THE ANAESTHETIC MACHINE—A STUDY OF FUNCTION AND DESIGN

G. BOQUET, J. A. BUSHMAN AND H. T. DAVENPORT

SUMMARY

A study of the time and motion of the anaesthetists' routine activities was made using conventional equipment. Films of manual and visual movements were studied in detail and the expectations of certain consultant anaesthetists regarding apparatus were recorded. Models of apparatus were used to test their acceptability. A modular system appeared preferable to a work station or to adaptation of present designs. More work and the construction of prototypes are indicated if the anaesthetic machine is to be modernized.

The aim of this study was to design an anaesthetic machine and some associated equipment with emphasis on the anaesthetist's working procedures and ergonomic factors concerning control and display. The designer (G. B.) had never previously been associated with the anaesthetic procedure, hence he had no preconceived ideas. Broad, preconceived ideas were contributed by the anaesthetist preceptors (J. A. B. and H. T. D.). For example, it was considered that a ventilator and monitoring devices were to be integral parts of a modern anaesthetic machine. The study tried initially to produce an understanding of how the anaesthetist used individual pieces of equipment and how he related to the surrounding activities.

An analysis of the anaesthetist's work was carried out during the induction and maintenance of anaesthesia. For each activity we attempted to define: duration, frequency, relative importance, and relationship to other activities and equipment.

METHODS

To study the anaesthetic procedure 15 operations were analysed using a filming technique. Initially, a single video film was made of an anaesthetic in progress, but on studying this there were too many limitations when using a single camera. The anaesthetist's activities were carried out over a wide area and it was impossible to record them all with a single conventional camera. It was found that there was a distinct difference between his visual and his manual activities and it was felt necessary to study both functions separately. Manual activities were recorded by a single video unit positioned behind the anaesthetist's working area where, with a wide-angled lens, all the equipment the anaesthetist would be likely to use could be included. Visual movements were more difficult to record, but this was achieved finally by using a Nac eye mark recorder. This device consists of a head piece which the subject wears throughout the recording time and, via a system of lenses and half mirrors, an image is produced that can be recorded on the video tape. The image is a view in the direction in which the subject is looking and on that image, by means of a light reflected off the cornea of his eye, a small arrow shows precisely on what object his eye is focusing. The angle of the full image in the horizontal and vertical plane is only 80° and therefore occasionally when the wearer looked at an object outside this viewing angle the arrow disappeared. However, over the duration of filming we undertook the number of times this happened was negligible.

Filming was carried out at two London Hospitals, St Peter's, Covent Garden, and Northwick Park, Harrow. The two hospitals have different operating theatre environments: Northwick Park is modern and newly equipped, whilst St Peter's is older and less sophisticated.

The four anaesthetists studied were one very experienced consultant, two experienced registrars and one relatively inexperienced senior house officer. Sixteen hours of filming was carried out and included a representative cross-section of the types of general anaesthetics performed at these hospitals.

Once the filming was concluded an extensive study was made of 31 manual and 26 visual activities,
these being noted every 0.5 s. These data were then entered onto a computer file to facilitate sorting and statistical analysis. The processed data were collated as follows:

1. The amount of time during which each activity occurred was expressed as a portion of the total anaesthetic time.
2. The percentage of time each manual activity occurred with each visual activity.
3. At what time and for how long each individual activity occurred.
4. The frequency with which each individual activity occurred before or after another.
5. How often a particular sequence of activities occurred.

To complement this numerical information it was thought necessary to produce an importance rating for each manual and visual activity. Seven consultant anaesthetists were asked to list manual activities and the visual activities in order of importance to the patient's well being. An average importance rating, ranging from 0 to 10, was produced for each activity.

RESULTS

1. The percentage of time each activity occurred (fig. 1)

It was apparent that the patient or surgical field took up approximately 60% of the anaesthetist's visual activity time, 40% of his visual activity time being occupied elsewhere. Of the other activities, the anaesthetic reservoir bag was the most observed dynamic display, taking up 10% of time. Other static and dynamic displays, that is, monitors, flow meters and vaporizers, each took up 3% of visual time and were observed less than the charts or sphygmomanometer. Visual contact with the ventilator was small, about 1%. However, the fact that the bellows' movement can be heard in the type used may explain why the anaesthetist did not look at the ventilator except when altering controls. Over the periods of recording the emergency oxygen switch was not used.

With regard to manual activity, during 72% of their time the anaesthetists were inactive (idle time). The more physical idle time occurs, the more it allows time for collecting of data from either the patient or the equipment. The most manual activities were contact with the patient and writing on the anaesthetic record, each of which required 6% of anaesthetic time. The anaesthetic record time ties in with the measurement of arterial pressure, being about 4% of the time, as they were usually carried out consecutively. The fact that there was little difference between the total visual recording activity and the plotting of the results would indicate that the records were infrequently used purely for reference purposes, but were mainly used for recording of events. Adjusting or altering the monitoring device occupied similar amounts of time, 5% of total manual time. However, below this level of activity, no other occurred for more than 2% of total time, with flow meter and vaporizer attention being close to this figure. There was little use of the anaesthetic reservoir bag for hand ventilation of the patient, which occupied only 0.4% of the time. (The

![Fig. 1. The percentage of time taken by various visual and manual activities during the anaesthetics filmed.](https://academic.oup.com/bja/article-abstract/52/1/61/252806/571252806)
Northwick Park Hospital anaesthetic machine has a built-in ventilator. Time taken with monitoring gas pressure, visual and manual together, was also only about 2%. This result was affected by the one hospital having a pipe-line gas supply. Gas pressure was checked as often as the flow meters and vaporizers where a cylinder supply of gas was used.

(2) The percentage of time for each activity in each quarter of the anaesthetic time

Frequency percentage of activities was split into four quarters of the different times when activities or groups of activities occur. The majority of the displays, that is flow meters, vaporizers, monitors and the anaesthetic reservoir bag, were all checked less as the operation continued. This would seem to indicate either a decline in the need to check them or diminishing concentration. The quietest period, visually and manually, occurred in the third quarter of the anaesthetic. Visually, there was much more activity within the surgical field in this quarter, which would indicate a reduction in all the other activities or perhaps a concern in the progress of the operation. The last quarter showed a return to more activity, visual and manual, towards the patient and the machine work top, but a low percentage of activity with most of the control and display units. There was obviously more concern with control and display units during the first quarter, when the anaesthetist was anxious to ensure that he was in control of various functions. The anaesthetic record was used consistently for the first three-quarters, but there was a sudden decrease in use in the final quarter which was the result of the lack of activity in the third quarter or other activities being required as the anaesthetic ended.

(3) The average duration of each activity (fig. 2)

The results in this section did not prove as helpful as was hoped. The duration, visual and manual, ranged between 3 and 8 s, with few exceptions. Manual idle time had by far the longest average duration—55 s. There was a block of four manual activities which ranged from 15 to 19 s, these were measurement of arterial pressure, recording, manual ventilation and attention to the patient. Some of these activities are related, and if the duration of time spent between each could be decreased then there would be more time available for collecting vital data. The time spent looking at the breathing bag, vaporizers, flow meter and gas pressure was very short, between 2 and 5 s. This would indicate that there was a large number of separate observations. Therefore, the display and controls should be positioned so that the movements of the anaesthetist's eye and head are decreased as far as possible.

(4) Importance of each activity (fig. 3)

An importance rating was produced to complement the data on how long each activity occurred. Some individual activities may be highly important but used very occasionally. There were variations
between different hospitals, because of the use of pipe-line or cylinder gas supply. Gas pressure and cylinders were given greater importance in the hospital with no pipe supply. The patient featured most in visual and manual activities. Visually, the four dynamic displays—that is, the reservoir bag, flow meters, monitors and ventilators—were the next important with least attention being paid to the vaporizer, probably because the vaporizer control is a static display. The rating of manual activities followed the same basic pattern, but the manual activity with the monitor was perhaps considered less important because it did not directly affect the patient. Also, the vaporizer adjustment was higher on the manual activity rating. The rating of importance of charts, manual and visual, was surprisingly low, but this may have been because they are used for recording facts which were used principally in a retrospective manner with regard to the care of the patient. Emergency oxygen control was rated low visually, but the manual rating was thought quite important. The disposal of rubbish and soiled apparatus was given little importance in rating; this is surprising.

(5) The frequency of connection between visual and manual activities

The interface value was a study of the sequence of activities to find out what activities occurred in relation to each other. There was generally much less manual than visual movement from one activity to another. However, certain manual movements do stand out. By far the strongest relationship was between the sphygmomanometer and the chart, a sequence which occurred continually throughout the anaesthetic. There was also a tendency to alter the vaporizer setting after altering the flowmeter, and there was a relation between the activities involving the patient, anaesthetic circuit and work top. Generally, the same groups applied in respect of visual and manual activity, therefore the interface study suggests the positioning of apparatus can be modified to be more efficient. The most notable connected visual movement was between the patient, surgeon and reservoir bag. Secondary visual activity was directed to the displays such as gas pressure, flow meters, vaporizers and monitors which were viewed in different orders (fig. 4).

DESIGN CONCLUSIONS

The results described were the more obvious and, possibly, more important. The information that can be obtained from the data is greater than was used in the present design. It was accepted that there may have been flaws in the methods used concerning, for instance, the number of hours filmed and the number of anaesthetists questioned and evaluated.

However, with the limits of time and equipment available it was felt that a reasonable sample was studied. The design conclusions that were drawn from this work were:

1. A better organized arrangement for control and display units could be used to relate to the anaesthetist's working situation.
2. A rationalization of the specific needs of work surface and storage could be envisaged.
FUNCTION AND DESIGN OF ANAESTHETIC MACHINES

(3) A rationalization of the inter-relationship of pieces of equipment is possible.

(4) Adaptability is essential to suit the different induction room and operating theatre requirements of individual anaesthetists.

These conclusions were then applied to a design by a process explained briefly below. First, sketches were made to study possible arrangements of control, display and work surface. These sketches were very schematic and more detailed ideas were then produced. Three systems, which covered the majority of possible arrangements, were studied. These were adaptation of the present system, a modular system and a work station system. From these ideas four full-sized cardboard mock-ups were produced of the anaesthetic work area and apparatus. These were then tried out functionally and shown to a number of anaesthetists and manufacturers whose comments and opinions were noted.

After rejection of some systems a more detailed mock-up was produced of the modularized system with a number of small variations and these were studied again. Because of the importance of control and display activities it was necessary to position them as close to the patient as possible without interfering with access to the patient. By splitting the control and display units into three modules positioned vertically, a compact system was produced with good display characteristics. The lowest module housed the gas pressure gauges, the flow meter and vaporizer controls. The middle module was the ventilator unit with the carbon dioxide absorber with its attached circuit and reservoir bag. The top module carried no gas flow and housed the electrocardiograph, the pulse monitor, respiration monitor and arterial pressure gauge. The reservoir bag, being the most checked visual display, was positioned close to the patient's head.

With the modules placed on top of each other, a slim unit was produced which occupied a relatively small surface area and could be positioned equally well on either side of the patient. An angled chart board was attached permanently to the unit because of the relationship between the arterial pressure gauge, monitors and chart work. The work surface and storage were treated separately because, apart from the chart work, the work surface activities had little direct relation to the control and display activities. Therefore, the work surface and storage units could be positioned to suit the individual anaesthetist's working arrangements (fig. 5). If required, the work surface unit could be attached to the control and display units to produce a complete traditional British style anaesthetic machine. The
Fig. 5. A photograph of the model anaesthetic machine with vertical modules at the side of the head of the operating table with the adjacent work and storage units.

system would be equally suitable for pipe-line or cylinder gas supplies.

COMMENT

The present design of the anaesthetic machine has, to a great extent, evolved historically. There are, of course, various makes which differ slightly, but the majority of machines in Britain have the arrangement of the original Boyle’s apparatus. Our ergonomic study was, of course, biased to a large extent by the fact that such apparatus was used. If the prototypes of new concepts (Cooper et al., 1978) could be studied in this way we may find that what we have now is what we are used to rather than the ideal.

As only one similar article on the subject in English is known to us (Drui, Belm and Martin, 1973) further study does seem indicated.

REFERENCES


FUNCTION AND DESIGN OF ANAESTHETIC MACHINES

Dans cet article d'autres travaux à effectuer ainsi que la marche à suivre pour la construction de prototypes dans le but de moderniser la machine à anesthésier.

DIE MASCHINERIE DER ANÄSTHESIE—EINE FUNKTIONS- UND KONSTRUKTIONSSUDIE

ZUSAMMENFASSUNG

LA MAQUINA ANESTETICA—UN ESTUDIO DE SU FUNCION Y DISEÑO

SUMARIO
Se llevó a cabo un estudio de tiempo y moción de las actividades rutinarias del anestesista al usar el equipo convencional. Se estudiaron las películas de los movimientos visuales y manuales en detalle y se registraron las expectativas de ciertos anestesistas consultores respecto de los aparatos. Se realizaron pruebas con modelos del aparato para comprobar su aceptabilidad. Un sistema modular pareció ser preferible para una estación de trabajo o para su adaptación al diseño actual. Será necesario llevar a cabo mayores trabajos y construir prototipos si se quiere modernizar la máquina anestetica.