ASTHMA ATTACKS MONITORING BY ELECTRICAL IMPEDANCE

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Summary

Asthma is a most common affliction associated with exposure to an agent in the work, open air or air pollution sites or at home. Asthma diagnosis and monitoring require specialised methods and instrumentation that cannot be exported out of the hospital laboratories to the working or open air environment or homes of the potential sufferers. An alternative method for detection of airway obstruction was developed using measurement of the changes in chest basic electrical impedance Z_0.

A portable device for diagnosis and monitoring of asthma was developed. The Z_0 signal was AD-converted and stored by a microprocessor system. In order to assess both Z_0 changes and coughing episodes, a continuous ADC loop with higher sampling frequency was programmed. In the absence of fast changing signals (absence of cough), no fast memorising will occur and Z_0 values will be recorded with low sampling rate. In the opposite case the waveform of cough induced impedance changes will be recorded. The memory of the portable instrument is downloaded in a PC system for assessment and analysis. Appropriate averaging and filtering procedures were applied. This device could be further improved to generate a signal when Z_0 starts to increase and thus to prevent an asthmatic crisis by warning the patient to take appropriate measures.

Introduction

The asthmatic crisis occurs as a result of respiratory airway obstruction. *Popov and Daskalov (1996)* hypothesised that it is possibly related to accumulation of air in the lungs. Therefore, an increase of the DC (basic) component of the thoracic electrical impedance Z_0 could be expected. The effect was studied by examination of potentially asthmatic patients using Metacholine inhalation challenge tests. Such test induces a partial and reversible obstruction in real asthmatics or no reaction in non-asthmatic subjects, as assessed by the forced expiration volume for 1s (FEV1). It was found that a marked increase in Z_0 (up to about 20% in some cases) occurred in asthmatics. Moreover, this effect was preceding a measurable reduction in FEV1.

These investigations stimulated us to develop a portable instrument for continuous monitoring of thoracic electrical impedance, analogous to the electrocardiogram Holter-type monitor.

Portable thoracic electrical impedance recorder

A portable physiological signal monitor should be lightweight, compact, autonomous and relatively inexpensive. The block-diagram of the impedance monitor is shown in Fig. 1. The analogue part comprises a 100 kHz sinusoidal signal generator, a voltage-current converter (U-I converter) and an input signal amplifier with detector and lowpass filter. The impedance range is 0 to 120 Ω and the operating current peak-to-peak amplitude is 2 mA. With a supply voltage of ±5 V, the maximum allowable impedance load can reach 3 kΩ (about 1.5 kΩ per injecting electrode).

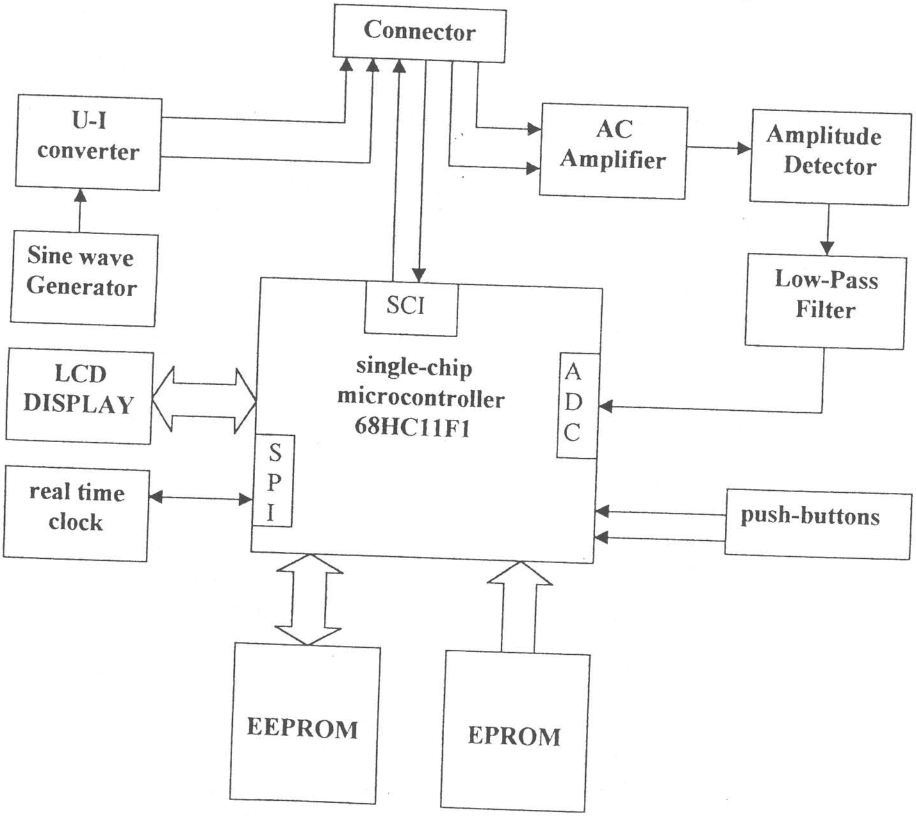

Fig.1
Block diagram of the portable thoracic electrical impedance recorder

Four aluminium foil electrodes are used, measuring 4x12 cm. Two pairs are used at both sides of the thorax and fixed by adhesive bands. The current injecting electrodes are located along the axillar line about 5 cm under the axillae and the voltage takeoff electrodes are placed alongside at about 1.5 cm medially. These large size electrodes (*Popov and Daskalov 1996*), combined with a differential voltage-to-current converter allow for considerable suppression of motion artefacts (*Al-Hatib 1998; Al-Hatib 1997*).

The recorder is fixed at the patient waist by a belt, allowing the use of short non-screened flexible leads to the electrodes, avoiding the degrading effect of parasitic cable capacitances. Thus the current source output impedance and the input impedance of the voltage amplifier retain their high values, virtually equal to those of the respective circuits.

The digital part of the recorder is based on the single-chip microcontroller 68HC11F1. Its 8-bit AD converter yields a resolution of 0.5 Ω which is acceptable for the measurements envisaged. This controller is operating in expanded mode, addressing a 32 kB EPROM, a 512 kB EEPROM and an LCD display by its built-in address decoder.

The Motorola flash-EEPROM M29F040 is used for storing measurement data. It has 8 sectors of 64 kB each which can be separately erased. A 16 page x 32kB organisation is adopted, i.e. each sector comprises two pages.

The LCD display (a single-line 16-symbol Hitachi module LM020L) shows the selected mode of operation, the elapsed time and the measured Z_0 values.

The portable recorder functioning is controlled by just two push-buttons. One is for setting the mode of operation and the other - for starting the respective function. Four basic modes are programmed: measurement, displaying the measured data, downloading data to a PC and erasing the memory. Measurement mode is disabled by a combined activation of buttons for a given time interval, thus avoiding inadvertent interruption of the monitoring by the patient. Erasing is done by sectors, thus reducing power consumption from the battery. A real time clock (the Motorola chip MC68HC68) makes use of the built-in serial peripheral interface.

The downloading to a PC is done by a serial link cable to be plugged in the patient leads connector. Thus a possible connection of the patient with the electrodes to the low electrical safety grade PC is avoided.

The recorder is powered by four 1.5 V AA size batteries, two for each of the positive and negative 5 V supply voltages, obtained by two transverters LT1108 (Linear Technologies).

Results

In a first experiment the recorder was used on a test subject with normal breathing function. Thus immunity to motion artefacts was verified. An one-hour recording is shown in Fig. 2. The subject activities included walking, stairs climbing, bus travel, eating, etc. It can be seen that the thoracic impedance did not show tendency to long-term changes, therefore motion artefacts are of virtually no influence.

Fig. 3 shows a three-hour recording of a patient admitted in the clinic after a night asthmatic episode. He was enduring breathing difficulties. The recorder was immediately attached and activated. During different procedures and tests the thoracic impedance did not show persistent changes. At the 2-nd hour a bronchodilating agent was administered (arrow mark in Fig. 3) and as a result a 10% drop of Z_0 was recorded.

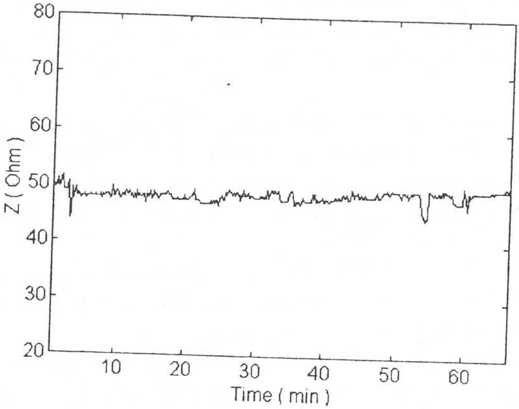

Fig. 2
One-hour recording of thoracic electrical impedance on a subject with normal breathing function. Motion artefacts are of virtually no influence

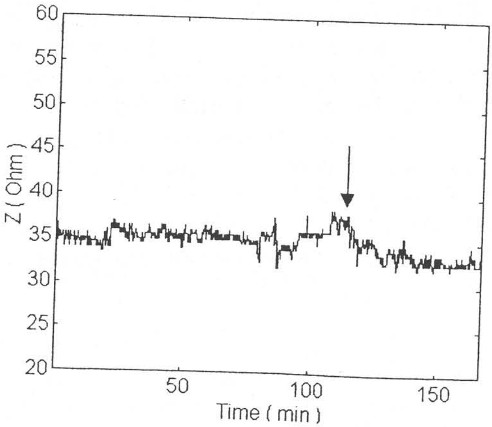

Fig. 3
Three-hour recording of a patient admitted in the clinic after a night asthmatic episode

A FEV1 measurement of this patient is shown in Fig. 4 before (solid line) and after (dotted line) bronchodilatation. The increased FEV1 value proves the effect of the medication and confirms the reduction of residual air volume in the lungs, as detected by the drop in the Z_0 recording.

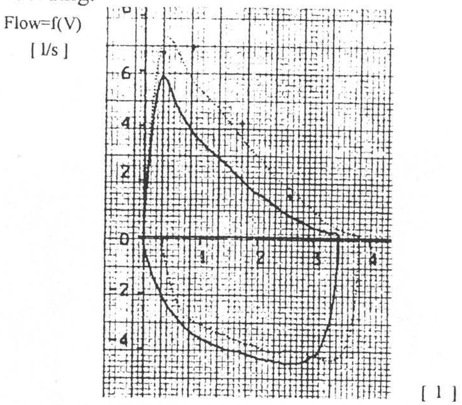

Fig. 4
FEV1 measurement before (solid line) and after (dotted line) bronchodilatation

Monitoring cough episodes frequency, duration and intensity can be important for asthma severity assessment and also for treatment follow-up. The thoracic impedance changes during coughing can be acquired by the recorder providing an adequately high (compared with Z_0) sampling frequency is used. A high sampling rate would limit the maximum recording time, as the memory capacity is limited.

Therefore, appropriate filtering should be applied and combined with a software loop with faster sampling which will be activated by signals of moderate slope - higher than Z_0 changes during normal breathing and lower than possible artefacts. Thus cough episodes can be included in the memory without occupying much of the memory capacity. An example of cough recording is shown in Fig. 5.

Conclusion

Long-term measurement of thoracic impedance can be an efficient means of detection and warning for asthmatic crisis. It allows recordings during real asthmatic episodes in the clinic (thus assessing treatment results), in working environment or at home. Thus relevant data accompanying critical processes could be obtained, possibly revealing some additional information on diagnosis and treatment of asthma.
Measurement of Z_0 can also be used for assessment of patient reaction to routine Metacholine tests, avoiding the need for patient co-operation in FEV1 measurement.
Coughing frequency, duration and intensity is easily and reliably detected and recorded by Z_0 changes, compared to acoustic and/or electromyogram methods.

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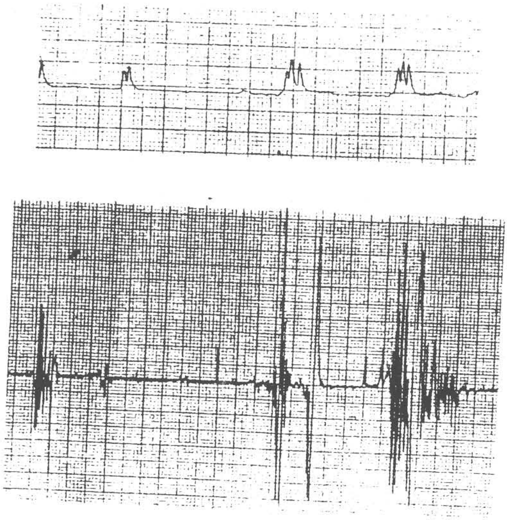

Fig. 5
Example of cough recording

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