Abstract: An apparatus for determining the position of an oesophageal catheter (5) inserted into the oesophagus of a patient (1), relative to the diaphragm is disclosed. The apparatus comprises: - at least one electrode (11) arranged to stimulate the muscular activity of the diaphragm by applying a stimulus signal, - a registering means (7) arranged to register the signals recorded by the electrode pairs of the oesophageal catheter at the specific point in time and the stimulus signal, - a control means (9) arranged to cause the electrode (11) to stimulate the muscular activity at a specific point in time, and determine which electrode pairs record the stimulus signal with the highest amplitude at the specific point in time, based on the signals received by the receiving means.

Title: A METHOD OF DETERMINING A POSITION OF AN OESOPHAGEAL CATHETER, A CONTROL UNIT AND A COMPUTER PROGRAM PRODUCT
Published: with international search report (Art. 21(3))
A Method of Determining a Position of an Oesophageal Catheter, a Control Unit and a Computer Program Product

Technical Field

The present invention relates to a method of determining the position of a catheter in a patient's oesophagus, a control unit for use with a ventilator, and a computer program product for use in such a control unit.

Background and Related Art

It is known in the art to use myoelectrical or neuroelectrical signals from a patient to control the function of a ventilator providing breathing support to the patient. US 5 820 560 and US 6 588 both disclose methods and devices for triggering ventilatory support to a patient using a myoelectrical signal obtained from the diaphragm. US 5 671 75 discloses a method and a device for registering the myoelectrical activity of the diaphragm by means of an oesophageal catheter having an array of electrodes. The signals from such a catheter can be used as the myoelectrical signal to control ventilator function. EP 1091 780 discloses the use of a neuroelectrical signal picked up, for example, from the phrenic nerve to control a ventilator.

A problem when obtaining a myoelectrical signal from the diaphragm is positioning of the catheter within the patient's oesophagus. To obtain a proper signal some of the electrodes of the catheter should be placed above the diaphragm and some below it. There is a possibility that the catheter will be inserted too far, or not be inserted far enough. In both cases, the catheter will detect a weak signal, or may not capture any signal at all. Alternatively, the catheter may capture myoelectrical signals from other muscles instead of, or in addition to the signal from the diaphragm. Hence, it is difficult to obtain an optimal catheter position and the ventilator may have to work in pneumatic triggering mode if the signal is too weak.

There are some problems associated with methods based on the registration of the EMG signal from the diaphragm.
- There may not be an EMG signal present, for example if the patient is sedated or has no breathing activity of his own for other reasons.
- The EMG signal may be very weak and/or difficult to detect, for example because of disturbances caused by breathing support provided to the patient.
- There is a risk that other myoelectric signals resembling that of the diaphragm but originating from other muscles are mistaken for signals from the diaphragm. Such signals may come, for example, from the abdominal muscles.

Co-pending application No PCT/EP2007/054149 discloses a method of positioning the catheter based on the ECG component that will always be present in a myoelectrical signal from the diaphragm. In this application, the damping of the ECG signal caused by the diaphragm is used. The ECG signal components from different electrode pairs are determined and compared and the difference in amplitude of the ECG signal between different electrode pairs is used to determine the position of the diaphragm relative to the electrode pairs. The greatest damping between two neighbouring electrode pairs should be caused by the diaphragm being positioned between these two electrode pairs. This method is predominantly based on the registration and comparison of the QRS complex of the ECG signal.

Co-pending Swedish patent application No. 0850076-1 discloses a method utilizing the presence of the p wave of the ECG signal. Since the damping of the p wave is very strong with increasing distance from the heart, any electrode pair picking up a p wave must be located fairly close to the heart’s atria, well above the diaphragm.

Summary of the Invention

It is an object of the invention to determine the position of an oesophageal catheter inserted in a patient, in relation to the patient’s diaphragm.

This object is achieved by a method of determining the position of an oesophageal catheter inserted into the oesophagus of a patient, said catheter comprising a number
of electrodes arranged to pick up a myoelectrical signal, comprising the following steps:

- stimulating the muscular activity of the diaphragm at a specific point in time,
- registering the signals recorded by the electrode pairs of the oesophageal catheter at the specific point or period in time,
- determining which electrode pairs record the stimulus signal with the highest amplitude.

The object is also achieved by an apparatus for determining the position of an oesophageal catheter inserted into the oesophagus of a patient for picking up myoelectric signals from the patient, comprising

- at least one electrode arranged to stimulate the muscular activity of the diaphragm by applying a stimulus signal,
- a registering means arranged to register the signals recorded by the electrode pairs of the oesophageal catheter at the specific point in time and the stimulus signal,
- a control means arranged to cause the electrode to stimulate the muscular activity at a specific point in time, and determine which electrode pairs record the stimulus signal with the highest amplitude at the specific point in time, based on the signals received by the receiving means.

The object is also achieved by a computer program product for controlling an apparatus of determining the position of an oesophageal catheter inserted into the oesophagus of a patient, said catheter comprising a number of electrodes arranged to pick up a myoelectrical signal, and at least one electrode arranged to stimulate the muscular activity of the diaphragm, said computer program product comprising computer readable code means which, when run in a control unit of the apparatus will cause the apparatus to perform the following steps:

- cause the electrode to stimulate the muscular activity of the diaphragm at a specific point in time,
- register the signals recorded by the electrode pairs of the oesophageal catheter at the specific point in time,
- determine which electrode pairs record the stimulus signal with the highest amplitude.

By stimulating the diaphragm and registering the signal at the time of stimulation it is ensured that the registered signal really is the signal from the diaphragm and not another bioelectrical signal that resembles that of the diaphragm. By registering the signals from all electrode pairs of an oesophageal catheter at the time of stimulation, the ones registering the strongest signal can be determined. This electrode pair or these electrode pairs will be the ones closest to the diaphragm. In this way the position of the catheter relative to the diaphragm can be determined and adjusted as desired.

The stimulus signal may be applied transcutaneously or subcutaneously, using any known method and suitable electrodes for applying the signal in the desired way.

The stimulus signal may be applied to a nerve controlling the function of the diaphragm, such as the phrenic nerve or to the diaphragm itself.

In a preferred embodiment the control means is arranged to determine if the electrode pairs that record the strongest stimulus signal are located in or close to the middle of the catheter and, if they are not, indicate that the catheter should be adjusted. This is preferably achieved by means of a computer program product.

This will provide a direct feedback to an operator that the catheter position should be adjusted. As a response to this, the method may comprise the step of adjusting the position of the catheter in the appropriate direction to bring the middle electrode pairs closer to the diaphragm.

The method steps may be repeated at regular or irregular time intervals. This will enable continuous monitoring of the catheter's position. Preferably the control unit
is arranged to repeat the method steps related to stimulating, recording the signals and determining the position of the electrodes repeatedly.

The stimulation of the diaphragm may be performed by invasive or non-invasive methods. Non-invasive methods have the advantage of being easier to perform and causing less discomfort to the patient. A non-invasive method would be to stimulate the phrenic nerve from the outside of the neck. On the other hand there is a risk of stimulating another nerve instead of, or in addition to, the phrenic nerve, which may cause undesired effects.

Electrical stimulation may be applied non-invasively using electrodes applied to the skin surface. Percutaneous electrodes have also been developed, which can be left in place over a period of time to allow specific reproducible stimulation patterns. The best site for transcutaneous stimulation of the phrenic nerve is on the neck a few cm above the clavicle, since this site is as far away from the vagus nerve as possible. Unwanted stimulation of the vagus nerve can cause severe bradycardia and other negative effects.

Invasive methods include invasive stimulation of the phrenic nerve as well as direct invasive stimulation of the diaphragm itself. Such methods have greater impact on the patient's body but offer better control of what nerve or muscle to stimulate. Several types of implanted electrodes can be found. Invasive electrodes can be placed using several different techniques, including neck incisions, thoracoscopic procedures or thorocatomy. For example, electrodes available from Avery Labs incorporate an antenna placed immediately under the skin, which allows activation of the electrode through intact skin.

European Patent application 1389 442 discloses a neural probe comprising a number of electrodes, which may be used to stimulate nerve cells. Another manufacturer of suitable stimulation electrodes for diaphragm pacing is Synapse Biomedical. Atrotech Oy manufacture a phrenic nerve stimulator.
The method according to the invention may be combined with other known methods for positioning the oesophageal catheter. For example, the method of co-pending application No. PCT/EP2007/054149 might be used first to position the catheter. Then the inventive method may be used to adjust the catheter position. The position may be adjusted so that the electrodes located in the middle of the catheter have the highest registered EMG signals. The NEX method may also be used for a first positioning of the catheter.

The inventive procedure may also be used during operation, to ensure that the catheter position has not changed too much, for example because of the patient's movements.

The computer program may also be arranged to cause the control unit to present the determined position of the catheter to the user on a display, for example, the display of the ventilator. This will assist the operator in determining the position of the catheter correctly.

Brief Description of the drawings

The invention will be described in more detail in the following, by way of example, and with reference to the appended drawings, in which:

Figure 1 illustrates a patient with an oesophageal catheter used to control a ventilator.

Figure 2 is a flow chart of a method according to an aspect of the invention.

Detailed Description of Embodiments

Figure 1 is a schematic overview of a patient 1 connected to a ventilator 3 and having an oesophageal catheter 5 inserted in order to record a myoelectric signal from the diaphragm. Instead of the ventilator, the inventive idea could be used with a device arranged to monitor the signal from the oesophageal catheter. This myoelectric signal is fed to a control input of the ventilator 3 to control the ventilation function
of the patient 1. The catheter 5 comprises a number of electrodes, for example, nine electrodes placed equidistantly in an array along the catheter to produce 8 subsignals, each subsignal being a difference signal between two neighbouring electrodes. The subsignals will be received by receiving means 7 and processed in a control unit 9 in the ventilator to produce the overall signal that can be used to control the ventilator. To this end, the control unit 9 comprises at least one computer program product used to control the ventilator to perform the calculations and other relevant functions.

The registration of a myoelectric (EMG) signal from the diaphragm may not always be successful. As for any bioelectric signal, the EMG signal recorded from the diaphragm will comprise disturbance, in particular from the heart, but also from other muscles such as abdominal muscles. If the catheter is inserted much too far into the patient, the disturbing signals may constitute the largest part of the signal picked up by some or all the electrode pairs. In this case, there is a risk that the control signal provided to the ventilator is not related to the patient's breathing activity. In other cases, the patient may exhibit no breathing activity, or too little breathing activity to enable a proper registration. The breathing activity can be reduced, for example, because of illness or sedation.

Even if the catheter is initially positioned in the right place it may be moved up or down within the patient's oesophagus because of the patient's breathing activity or other movements, so that after a while the diaphragm activity is not registered in the right way.

According to the invention, therefore, the arrangement of Figure 1 also includes at least one electrode 11 for stimulating the diaphragm. The electrode 11 may be of any kind suitable for stimulating nerve or muscle cells, depending on where the stimulus is provided. The stimulus may be provided transcutaneously or subcutaneously to the phrenic nerve, or directly to the diaphragm. The electrode 11 may be controlled by a electrode control unit 13, which may be positioned in the ventilator
3, as shown in Figure 1. It may also be a separate unit. If it is part of the ventilator, it may be integrated with the control unit 9 or it may be a separate unit. The electrode control unit 13 typically comprises a computer program for controlling the stimulation function.

Figure 1b shows a schematic example of an oesophageal catheter 5 like the one shown in Figure 1a. The catheter has nine electrodes, numbered e1, e2, ..., e9 in the Figure. Each channel is recorded as the difference signal between two adjacent electrodes, that is, between e1 and e2, between e2 and e3, etc. Hence, the uppermost channel will be the one recorded between the two uppermost electrodes e8 and e9, also referred to as the uppermost electrode pair. Ideally, the catheter 5 should be positioned in such a way that the electrodes e4, e5, e6 located in the middle of the catheter 5 should be near the diaphragm, in order to pick up the best signal from the diaphragm. It should be understood that this configuration of the catheter is only an example. It is, however, usually suitable to place the electrodes in the middle of the catheter near the diaphragm.

A method according to an aspect of the invention comprises the steps shown in Figure 2:

Step S20: Position the catheter in the patient's oesophagus. As discussed above, a number of methods exist for finding an appropriate position for the catheter.

Step S21: Stimulate the muscular activity of the diaphragm at a specific point or period in time by applying a stimulus signal either to a nerve controlling the function of the diaphragm, or to the diaphragm itself. The stimulus signal may be applied as a short pulse at a point in time or over a period of time, typically during one breath.

Step S22: Register the signals recorded by the electrode pairs of the oesophageal catheter at the specific point or period in time.

Step S23: Determine which electrode pairs record the stimulus signal with the highest amplitude.

Step S24: Are the electrode pairs that record the strongest stimulus signal located in or close to the middle of the catheter? If yes, end of procedure; if no, go to step S25.
Step S25: Indicate that the catheter is not in an optimal position. To do this, the control unit 9 will indicate the position of the catheter on a display. The control unit may also issue an explicit message that the catheter position should be adjusted, for example, on the display, or through an audio alarm.

Step S26: Adjust the position of the catheter in the appropriate direction to bring the middle electrode pairs closer to the diaphragm. This will normally be done manually by health care personnel. Return to step S21.

If the answer in step S24 is yes, this indicates that the catheter is in an appropriate position for registering the EMG signal from the diaphragm. By repeating the procedure at regular or irregular time intervals, the position of the catheter can be monitored over time. It may be advantageous to wait for a certain period of time and then repeat the procedure to ensure that the catheter remains in the right place and to adjust it if it moves. The algorithm may also be performed in other situations, for example, when the EMG signal ceases or deteriorates dramatically, or if it is detected that ventilation correctly with the patient's breathing efforts. The latter situation is discussed in co-pending application No. PCT/SE2007/051048.

The stimulation performed in step S21 can be carried out to provide a well-defined EMG signal from the diaphragm when the spontaneous activity of the diaphragm is too weak to be recorded properly. It may also be used if there is normal activity of the diaphragm, to provide a well-defined peak of the EMG signal at a specific point in time, to ensure that the signal picked up by the electrodes is really the signal from the diaphragm and not a disturbing signal from some other muscle.

The timing of the stimulation performed in step S21 should be determined based on a number of factors. From a technical point of view a period with no disturbances from other signals, such as EMG and ECG, might be preferable, to enable an unambiguous detection of the stimulus signal. If the patient has any spontaneous breathing activity, from a clinical point of view it would be suitable to synchronize the
stimulus signal with the patient's inspiration phase. The point in time at which the stimulus signal is applied should be known in order to detect when the stimulus signal will be detected.

In step S24, if the initial positioning of the catheter was unsuccessful it may be that the catheter is positioned in such a way that none of the electrodes are measuring on the diaphragm. In this case, the catheter should be adjusted up or down, preferably a distance corresponding to at least the length of the catheter that is covered by the electrodes. Then the procedure should return to step S21.

It may also happen that the amplitude of the stimulus signal is too low for it to be registered properly. If a contraction or a pneumatic triggering can be detected during stimulation, it may be concluded that the amplitude is sufficiently high. If it is determined that the amplitude is too low, the amplitude may be increased until the stimulus signal is detected by the electrodes or causes a response in the patient.

As will be understood, the steps S21 - S25 will normally be performed by software running in the control unit of the apparatus. Step S26 will normally be performed by healthcare personnel.
Claims

1. A method of determining the position of an oesophageal catheter inserted into the oesophagus of a patient, said catheter comprising a number of electrodes arranged to pick up a myoelectrical signal, comprising the following steps:
   - stimulating the muscular activity of the diaphragm at a specific point in time,
   - registering the signals recorded by the electrode pairs of the oesophageal catheter at the specific point or period in time,
   - determining which electrode pairs record the stimulus signal with the highest amplitude.

2. A method according to claim 1, wherein the stimulus signal is applied to a nerve controlling the function of the diaphragm, such as the phrenic nerve.

3. A method according to claim 2, wherein the stimulus signal is applied transcutaneously.

4. A method according to claim 2, wherein the stimulus signal is applied subcutaneously.

5. A method according to claim 1, wherein the stimulus signal is applied to the diaphragm itself.

6. A method according to any one of the preceding claims, further comprising the steps of
   - determining if the electrode pairs that record the strongest stimulus signal are located in or close to the middle of the catheter and, if they are not,
   - adjusting the position of the catheter in the appropriate direction to bring the middle electrode pairs closer to the diaphragm.
7. A method according to any one of the preceding claims, wherein the method steps are repeated at time intervals.

8. An apparatus for determining the position of an oesophageal catheter (5) inserted into the oesophagus of a patient (1) for picking up myoelectric signals from the patient, comprising
   - at least one electrode (11) arranged to stimulate the muscular activity of the diaphragm by applying a stimulus signal,
   - a registering means (7) arranged to register the signals recorded by the electrode pairs of the oesophageal catheter at the specific point in time and the stimulus signal,
   - a control means (9) arranged to cause the electrode (11) to stimulate the muscular activity at a specific point in time, and determine which electrode pairs record the stimulus signal with the highest amplitude at the specific point in time, based on the signals received by the receiving means.

9. An apparatus according to claim 8, wherein the electrode (11) is arranged to apply the stimulus signal to a nerve controlling the function of the diaphragm, such as the phrenic nerve.

10. An apparatus according to claim 9, wherein the electrode (11) is arranged to apply the stimulus signal transcutaneously.

11. An apparatus according to claim 9, wherein the electrode (11) is arranged to apply the stimulus signal subcutaneously.

12. An apparatus according to claim 8, wherein the electrode (11) is arranged to apply the stimulus signal to the diaphragm itself.

13. An apparatus according to any one of the claims 8-12, wherein the control means (9) is arranged to determine if the electrode pairs that record the strong-
est stimulus signal are located in or close to the middle of the catheter and, if they are not, indicate that the catheter should be adjusted.

14. A computer program product for controlling an apparatus of determining the position of an oesophageal catheter inserted into the oesophagus of a patient, said catheter comprising a number of electrodes arranged to pick up a myoelectrical signal, and at least one electrode (11) arranged to stimulate the muscular activity of the diaphragm, said computer program product comprising computer readable code means which, when run in a control unit of the apparatus will cause the apparatus to perform the following steps:
   - cause the electrode to stimulate the muscular activity of the diaphragm at a specific point in time,
   - register the signals recorded by the electrode pairs of the oesophageal catheter at the specific point in time,
   - determine which electrode pairs record the stimulus signal with the highest amplitude.

15. A computer program product according to claim 14, further comprising code means that will cause the apparatus to perform the following steps:
   - determine if the electrode pairs that record the stimulus signal with the highest amplitude are located at or near the middle of the catheter, and if they are not,
   - indicate to an operator of the apparatus that the catheter's position should be adjusted.
Fig. 2

START

1. Position catheter (S20)
2. Stimulate muscular activity (S21)
3. Register electrode signals (S22)
4. Determine amplitude (S23)
5. Check if electrodes are in the middle (S24)
   - Yes: END
   - No: Proceed to next steps
6. Indicate catheter position not good (S25)
7. Adjust catheter position (S26)
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

INV. A61B5/06 A61B5/0488

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

A61B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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<th>Relevant to claim No</th>
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<td>Y</td>
<td>WO 2008/131797 A (MAQUET CRITICAL CARE AB [SE]; BLOMQUIST KARIN [SE]; JALDE FREDRIK [SE]) 6 November 2008 (2008-11-06) page 2 - page 3; figures page 5 - page 7</td>
<td>8-15</td>
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Further documents are listed in the continuation of Box C

See patent family annex

Date of the actual completion of the international search

3 April 2009

Date of mailing of the international search report

23/04/2009

Name and mailing address of the ISA/Authorized officer

European Patent Office, P B 5818 Patentilaan 2 NL - 2280 HV Rijswijk Tel (+31-70) 340-2040, Fax (+31-70) 340-3016

Mundakapadam, S

Form PCT/ISA/210 (second sheet) (April 2005)
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<td>Y</td>
<td>EP 1 393 773 A (SIEMENS ELEMA AB [SE]) MAQUET CRITICAL CARE AB [SE]) 3 March 2004 (2004-03-03) paragraphs [0001], [0010], [0011], [0017] - [0021], [0026], [0028], [0032], [0033]; figures</td>
<td>8-15</td>
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<td>A</td>
<td>GB 2 294 642 A (BRAIN ARCHIBALD IAN JEREMY [GB]) 8 May 1996 (1996-05-08) page 2 - page 3; figures page 5 - page 7</td>
<td>8</td>
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Continuation of Box II.I

Claims Nos.: 1-7

Claims 1-7 are directed to methods for determining the position of an oesophageal catheter inserted into the oesophagus of a patient. These methods require the insertion and manipulation of the catheter in the oesophagus (cf. also page 8, lines 18-21), which is regarded as a surgical intervention. Claims 1-7 thus relate to methods for treatment of the human or animal body by surgery (Rule 39.1(iv) PCT). Moreover, stimulation of the diaphragm covers invasive methods, cf. claims 2, 4-5 and eg. page 5, lines 19-26.
This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. [Y] Claims Nos.: 1-7  
because they relate to subject matter not required to be searched by this Authority, namely:  
see FURTHER INFORMATION sheet PCT/ISA/210

2. □ Claims Nos.:  
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. □ Claims Nos.:  
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

This International Searching Authority found multiple inventions in this international application, as follows:

1. □ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. □ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. □ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. □ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest  
□ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

□ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

□ No protest accompanied the payment of additional search fees.
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<tr>
<td>WO 2008131797 A</td>
<td>06-11-2008</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>JP 2004081869 A</td>
<td>18-03-2004</td>
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<td></td>
<td></td>
<td>US 2004044377 A1</td>
<td>04-03-2004</td>
</tr>
<tr>
<td>GB 2294642 A</td>
<td>08-05-1996</td>
<td>CA 2162013 A1</td>
<td>04-05-1996</td>
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<tr>
<td></td>
<td></td>
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<td>17-12-1996</td>
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