the heart rate and the LF/HF ratio of the surgeon was much higher during advanced laparoscopic procedures, the latter may further increase the risk to surgeons.

Numerous studies have shown that the heart rate significantly increases to up to 150 beats/min during surgery16,17 or other stressful tasks.18 Payne and Rick19 as well as others20 compared the heart rates of surgeons and anesthesiologists during surgery and detected a much higher heart rate in surgeons. Although surgeons rated their stress as “severe” or “quite severe” and “lasting for hours,” it seems that experienced surgeons are well adapted to the particular stress of surgery.1

Physicians do not like to assess the risk to themselves encountered during work. Usually, they evaluate a procedure based on the advantages and disadvantages for their patients. It is rather unusual to investigate whether a surgical technique may have drawbacks for surgeons, such as being more demanding and exhausting.

It has been reported that surgeons in Sweden are at an increased risk of death from ischemic heart disease compared with general practitioners, but the risk factors are not well established. Major differences emerged with regard to psychosocial work characteristics. Surgeons had higher scores for pace of work, hectic work, inability to relax after work, and perception of work as physically demanding. Because some surgeons may have undetected ischemic heart disease, the increase in sympathetic activity during their work may have deleterious effects, ranging from worsening of ischemia to lethal arrhythmias or sudden death. Therefore, if stress is higher during advanced laparoscopic procedures, the latter may further increase the risk to surgeons.
A variety of conditions or stressors may give rise to different adaptation or perception patterns depending on previous experience and training, the ability to cope with a particular situation, and the emotional status at the time. It is not surprising that different individuals react to stress in different ways. The low level of concordance of strain, even under defined stress conditions, confirms that responses to stress are individual in nature. Thus, strain seems to be more relevant than stress.

Mental strain in the operating room is very difficult to define and to measure. It seems that measuring HRV is currently the best method of assessing mental strain and is more sensitive than measuring heart rate alone. This is in accordance with Czyzewska et al., who described HRV as the most reliable parameter in the measurement of mental load during decision-making in surgery. However, the interpretation of our results is difficult because we do not really know the detailed mecha-

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**Table 3. Results of Analysis of Variance of Heart Rate, LF and HF Components, and LF/HF Ratio After Sigmoid Resection**

<table>
<thead>
<tr>
<th></th>
<th>Heart Rate</th>
<th>HF Component</th>
<th>LF Component</th>
<th>LF/HF Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>df</td>
<td>MS</td>
<td>F</td>
<td>P</td>
</tr>
<tr>
<td><strong>Between-subjects factor</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technique</td>
<td>1</td>
<td>0.004</td>
<td>1.96</td>
<td>.18</td>
</tr>
<tr>
<td>Expert</td>
<td>1</td>
<td>0.003</td>
<td>0.18</td>
<td>.68</td>
</tr>
<tr>
<td>Technique × experience</td>
<td>1</td>
<td>0.006</td>
<td>0.30</td>
<td>.59</td>
</tr>
<tr>
<td>Residual</td>
<td>16</td>
<td>0.002</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td><strong>Within-subjects factor</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Function</td>
<td>1</td>
<td>0.107</td>
<td>66.1</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Function × technique</td>
<td>1</td>
<td>0.075</td>
<td>46.1</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Function × experience</td>
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<td>0.0002</td>
<td>0.11</td>
<td>.75</td>
</tr>
<tr>
<td>Function × experience × technique</td>
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<td>0.0015</td>
<td>0.92</td>
<td>.35</td>
</tr>
<tr>
<td>Residual</td>
<td>16</td>
<td>0.002</td>
<td>0.025</td>
<td></td>
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*HF indicates high-frequency; LF, low-frequency; and MS, mean squares.*
nisms of heart rate regulation under conditions such as performing surgery. While it is well established that vagal activity is the major contributor to the HF component,\textsuperscript{23} the interpretation of the LF component and LF/HF ratio is still controversial. The LF component reflects both sympathetic and vagal activity\textsuperscript{24} and autonomic withdrawal. A saturatingly high level of sympathetic input may therefore reduce HRV.\textsuperscript{25}

Thus, the sympathetic share cannot simply be determined by computing the relative amount of the LF component. The value of the LF component as an exact index for the balance between sympathetic and vagal HRV is unknown.\textsuperscript{9} Most investigators of HRV agree that the LF/HF ratio reflects the sympathovagal balance more reliably.\textsuperscript{7,12} Pagani et al\textsuperscript{10} and McCravy et al\textsuperscript{11} reported that mental strain especially induced marked changes in the sympathovagal balance, which moved toward sympathetic predominance.

Heart rate variability as an objective index of the sympathovagal balance is limited by the individual dynamics of intrinsic HRV, which varies with age and weight, physical activity, innervation, cigarette smoking, core temperature, and right atrial wall stretch. Only 2 surgeons were included in the study to avoid distortion resulting from these factors.

Our results indicate that advanced laparoscopic surgery like sigmoid resection is more demanding than conventional surgery and puts higher mental strain on surgeons. However, there are at least 2 counterarguments to our conclusions. The first argument is that we have no clear idea about the relevance of our findings. Although the method of measuring HRV as an indicator of mental strain in a clinical setting is still in its infancy, there is some evidence from experimental studies that a strong correlation exists between mental strain and an increase in the LF/HF ratio.\textsuperscript{4,24} There is currently no clear cut-off point or scale for critical mental strain during surgery, but we think it is important to demonstrate that mental strain is definitely higher in advanced laparoscopic surgery. Whether a small difference in LF/HF ratio, as demonstrated here, is actually relevant or whether these results may influence the working conditions or the overall risk of surgeons, remains to be investigated in future studies. However, surgeons should be aware that such procedures are mentally more demanding and also more time-consuming so that the risk of inadvertent inciden
tces may increase after several procedures in 1 day.

The second argument is that we were not able to differentiate between the effects of mental strain and physical activity on HRV, since physical exercise also shifts the sympathovagal balance.\textsuperscript{12,26} We did not find an increased heart rate during the conventional procedure, which would have reflected the higher physical demands in conventional surgery. But although the heart rate was almost the same, the LF/HF ratio was still reduced. If conventional surgery had been physically and mentally more demanding we should have found both a higher heart rate and a higher LF/HF ratio. Thus, the method of measuring HRV seems to be sensitive enough to allow at least some differentiation between physical demands and mental strain.

Our results regarding the different surgical techniques are also indirectly confirmed by the fact that differences between the surgeon and assistant as well as differences between experienced and less experienced surgeons have also been found in previous studies.\textsuperscript{21,27} Goldman et al\textsuperscript{21} analyzed heart rate in relation to the degree of responsibility during surgery. A significant increase in heart rate by at least 20 beats/min occurred in 67% of the primary surgeons and in only 27% of the secondary surgeons. Fatigue, operative difficulty, and anesthesiological problems were identified as causes of tachycardia during surgery. Although the authors only looked at heart rate, our results confirm that the surgeon experiences significantly more mental strain than the assistant and that the experienced surgeon is also more relaxed and copes better with difficult situations than the less experienced one.

Because the more demanding technique of laparoscopic sigmoid resection causes higher mental strain than conventional surgery, we have to realize that advanced laparoscopic surgery has advantages for patients but disadvantages for the surgical team. Therefore, surgeons should be aware that if they try to accomplish 2 or 3 prolonged procedures per day, they may encounter more mishaps during laparoscopic surgery resulting from a possible lack of concentration. Minor mistakes, which may be without consequences in conventional surgery, may lead to major difficulties in laparoscopic surgery.

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**REFERENCES**

12. Yamamoto Y, Hughson RL, Peterson JC. Autonomic control of heart rate during
he authors of this study conclude that although laparoscopic colorectal surgery may be good for the patient, it may, in fact, be bad for the operating surgeon(s)! What a provocative, refreshing, unique, but perhaps not new, idea.

It is a well-known fact that individual physicians have vastly different reactions to stress, with “emergency” catecholamine release being much more prevalent in surgical vs nonsurgical personnel. This global difference between specialties was emphasized by the British surgeon Sir Ian Aird more than 50 years ago in an analysis of the hobbies of doctors—surgeons competed in the Olympics, whereas psychiatrists collected butterflies. Who is to quibble as to who is the wiser?

What is less well known, or certainly less often discussed in open forum, is the fact that there is currently a generation of practicing surgeons (they could be termed, gray-haired, experienced, or non-Nintendo) who are distinctly uncomfortable with laparoscopic surgery, complex laparoscopic procedures in particular. This generation (of which I am a proud member) has found it difficult to “switch horses” toward the end of our respective surgical races (careers). I believe that this group of surgeons has been driven by many factors to perform technical procedures with which they are not comfortable. It is thus of no surprise to me that a higher LF/HF ratio (stress indicator) was found during the performance of the laparoscopic procedure in this study. I am quite sure that similar data could be obtained comparing stress levels not only among other surgical procedures, but among variables such as patient circumstance. Think of the difference between an elective repair of a 7-cm abdominal aortic aneurysm in a 120-lb (54-kg) female vs the same procedure for the repair of a 12-cm ruptured aneurysm in a 280-lb (126-kg) male with hemodynamic instability—stressful indeed!

This study should be expanded to include not only the medical professions, but other professions as well. I wonder, for example, what the LF/HF ratio is in an airline pilot in charge of many lives or in an operator of a powerful machine during adverse weather conditions. Such studies would be beneficial to both the person undergoing the stress and the person(s) who are directly affected by the stressee.

This study brings to our attention a serious issue, one that may affect not only our patients but ourselves. Understanding our response to and performance under stressful conditions will aid in the way we manage stress in work and in life.

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