THE USE OF A DIGITAL COMPUTER FOR THE ON-LINE REAL-TIME ASSESSMENT OF NEUROMUSCULAR BLOCKADE IN ANAESTHETIZED MAN

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SUMMARY

A computer program written mainly in a high level language (ALGOL), but with the sampling routine and certain calculations written in assembly language (SIR), has been developed to assess neuromuscular blockade in anaesthetized man by means of an Elliott 903 digital computer. The program allows the on-line real-time analysis of a range of variables including twitch height, maximum slope of twitch and twitch pulse widths, peak height of tetanic contraction, end-height of tetanic contraction, the tetanic tension ratio and the percentage tetanic transmission. The program has been used to investigate the pattern of action of neuromuscular blocking drugs and has particular value in the study of the pharmacokinetic action of these drugs.

Assessment of neuromuscular blockade in man during anaesthesia is commonly made by measuring the force of thumb adduction elicited by electrical stimulation of the ulnar nerve.

Recently, simultaneous measurements of both tetanic and single twitch contractions of the adductor pollicis muscle have been employed for this purpose and the method has proved useful for the determination of specific aspects of neuromuscular blockade in man (Sugai, Hughes and Payne, 1973). In this procedure both types of contractions are elicited continuously by electrical stimulation of the two ulnar nerves by different modes of stimulation.

A preliminary report of a computer technique using a PDP 12 computer to facilitate the analysis of results has been published previously (Garner, Sugai and Payne, 1973). Subsequently, however, it was found more convenient to rewrite the program for an Elliott 903 computer, since the availability of a visual display unit at the hospital linked to this computer made it possible to display the results on-line. With this program an on-line real-time analysis could be carried out, not only on the magnitude of tetanic and single twitch contractions, but also on other variables such as the degree of fade of tetanic contractions considered to be characteristic of the action of non-depolarizing agents (Paton and Zaimis, 1951).

METHODS

(a) Technique for recording the force of contraction of the adductor pollicis muscle

The force exerted by the thumb adduction of patients under anaesthesia was measured by the use of Statham force transducers (Model UC). Two force transducers were mounted one on each hand. A Statham transducer model UC/3 with load cell UL 4-20 was used for the measurement of tetanic contractions and one with a load cell UL 4-5 was used for the measurement of single twitch contractions. The frequency response of the transducers was flat from 0 to 90 Hz with any one of the load cells attached.

One ulnar nerve was stimulated tetanically for a duration of 1 sec at variable frequencies between 30 and 100 Hz at 12-sec intervals; individual pulses had a duration of 200 μsec. The other nerve was stimulated with single pulses of 200-μsec duration every 12 sec.

Figure 1 shows diagrammatically the force of contraction of the adductor pollicis muscle elicited by tetanic and single stimulations. The figures were produced by the Elliott 903 computer from the data obtained from an on-line and real-time analysis.

(b) Computer technique

The Elliott 903 program was written mainly in ALGOL, a high level computer language, but the sampling routine and part of the calculations were...
TETANIC CONTRACTION

CONTROL
(Sustained tetanus)

PARTIAL BLOCKADE
(Tetanic fade)

TETANIC TENSION RATIO = \( \frac{B}{A} \times 100 \) or \( \frac{D}{C} \times 100 \)

TETANIC TRANSMISSION = \( \frac{C}{A} \times 100 \)

SINGLE TWITCH CONTRACTION

NORMAL

PARTIAL BLOCKADE

Fig. 1. Diagrammatic representation of the force of contraction of the adductor pollicis muscle elicited by tetanic and single twitch stimuli and derived from data obtained from the on-line real-time neuromuscular blockade analysis program.

The relevant information is transmitted from the operating theatre in St Peter's Hospital, Covent Garden by means of a three-channel telephone data link (Hill and Payne, 1972) through the switched telephone network to the computer at the Royal College of Surgeons. The three signals, the stimulus, the tetanic contraction and the single twitch responses are fed into amplifiers on the input interface of the Elliott 903 computer. The tetanic and single twitch signals are then delivered to two channels of the analogue-to-digital converter of the Elliott 903 and the stimulus is supplied to a digital input to trigger the program. The twitches and stimuli are also recorded on a Mingograf recorder for comparison with the original signals transmitted from St Peter's Hospital. In addition, the signals are recorded on a Thermionic Products T3000 instrumentation tape recorder for analysis at a later date if problems arise with the computer at the time of the run; for the convenience of the computer operator they are also displayed on a Lan-Elec 4 channel oscilloscope. Figure 2 is a schematic diagram of the arrangement for the computer analysis of neuromuscular blockade.

EQUIPMENT AT ST PETERS HOSPITAL

Fig. 2. Schematic diagram of the arrangements for the computer analysis of neuromuscular blockade.

Tetanic and single twitch responses are analysed simultaneously. The twitch signals are digitized at the rate of 75 samples/sec for 1.8 sec starting as soon as the stimulus occurs. After the sampling of the
twitches has been completed the following variables are calculated: twitch heights, maximum twitch slopes and twitch pulse widths, end-height, peak-height and turning point of the tetanic contraction, and the tetanic-tension ratio and an alternative version of the tetanic-tension ratio (turning point height/peak tetanic height). Immediately after calculation, the results are transferred to paper tape and to two visual display units (VDU), one of which is in the computer room and the other in the operating theatre. After the results have been transferred, the baselines are sampled ready for the measurement of the next set of twitches. The VDU at St Peter's Hospital is connected to the computer by a standard telephone data link. Once the program has been loaded into the computer its operation can be controlled completely from the Hospital by instructions given to the computer through the VDU.

A special version of the program was produced which did not have visual display input and output facilities, but which could run at twice or four times the speed of the main program. This meant that time could be saved if data had to be tape-recorded and analysed off-line.

Before the first injection of the neuromuscular blocking agent is given five sets of contractions are analysed to provide control values. The program is then set running again and, using the stored mean control tetanic height, the tetanic transmission (peak tetanic height/control peak tetanic height) is calculated together with the other variables at 12-sec intervals. Figure 3 shows an example of the print-out of such an analysis. In addition to the analysis, the computer can be used to plot graphs of the tetanic-tension ratio against the tetanic transmission for the duration of each experiment as shown in figure 4.

**Fig. 3.** Example of a print-out from the neuromuscular blockade analysis program. Such outputs are used to produce the type of diagram illustrated in figure 4. The print-out indicates the type and width of the pulse, the maximum height of the contraction (MAXH) the maximum rate of increase of the slope (MDP/DT) and the height at the off-set of the contraction (OFFH) as well as the tetanic tension ratios (TTR1, TTR2) and the tetanic transmission (TT) expressed as percentages. The remaining data are concerned essentially with the proper running of the program.

**Fig. 4.** The relationship between tetanic-tension ratio and tetanic transmission after the injection of a non-depolarizing type of drug. The diagram was produced by the Elliott 903 computer from the data obtained from the on-line real-time program. This is followed by a marked reduction in both transmission and tetanic-tension ratio as the drug becomes effective. The sigmoid curve indicates the recovery process.

**DISCUSSION**

For some years the measurement of the single twitch contractions of the thumb has been used widely for the monitoring of neuromuscular blockade in man (Katz, 1965). More recently, the measurement of tetanic contractions of the adductor pollicis has been shown to be important for this purpose, since such contractions are not only more sensitive to both
depolarizing and non-depolarizing agents, but also show a different response to many situations (Sugai, Hughes and Payne, 1973).

The method described employs the simultaneous measurement of both tetanic and single twitch contractions of the thumbs for the assessment of neuromuscular blockade in man. The use of a digital computer enables fast and simultaneous analysis of the two types of calculation to take place on-line and in real-time.

One problem associated with this method is that, during anaesthesia, the resulting neuromuscular blockade paralyses the respiratory muscles and this deep neuromuscular blockade usually abolishes the adductor pollicis contractions completely, so that it is impossible to detect further change in the extent of neuromuscular blockade by measuring the force of the addition of the thumb (Bodman, 1952).

In addition, anaesthetic agents potentiate the effect of neuromuscular blocking agents so that it is difficult to isolate the action of neuromuscular blocking agents in these instances.

Despite these limitations, the present method is useful during recovery from neuromuscular blockade and also during clinical pharmacological investigation under controlled conditions. In the latter case, anaesthesia is usually controlled rigidly and a dose of neuromuscular blocking agent is chosen to cause only partial paralysis of the adductor pollicis muscles. The method has particular value in the study of the pharmacokinetics of neuromuscular blocking drugs (Levy and Gibaldi, 1972).

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REFERENCES
L'UTILISATION D'UN ORDINATEUR NUMERIQUE POUR L'EVALUATION DIRECTE EN TEMPS REEL D'UN BLOCAGE NEUROMUSCULAIRE CHEZ L'HOMME ANESTHESIE
RESUME
On a mis au point un programme d'ordinateur qui a été dans l'ensemble préparé en langage évoluté (ALGOL), alors que l'échantillonnage de routine et certains calculs sont écrits en langage d'assemblage (SIR), pour évaluer à l'aide d'un ordinateur numérique Elliott 903, le blocage neuromusculaire de l'homme anesthésié. Ce programme permet d'effectuer l'analyse en direct, en temps réel, d'une série de variables, entre autres la hauteur d'une crispation, son coefficient angulaire et ses largueurs d'impulsion, la hauteur de pointe d'une contraction tetanique, la hauteur de fin de contraction tétrantique, le rapport de tension tétrantique et le pourcentage de transmission tétrantique. Le programme a été utilisé pour étudier le type d'action des drogues provoquant le blocage neuromusculaire et il présente une valeur particulière dans l'étude de l'action pharmacocinétique de ces drogues.

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USO DE UNA COMPUTADORA DIGITAL PARA LA EVALUACION EN DIRECTO Y EN TIEMPO REAL DEL BLOQUEO NEUROMUSCULAR EN EL HOMBRE ANESTESIADO
SUMARIO
Se ha desarrollado un programa de computadora principalmente en un lenguaje a nivel superior (ALGOL), pero con la práctica de maniobras y ciertos cálculos escritos en lenguaje de reunión (SIR), para determinar el bloqueo neuromuscular en un hombre anestesiado, utilizando una computadora digital Elliot 903. El programa permite el análisis en directo y en tiempo real de una serie de variables que incluyen la altura de los picos, su máxima pendiente y la anchura de los picos de las contracciones tetánicas y el porcentaje de su transmisión. Se ha usado el programa para investigar el cuadro clínico de la acción de las drogas del bloqueo neuromuscular y tiene especial valor en el estudio de la acción farmacocinética de dichas drogas.