Experimental studies with a clinical monitor and diagnostic computer

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Summary
A clinical monitor and computer is described which uses input information about heart rate, blood pressure and oxygen saturation. The data are processed in a simple diagnostic computer, the circulatory failure analyser, to give a diagnosis of cardiac arrest, hypoxia and oligaemic shock and to give early warning of tachycardia, bradycardia, hypertension, hypotension and cyanosis. The analyser was tested on simulated signals and experimentally in animals. The validity of the logic utilized by the computer was confirmed and the sensitivity as a monitor was assessed.

In a new approach to patient monitoring (Stewart, 1969) it was proposed that physiological data from a patient, for example heart rate, blood pressure, and oxygen saturation be processed to give a simplified output. This should consist firstly of a warning, graded according to clinical urgency, of change or deterioration in a patient’s condition, and secondly of a display indicating the diagnosis together with its component features. At present many monitoring systems give warning only of primary cardiac arrest, that is ventricular fibrillation or ventricular asystole. Such devices would not indicate acute circulatory failure from other causes before the occurrence of irreversible brain damage. Warning should be given of hypoxia and oligaemic shock, important causes of acute circulatory failure in addition to cardiac arrest. Thus all the common forms of dangerous deterioration would be detected sufficiently early for resuscitation to be possible.

The approach has now progressed to the construction of a prototype circulatory failure analyser (Sadera et al., 1970) which performs the clinical logic functions specified. The present paper reports the results obtained with the circulatory failure analyser (Fig. 1) when tested on simulated signals and experimentally in animals. The validity of the logic was assessed during standardized conditions of obstructive hypoxia and in addition the sensitivity and response of the analyser were estimated.

The circulatory failure analyser

The circulatory failure analyser has been described in some detail by Sadera et al. (1970): The analyser receives input from three sensors. From each sensor information about a parameter is derived and an analogue signal, proportional to the magnitude of that parameter, forms the input to the appropriate channel of the analyser. Input signals to all three channels are processed by the analyser which performs successively, in its three main parts, the functions of translation, diagnosis and communication. In the translation units, one for each channel, an analogue signal is converted to a digital one of high,
normal or low, according to level comparators on which are set the clinically acceptable high and low limits of the appropriate parameter. Thus for heart rate the high, normal and low digital signals would correspond to tachycardia, normal and bradycardia. In the diagnostic unit all three digital input signals are processed by switching circuits arranged in accordance with the clinical logic to make a diagnosis and a determination of clinical urgency. In the communication unit the output is presented in an audio-visual form. Alarm conditions are indicated by red lights adjacent to the diagnoses of arrest, shock and hypoxia. The component features, tachycardia, bradycardia, hypertension, hypotension, cyanosis and high oximeter reading, are also indicated by red lights. Each normal condition is indicated by a green light. In addition the sensor warning of 'check' is given if malfunction of a sensor is detected. The auditory warning is graded as 'early warning' indicated by a buzzer and 'urgent alarm' indicated by a bell. The warning and alarm conditions are also duplicated in visual display form.

No display of wave form on an oscilloscope or of absolute values on meters is incorporated in the analyser but sockets are provided at appropriate points to obtain these displays if desired. They were obtained during the experiments to check the performance of the analyser.

In each of the input channels the derived signal from the sensor is in analogue form and the processing in the circulatory failure analyser is performed digitally. Thus the circulatory failure analyser combined with three sensors is a hybrid computer which carries out the function of diagnosis and clinical monitoring.

**Simulated signals**

The analyser was tested initially using simulated signals in the expected biological range. Heart rate was simulated with a delayed sweep and pulse generator (Rank Organisation) and an integrator (Mercury Electronics Limited). The original signal was also displayed on a calibrated oscilloscope (Telequipment Type D43R) to check the calibration and linearity of response of the integrator. Blood pressure was simulated with a mercury column. This static pressure signal was measured with a Statham strain gauge pressure transducer (P23D series) and the output signal was amplified (Honeywell 2585).

By means of a sphygmomanometer bulb the simulated blood pressure could be adjusted in the physiological range. Skin colour was simulated with colour filters applied to an ear oximeter of photocell type (Mercury Electronics Limited).

Each of the three input channels was tested individually using the simulated signals. All possible combinations of the three input channels were then examined. It was confirmed that the logic unit had been correctly programmed and that a correct diagnosis was obtained on the audio-visual output panel in each instance.

At high simulated heart rates of 250–400 beats/min the output voltage from the integrator was fairly constant and linear. A switching response was obtained for a change in rate of 30–50 beats/min. As the rate frequency was decreased fluctuations occurred in the output voltage and the sensitivity was greatly decreased. The response was satisfactory however in the range expected, in the experimental animal to be used, and modification was not therefore necessary for the present experiments. Voltage signals from the strain gauge transducer were shown to be linear after amplification and switching occurred with a change of 5–7 mmHg over a range of 0–300 mmHg. With the ear oximeter switching was achieved with voltage signal changes of ±20%.

Thus the tests with simulated physiological signals indicated that the logic of the analyser and the sensitivity of the sensors being used were suitable for biological testing.

**Biological signals**

Non-survival experiments were performed on eight New Zealand White rabbits of 3–4 kg weight. These were anaesthetized with intravenous urethane (2.0 g/kg) in a 50% aqueous solution. The trachea was exposed, divided and intubated with an endotracheal tube so that tracheal occlusion could be achieved when desired.

Electrocardiogram leads were attached to wet electrode plates fixed to the four shaved limbs of the rabbit and to a Honeywell electrocardiogram amplifier (Type 2581). The amplified signal was displayed on an oscilloscope and led to the integrator mentioned above. Clinical heart rate integrators count the R waves of the electrocardiogram. As the T wave in the rabbit is usually at the same peak voltage as the R wave the integrator used in this experiment had been specially designed to discriminate between the shorter narrow R waves and the longer wide T waves so that only R waves were counted. The carotid artery was cannulated and the catheter attached to the pressure transducer and amplifier described, and thence to the circulatory failure analyser and to a calibrated meter. The oximeter was firmly attached to the shaved ear of the rabbit and covered with black tape to exclude extraneous light.

After stabilisation of the three physiological parameters the control settings of the analyser were adjusted and tracheal occlusion was used to produce hypoxia of known severity. This experimental preparation had been studied (Levy, 1968) and information on heart rate, blood pressure and oxygen saturation in relation to duration of tracheal occlusion.
sion was known. Each of the three parameters was examined individually. This was achieved by setting the upper and lower limits of the other two parameters as far apart as possible so that for them the normal limits were very wide. It was found that, in each channel, the signals were processed by the logic unit as expected and the sensitivity of the individual sensors was in accordance with the results previously derived with simulated signals.

In the final series of experiments the limits of each parameter were set as they would normally be used in clinical practice. A variety of clinical emergencies was produced by variable periods of tracheal occlusion, alone or combined with controlled blood loss. In this way acute circulatory failure and cardiac arrest due to oligoemic shock or to hypoxia were produced. In most tests the period of occlusion required to produce the test condition was short and after each test the animal was allowed to return to a stable state. Thus each of the eight animals was used for multiple tests, culminating with cardiac arrest. In all instances the diagnosis made by the analyser unit was correct, as indicated by the meter and oscilloscope displays. The sensitivities of the heart rate sensor at ±10% and of the blood pressure sensor at ±5% were satisfactory but the sensitivity of the oximeter at ±20%, although useful, was too wide to give as early a warning as was desirable in all clinical situations. The sensitivity of the oximeter should be improved or an alternative parameter such as respiration rate substituted.

Conclusion

The aim of this study was to test a circulatory failure analyser when used as a patient monitor and diagnostic computer. In assessing the sensitivity of the analyser it became clear that an important limiting factor is the quality of the input information. Within these limitations the analyser functioned perfectly and processed the information in accordance with the clinical logic specified. A solid state clinical version of the analyser has been constructed (Greer, 1970) and the experimental results obtained with the prototype and presented here are sufficiently encouraging to warrant clinical trials.

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References


