Abstract

During surgery under local anesthesia, awareness of the patients’ physiological and mental condition and control of these are important to the surgeon. However, acquiring this awareness and knowledge during the training period is difficult, as these skills are developed only with actual contact with the patient and experience during surgery. With this in view, we are developing a model that can represent a patient’s physiological and mental responses to each stage of surgery. This model is expected to be used during training, where trainee doctors can experience the behavior of the patient and acquire the skills mentioned above. Measurements were taken during actual surgery. The heart rate, breathing rate and amplitude, complaints of pain and body movements were recorded as the patient’s response. The endoscopic view and the scene in the operating room were recorded in order to find the factors which cause each patient’s response. To develop the model, the causal relationship between surgical procedures and patients’ responses was investigated. It becomes clear that the patient’s response is depended on the pattern of procedure sequence, movement of surgical area and the type of surgical tool. We constructed a model of this behavior using a Bayesian network.

Key Words
Surgery Simulation and Simulators; Physiological and Mental Reaction; Human Interaction Model; Medical Training; Endoscopic Sinus Surgery

1. Introduction

In the fields of ophthalmology, dentistry and otorhinolaryngology, medical treatment and surgery are conducted using local anesthesia [1, 2]. In many cases, the patient is overtly conscious of pressure, vibration and sound from the surgical procedure. The mental stress caused by these feelings changes the hemodynamics, resulting in an elevation of blood pressure and an increase in the amount of bleeding [2]. Moreover, the pain, which is not completely blocked by anesthesia, causes body movement. When these responses occur, the doctor must give some type of treatment such as administering a depressant, or sometimes temporarily stopping the surgery.

Therefore, the doctor needs to acquire not only the skills to handle surgical instruments well, but also the skills to understand and infer the patient’s exact level of stress and to keep it under control. Surgical skills can be acquired during the training period using animals or artificial models [3]. However, acquiring the skills to infer and keep the patient’s level of stress under control is difficult in the training period, as this skill is learned only with actual surgery.

In this study, we develop a model, which can represent a patient’s responses, such as changes in hemodynamics, complaints of pain, and body movement at each stage of the surgery.

In the medical field, many studies have been conducted to investigate the stress of patients during surgery. Most studies make broad comparisons, such as considering the levels of stress before and after the operation [4]. However, during the actual surgery, the doctor must treat a patient whose condition is steadily changing. If the patient is in pain, the doctor should be aware of it and administer an anesthetic to the patient immediately. To our knowledge, there have been no published studies of the influences of each surgical procedure on patients having surgery conducted under local anesthesia.

Hence, we conducted our study to observe: (1) the sequence in which steps are done during different surgical procedures, and (2) how the patient responded to each procedure. Then, (3) a probabilistic causal relationship model between action from the doctor and response of the patient was developed.

2. Endoscopic Sinus Surgery and its Steps

The subjects of our research are patients who have sinusitis and undergo endoscopic sinus surgery using local anesthesia. Sinusitis is a result of the retention of mucus
in the paranasal sinuses. This occurs as a result of the route, which reaches the paranasal sinuses from the nasal cavity, being blocked by polypus and/or inborn structural errors of the bone wall. The aim of the surgery is, therefore, to remove the polypus and bone walls and make clearer routes.

As a result of analysis of the steps of the surgery, it is seen that the surgery has two sections, the operation and the rest section, the two steps being repeated during the surgical procedure. Figure 1 represents a flow chart outlining the surgical steps. During the rest period, the surgeon and patient wait until the anesthesia takes effect. On the other hand, in the operation section, the surgeon works on the patient. The operation section is composed of four surgical phases: the preparation phase, the opening phase, the post-treatment phase and the packing phase. During the first phase, the anesthetic packing (or gauze) that was inserted in the nasal cavity is removed. During the second phase, the polypus and bone walls are removed using several types of forceps. During the post-treatment phase, bleeding that occurred during the opening procedure is aspirated. During the last phase, anesthetic packing is inserted in the nasal cavity and the patient rests.

3. Interaction Model between Doctor and Patient

The main goal of our study was to investigate the interaction between the doctors’ actions and the patients’ responses to those actions, and to develop a model that can represent them. Figure 2 presents an outline of the interaction between them. The interaction can be divided into two layers. The intra-section layer represents the causal relationship between a doctor’s action and the patient’s response to each action in the different operation sections, for example, the kind of procedure that increases the heart rate.

The inter-section layer represents the causal relationship between the treatment given by the doctor to keep the patients’ condition under control in the rest section and the patients’ response to such treatment. For example, the kind of treatment that is given in case of an increased heart rate.

In this study, we focused on the intra-section layer of interaction, and investigated the probable causal relationship between “Procedures” and “Responses” in this layer, and developed a model that represents them, using a Bayesian network [5].

4. Subjects and Measurements

The subjects of our study were seven Japanese adults, from whom written informed consent was obtained for the measurement procedure and publication of their data. This agreement was approved by the ethical committee of AIST.

The measurements were taken during actual surgery. For accurate results, it was essential that the surgical procedure was not disrupted by the measurements and the measuring devices were non-invasive and non-stressful to the patients. To enable this, breathing rate and amplitude and heart rate were measured. At the same time, an endoscopic view of the surgery and the scene in the operating room were recorded using video cameras. Using the recorded endoscopic view and footage of the operating room, the sequence of the surgery was segmented into two types of sections, the operation and rest sections, and each operation section was segmented into four phases. In each phase, the area the doctor worked on, the instrument that the doctor used and the number of times that the doctor touched the area was recorded. The complaints of pain were also recorded. The
average, minimum and maximum value of heart rate, breathing rate and amplitude were calculated for each segmented phase, and used as physiological indices. The characteristic values (CV) of each index were calculated as follows: If an index tended to increase during a phase, the maximum value was selected as the CV of the phase. If an index tended to decrease, the minimum value was selected. The difference of the CV of the heart rate and breathing amplitude between one phase and the next are calculated, and labeled as “delta-HR” and “delta-BR”, respectively. We used them as the indices that indicate the influence of each surgical phase on the autonomic nervous response.

Figure 3 shows an example of how to calculate the CV of the heart rate and the delta-HR. In this case, the delta-HR value is 4.

5. Modeling the Intra-Section Layer

To construct a probabilistic causal relationship model, the probability nodes, which comprise the model, are required. The nodes, in the context of our study, are the variable factors of the patients’ response. To select the candidates of the variable factor, the physiological indices were analyzed using analysis of variance (ANOVA) and frequency distributions. This paper will discuss only part of this analysis.

Analysis was performed using the SPSS program (ver.11.0, Japanese edition). In all tests, a level of significance of 0.01 was accepted as significant.

In this analysis, one patient’s data was removed. The behavior of the patient was significantly different from others. It suggests a need to classify patients by several types and is a point that remains to be resolved.

Among Surgical Phases

Delta-HR, delta-BR and the breathing rate of six patients were compared among surgical phases. There were no significant differences in each index among patients, but there were significant differences in each index among surgical phases. Significant effects were further analyzed using Games-Howell multiple comparisons.

Figure 4 presents the result of the ANOVA and multiple comparisons.

According to current physiological theories [6], when a person holds their breath, the heart rate decreases. In the result of ANOVA among surgical phases, in the opening phase, the breathing movement (delta-BR and rate) and the delta-HR significantly decreased. Therefore, it is safe to suppose that the patients hold their breath in the opening phase and their breathing movement increases after this phase.

In the Opening Phase

Using the variation sign (+, -) of delta-HR, the qualitative behavior of the heart rate in the opening phase was analyzed using frequency distributions. Table 1 presents the results. During this phase, the probability of an increasing heart rate was 18.2%. When the patient was in pain or felt pressure or vibration, or the surgical area was moved out, the heart rate was likely to increase. On the other hand, when the surgical area moved in, it was likely to decrease.

When a human being is in pain or feels fear or anxiety, the heart rate and breathing movement is increased [6]. Therefore, it seems that the behavior of patients’ responses in the opening phase agrees with our knowledge of physiology.
According to the results of the entire analysis, the procedure types (8 types), surgical phases (4 phases), area movement (move in or move out), tool types (14 types) and surgical areas (15 areas) were selected as the input (surgeon’s action) inside of patient sensory receptors.

<table>
<thead>
<tr>
<th>Input</th>
<th>Previous Procedure Type</th>
<th>Current Procedure Type</th>
<th>Tool</th>
<th>Surgical Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inside of Patient</td>
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<tr>
<td>Sensory Receptors</td>
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<td>Higher Brain Activities</td>
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<td>Recognition of Surgical Phase</td>
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<td>Area Movement</td>
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<td>Pain</td>
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<td>Pressure/vibration</td>
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<td>Behavior</td>
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<tr>
<td>Breathing Movement</td>
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<tr>
<td>Output (Patient’s response)</td>
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<td>HR change (+, -)</td>
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<td>Mental Stress</td>
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</tbody>
</table>

Figure 5: The Probabilistic Causal Relationship Model in the Intra-Section Layer.

probability nodes of the doctors’ action. The change in heart rate (increase or decrease), breathing movement (increase or decrease), occurrence of pain (presence or absence) and pressure-vibration (feel them or not) were selected as the probability nodes of response of the patient. The number or phrases in parentheses indicate respectively the number of states or states name of each probability nodes.

Constructing the probabilistic causal relationship model using a Bayesian Network

The model was constructed using the BAYONET program [7]. The program creates a directed graph among the probability nodes according to the information criteria such as maximum likelihood, AIC or MDL. Figure 5 presents the model created by the BAYONET based on the data of six patients. The Minimum Description Length was used in order to evaluate the model structure.

According to the model created, (1) the surgical phase was reasoned from previous and current procedure types. (2) The occurrence of pain and pressure-vibration were reasoned from currently used tools and surgical areas. (3) To simplify the model, the occurrence of pain and pressure-vibration were merged into “Mental Stress”. (4) The breathing movement was reasoned from the current state of surgical phases, area movement and mental stress. (5) The change in the heart rate was reasoned from the breathing movement.

This is the most probable model according to our data, and does not incorporate current knowledge of physiology. However, its resultant structure is similar to models based on the knowledge of physiology.

6. Conclusion

As a result of this work, it was found that the patients’ physiological and mental response is dependant on the pattern of procedure sequence, movement within the surgical area and type of surgical tool being used. Using this information, we successfully constructed a behavior model using a Bayesian network.

The classification of patients by attributes, investigation of the inter-section layer and construction of entire interaction model remains to be completed.

This model is expected to be used during training, where trainee doctors can experience the likely behavior of the patient during surgery and hence acquire the skills of inferring the patient’s condition and keeping it under control.

References