at which only paced beats occur, may be surprisingly slow and is rarely above 90 beats/min. Fig 5A shows the ECG of a patient who had just been resuscitated after ventricular fibrillation, and shows the R-on-T phenomenon with bursts of ventricular activity. Ventricular fibrillation occurred twice more in the next few minutes but, as shown in Fig 5B, the abnormal rhythms were completely suppressed by pacing at 68 beats/min. This method of preventing ventricular fibrillation should at least be considered in any patient showing multiple ventricular ectopic beats after an infarct.

Poisoning

Cardiac arrest related to poisoning is a fairly rare event in hospital. Of 7 such cases, all with asystole, 3 were due to barbiturates, 2 to digoxin and 2 to quinidine.

The 3 cases of barbiturate poisoning all had airway obstruction and 2 were resuscitated by external massage and oxygen alone: the external pacemaker was used in the third case, probably unnecessarily. The other 4 cases were iatrogenic although one of the patients took a large overdose of digoxin by mistake. External pacing was rapidly effective in all 4 patients, although it was needed on 3 separate occasions in the case of one elderly man with quinidine arrest. All 7 patients recovered and are mentally normal eight to twenty months later.

Table 2
Electrical energy needed for pacing and defibrillation

Technique	*Electrode site*	*Impulse energy (Joules)*
Defibrillation	On heart	40
	On chest wall	200
Pacemaking	In right ventricle	0·000005
	On heart	0·00005
	On chest wall	0·05

It is apparent that the technique of artificial pacing can be usefully employed in many patients with cardiac arrest, and it is interesting to compare the amounts of electrical energy needed for pacing with those required for defibrillation. Table 2 gives approximate figures and is based on work to be reported fully elsewhere. These figures can be better appreciated by realizing that the total energy needed to pace the heart via an electrode catheter at 60 beats/min for one year would light a 100 watt bulb for only one second; the same bulb would light for two seconds with the energy needed for a single impulse in closed chest defibrillation.

Summary: Artificial pacemaking can be applied to the treatment of cardiac arrest in two ways. It can be used to restart the heart from asystole and then maintain a high cardiac output, or it can prevent the onset of ventricular fibrillation. The procedures are simple and do not require complicated or dangerous apparatus.

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Organization of a Resuscitation Service and Results of Treatment

The term 'cardiac arrest' is used to describe the sudden and unexpected failure of the heart to maintain an adequate cardiac output. This may be due to a complete arrest of the heart, to ventricular fibrillation, or to an extreme weakness of the normal beat. Whatever the cause, the effects are the same: the pulse disappears, the patient becomes unconscious and, after a few gasps, breathing stops. The pupils dilate and there may be facial twitching or convulsions. Tissue damage occurs immediately but may be minimized, or indeed reversed, by the artificial maintenance of both circulation and respiration.

Resuscitation can only be effective if it is started immediately and is efficiently performed. To ensure success all medical and nursing staff must be thoroughly trained and the correct equipment and drugs must be readily available.

ORGANIZATION

The responsibility for the organization of a resuscitation service has been delegated to a subcommittee of the Medical Committee. This subcommittee is convened by the Resuscitation Officer and it meets at regular intervals to assess results and to decide future policy. The Resuscitation Officer is responsible for the day-to-day running of the service, the provision and maintenance of equipment and for the training of doctors and nurses.

Aims

It has been decided that an attempt should be made to resuscitate patients in the following categories:

(*a*) All patients sustaining a cardiac arrest as a direct result of any medical or surgical procedure however trivial. This includes all patients undergoing surgical operations, medical or radiological investigations and the injection of drugs.

(*b*) All patients collapsing in the outpatient or casualty department.

(*c*) All post-operative patients.

(*d*) All patients thought to have a myocardial infarct or Stokes-Adams attack.

(*e*) Other patients designated as being at special risk by the consultant in charge (e.g. patients in renal failure or undergoing treatment with quinidine).

Treatment

Treatment is based on the principle that the person on the spot is responsible for diagnosing the arrest and for establishing artificial ventilation and an effective circulation: this is then maintained until more definitive treatment, aimed at restarting the heart, can be carried out by the duty surgeon and anæsthetist.

This scheme has several practical advantages. It simplifies the teaching required by restricting the more complicated procedures to experienced personnel and yet it ensures that an effective artificial heart-beat is provided within the shortest possible time. Economies can also be effected in the provision of equipment, since only the simplest apparatus need be immediately available. The more expensive apparatus can then be concentrated at certain strategic points throughout the hospital.

Equipment

Ideally, every ward and department should be equipped with a full set of resuscitation apparatus. Since the cost of this would be prohibitive, some simpler scheme has to be devised. The equipment is now distributed as follows:

(1) On every anæsthetic trolley there is clipped a Perspex tube containing a sterile syringe and 5 ml ampoules of calcium chloride (10%) and adrenaline (1/10,000).

(2) Between each pair of wards an inflating bellows, facemasks, pharyngeal airways, a knife and drugs (approximate cost £20 per set).

(3) At sites of special risk and at other strategic points—ten cardiac arrest trolleys (Sykes 1960). These contain all the apparatus necessary for intubation, an oxygen inflation unit, oxygen Venturi suction, cardiac and anæsthetic drugs, sterile scalpel and disposable syringes (approximate cost, including equipment, £70 each).

(4) In the main theatres and in the angiocardiographic unit – two larger trolleys each containing an electrocardiograph, internal/external defibrillator, spare oxygen cylinder and a thoracotomy drum. The latter contains sutures, instruments and drainage tubing for closing the chest. (Approximate cost £300 complete). Similar thoracotomy drums have now been added to the cardiac arrest trolleys situated in the cardiac, renal and pædiatric wards.

Training

Since it is unlikely that medical staff will always be present when a cardiac arrest occurs, it is obvious that both medical and nursing staff must be trained in the recognition and emergency treatment of cardiac arrest. If experienced cardiologists or thoracic surgeons are resident within the hospital, the more definitive treatment of the heart can be left to them. If the number of resident staff is more limited it is necessary to train at least some of them to undertake thoracotomy, defibrillation and pacemaking.

At Hammersmith Hospital instruction is given to each department twice a year, to coincide with the new intake of resident staff. Nurses receive instruction at the commencement of the second year of training and again on the assumption of staffing duties.

The lectures given cover diagnosis, principles of treatment and the organization of the service. Detailed instruction is given on the maintenance of the airway, expired air resuscitation and external cardiac compression. The techniques are demonstrated on a Resusci-Anne manikin. This is also used by the Sister Tutors, for the individual training of nurses. Further aspects of the technique are illustrated by a short film which concludes the lecture.

Procedure

When a cardiac arrest occurs the diagnosis is made by the nurse or doctor on the spot. The airway is cleared and artificial ventilation and external cardiac compression are commenced. The telephone operator is now informed. She immediately 'bleeps' the duty thoracic surgeon and duty anæsthetist and if she gets no reply within thirty seconds she issues a general 'cardiac call' on the Tannoy. Meanwhile a nurse has fetched either the ward resuscitation box or a cardiac arrest trolley and a porter has been dispatched to fetch the nearest defibrillator trolley.

The definitive treatment of the heart is decided after an ECG has been obtained and the duty surgeon and anæsthetist have arrived. If ventricular fibrillation is present and external compression is effective external defibrillation is attempted. If this fails, if external compression is ineffective, if the heart is in asystole or if there is a possibility of intrathoracic hæmorrhage, thoracotomy is performed and the appropriate manipulations are carried out internally.

RESULTS

Material

This analysis covers a seven-year period from December 1, 1956, to November 30, 1963. The Resuscitation Service was introduced in December 1959. Before this date the only source of case records was the Medical Records Department. After this date, names of patients suffering a cardiac arrest were obtained from the telephone supervisor (who records all emergency calls) and from a special book kept in the Anæsthetic Department. This book is also used to record critical comments on the organization of the service and on the adequacy of the equipment provided.

In the three years before 1959 there are records of 20 patients who had a cardiac arrest, 4 of whom survived. In the four years after the introduction of the service there are records of 263 cardiac arrests occurring in 231 patients. In the seven-year period from 1956–63 there were records of 283 cardiac arrests occurring in 251 patients. This may, at first sight, appear to be a relatively high incidence of cardiac arrest. There are two reasons for the large number of arrests. First, special units such as the Cardiothoracic Unit and Renal Unit tend to attract a high proportion of severely ill patients in whom there is a high risk of cardiac arrest. Secondly, if the service is extended to wards and outpatient departments, it is inevitable that a certain number

Table 1

Age distribution of 251 patients with cardiac arrest 1956–63

Age (years)	0–9	10–19	20–29	30–39	40–49	50–59	60–69	70–79	80+
No. of cases	41	16	24	26	35	50	40	14	5

Table 2

Results of treatment 1956–63

Year (Dec. 1–Nov. 30)	*No. of patients treated*	*No. of arrests*	*No. of survivors*	*Survival rate (%)*
1956–9	20	20	4	20·0
1959–60	39	49	5	12·8
1960–61	47	57	4	8·5
1961–62	75	79	12	16·0
1962–63	70	78	9	12·8
Total 1956–63	251	283	34	13·5

Table 3

Disease precipitating admission to hospital 1956–63

	No. of patients	*No. of survivors*
Congenital or acquired heart disease (excludng ischæmic)	87	10
Ischæmic heart disease	40	7
Renal failure	30	2
Malignant disease	18	2
Poisoning	5	1
Trauma	5	1
Pneumonia	5	1
Pulmonary embolism	13	2
Miscellaneous	48	8
Total	251	34

Table 4

Sites of cardiac arrest 1956–63

Place	*No. of patients*	*No. of survivors*	*Survival rate (%)*
Operating theatres	19	9	47·4
Wards	148	13	8·9
Medical departments	4	3	75
Radiodiagnostic department	7	5	71·4
Casualty and out-patient departments	26	2	7·7
Recovery ward	47	2	4·3
Totals	251	34	13·5

Table 5

Factors precipitating the initial cardiac arrest in 34 survivors 1956–63

	No. of cases
Induction of anæsthesia	5
During operation or diagnostic procedure	7
Post-operative	7
Stokes-Adams attack	4
Pulmonary embolus	2
Myocardial infarct	3
Renal failure	2
Miscellaneous	4
Total	34

Table 6

Survival rate related to method of treatment

	External		*Internal*		*External-internal*	
Year	*Survived*	*Died*	*Survived*	*Died*	*Survived*	*Died*
1956–61	0	0	13	93	0	0
1961–2	7	30	1	9	4	24
1962–3	8	38	0	0	1	23
Totals	15	68	14	102	5	47
Survival rate (%)	22·0		13·7		10·6	

Table 7

Results of treatment – 78 cardiac arrests in 70 patients 1962–63

Number of arrests	*Method*	*Compression effective*	*Spontaneous heart beat*	*Pre-arrest CNS and CVS states*	*Ultimate survival*
54	External	36 (67%)	24 (44%)	17 (31%)	8
24	External-internal	8 (33%)	6 (25%)	3 (12%)	1
78●		44	30	20	9

●Treatment abandoned on 18 occasions when true nature of disease process became known to operator of patients will be treated unnecessarily, since the full facts of the case may not be available to the person on the spot when the arrest occurs. In this series, this situation has happened not infrequently. Fortunately, the use of external compression has largely eliminated the distress caused to relatives by over-enthusiastic treatment.

The age distribution of the patients treated is shown in Table 1. A further analysis of the results is presented in Tables 2–7.

Complications of Treatment

As would be expected from such a vigorous approach a certain amount of physical damage to the subject is inevitable. However, serious complications have been infrequent. The sternum has been fractured in 2 patients who survived and ventilation had to be maintained mechanically until fixation was achieved surgically. Unfortunately, one of these patients subsequently died. Other cases have suffered fractured ribs, and a hæmothorax has been seen on a number of occasions.

One rather startling complication of external cardiac compression has been the rapid return of consciousness resulting from effective treatment. For this reason we have now added a supply of anæsthetic drugs to the cardiac arrest trolleys.

Conclusion

Every hospital should make its own arrangements for the emergency treatment of cardiac arrest. It is essential to ensure that equipment is adequate and that both doctors and nurses receive regular instruction in methods of treatment.

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Automatic External Cardiac Massage Machine

Some eighteen months ago it was thought that it might be useful to investigate the effects on the circulation of prolonged external cardiac massage or compression. The experiments required that the rate of compression and the pressure wave contour should, though variable, be constant, once set, for periods of over an hour.

An automatic machine analogous to a respiration pump was designed in conjunction with a firm of engineers specializing in automatic air powered machines in industry. The power required to carry out external cardiac massage in the human patient is relatively large – between a quarter and a half horsepower – and this output can be maintained for only ten minutes or so by the average man. It was intended that the machine design should be such that it could be adapted to human use in emergency and that it should be fully portable. These requirements excluded electric mains or batteries as a prime energy source and as oxygen is necessary for lung inflation its simultaneous use as a source of power seemed desirable. It is possible to design a machine in which the chest compression ram is operated by compressed gas while the timing circuit is operated by electrical or electronic means but this mixture of actuating sources is likely to be unreliable in an apparatus which may remain idle for long periods and may be subjected to rough and unskilled handling. The extension of automation in industry has shown that operations of the type required by external cardiac massage through the unopened chest wall are best carried out by compressed gas devices and that such machines can be accurately controlled by air-operated timing circuits.

The prototype machine shown in Fig 1 weighs 20 lb and, once set, is simple to operate even by semi-skilled persons. The usual 24 cu. ft. oxygen cylinder will run it for about half an hour and the frame can be fitted over the human chest in less than a minute. The timing circuit can be set to compress the chest at any desired rate and for a variable number of strokes when the machine automatically stops to inflate the chest. The pressure applied to the chest is infinitely variable, without stopping the machine, from a few pounds to over 100 lb. The force applied is indicated by a gauge close to the hand wheel controlling it. This control is the only one requiring attention during operation of the machine, the rate and pressure wave configuration having been set in

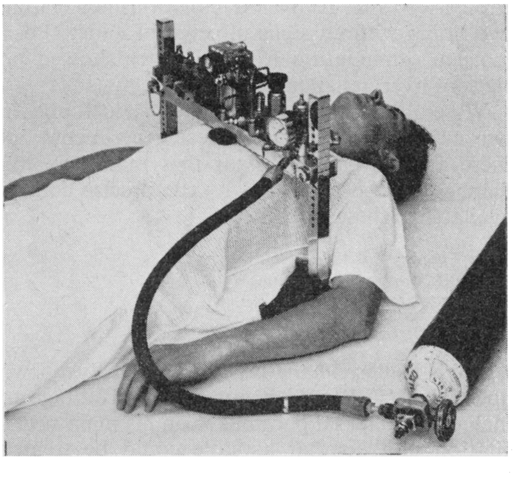

Fig 1 *Automatic portable cardiac compressor.* (*Reproduced from Bailey* et al. *1964, by kind permission*)