TREATMENT OF SEVERE CASES
OF RESPIRATORY PARALYSIS BY THE
ENGSTRÖM UNIVERSAL
RESPIRATOR

BY

CARL-GUNNAR ENGSTRÖM, M.D.

*(From the Municipal Hospital for Infectious Diseases,
Stockholm)*

Respiratory paralysis is by no means exclusively a complication of certain infectious diseases—above all of poliomyelitis—but it represents in many medical and surgical ailments the decisive accident that causes the fatal issue. Apart from cardiac and circulatory failure, the arrest of spontaneous breathing is the most frequent cause of death. If it could be controlled, a way for later reconstitution of health would be opened for many patients. When respiratory paralysis is caused by lesions in the rhombencephalon it is not infrequently accompanied by other complications of a central origin, of which deglutitive insufficiency with its risk of aspiration, central circulatory failure, hyperthermia, and coma (or stupor) may be mentioned. Treatment then becomes an intricate and many-sided problem for both doctor and nurse.

During the years 1949 and 1950 Sweden was ravaged by severe, widespread epidemics of poliomyelitis, which offered a mass of material for study of these problems. At that time respiratory paralysis of poliomyelitis was treated at the Stockholm Hospital for Infectious Diseases, with two types of cuirass respirators, called after their inventors Sahlin and Freiberger. In spite of supplementing this therapy with tracheotomy, the mortality from respiratory paralysis of central origin, with paralysis of deglutition and other symptoms of brain-stem encephalitis, was about 85%. Clinico-physiological studies on these respirator cases showed that the fatal issue was usually due to an increasing retention of carbon dioxide ; application of an additional oxygen supply kept the oxygen saturation in the arterial blood at normal levels (Engström, 1950 ; Engström and Svanborg, 1950, 1952), as the following typical case history demonstrates.

A 35-year-old patient, pregnant for seven months, fell ill with poliomyelitis on November 6. Two days later a rapidly progressing respiratory paralysis with pareses of the upper extremities supervened. A body respirator was applied, artificial respiration being supplemented by oxygen through a nasal catheter. However, the patient could not synchronize with the respirator, she was restless, and obviously worse. On November 19 tracheotomy was performed because paralysis of the larynx was suspected. In spite of continual oxygen supply by tracheal cannula, blood transfusion, and intravenous drip infusion, her general condition continued to deteriorate. Death occurred at 6 p.m. the following day. At necropsy atelectases of the lungs, lung oedema, and cyanosis of organs were found.

As a result of these studies it was recognized that these body respirators were not sufficient for artificial respiration of severe cases, especially with regard to proper elimination of carbon dioxide. At this point I started trials with intermittent insufflation, and it soon became clear that the unfavourable influence of (purely inspiratory) positive-pressure breathing on the circulation could be avoided by completing the respiratory cycle with an active expiration (rhythmical compression of the thorax).

Based on these experiences, a respirator was constructed (Engström, 1953) which produced an active insufflation and an active expiration either by compression of the thorax or by means of an intermittent negative-pressure phase.

Method

The respirator (Figs. 1 and 2) gives an active insufflation with a predetermined volume which is passed direct into the air passages by means of a face-mask, an intubation catheter, a tracheal tube, or an intratracheal cannula. The active expiration is produced by mechanical compression
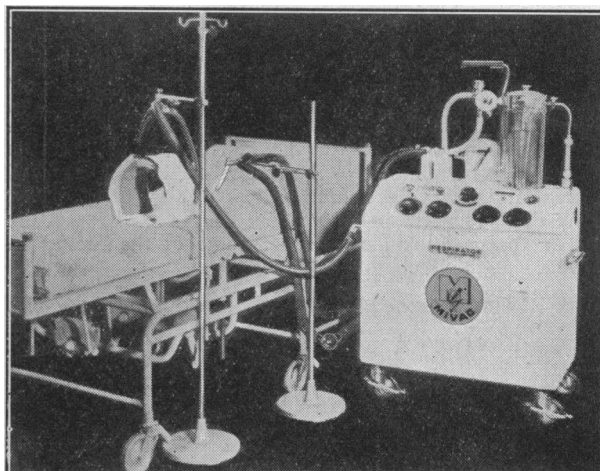

FIG. 1.—The Engström universal respirator providing intra-tracheal insufflation and active expiration by belt.

of the lower thorax by means of an inflatable belt or by use of a special accessory, the so-called Venturi suction apparatus (Engström, 1954) (Fig. 3). The latter applies intermittently an adjustable negative pressure direct into the air passages. For less severe cases the respirator can be used to drive a cuirass. The respiratory frequency, the volume insufflated, and the insufflation rate can be adjusted independently.

The direct insufflation method always permits the administration of a sufficient tidal volume. Since the insufflated volume can be exactly adjusted, adequate ventilation can usually be effected without the help of complicated laboratory control determinations. The rapid decline of the positive insufflation pressure, in combination with the active effect under the expiratory phase, impedes any dangerous rise of mean intrathoracic pressure, which is especially important in cases of impending circulatory shock (Maloney and Whittenberger, 1950). Oxygen can be added to the inspired gas in an exactly defined concentration.

In principle, insufflation is given by way of a half-closed system, thus avoiding the use of accessory apparatus for carbon dioxide absorption. The care of the patient is greatly facilitated by his easy accessibility, which among other advantages allows change of body position at will during treatment. The simple automatic control of resistance in the air passages greatly enhances effective supervision of the air passages in severe cases. The instrument was introduced at a session of the Swedish Medical Association on October 16, 1951 (Sjöberg et al., 1952).

Clinical Experience

The first case treated with the instrument was that of a chronic respirator patient who, after more than 10 years' treatment with a cuirass respirator, contracted an acute complication in the form of a paralytic ileus, probably due to the passage of a renal calculus through the ureter.

The acute complication, which led to death within a few days, started with diarrhoea, pain in the epigastrium, and meteorism. Parallel with increasing meteorism, artificial respiration with the cuirass respirator became deficient, thus eliciting the signs of
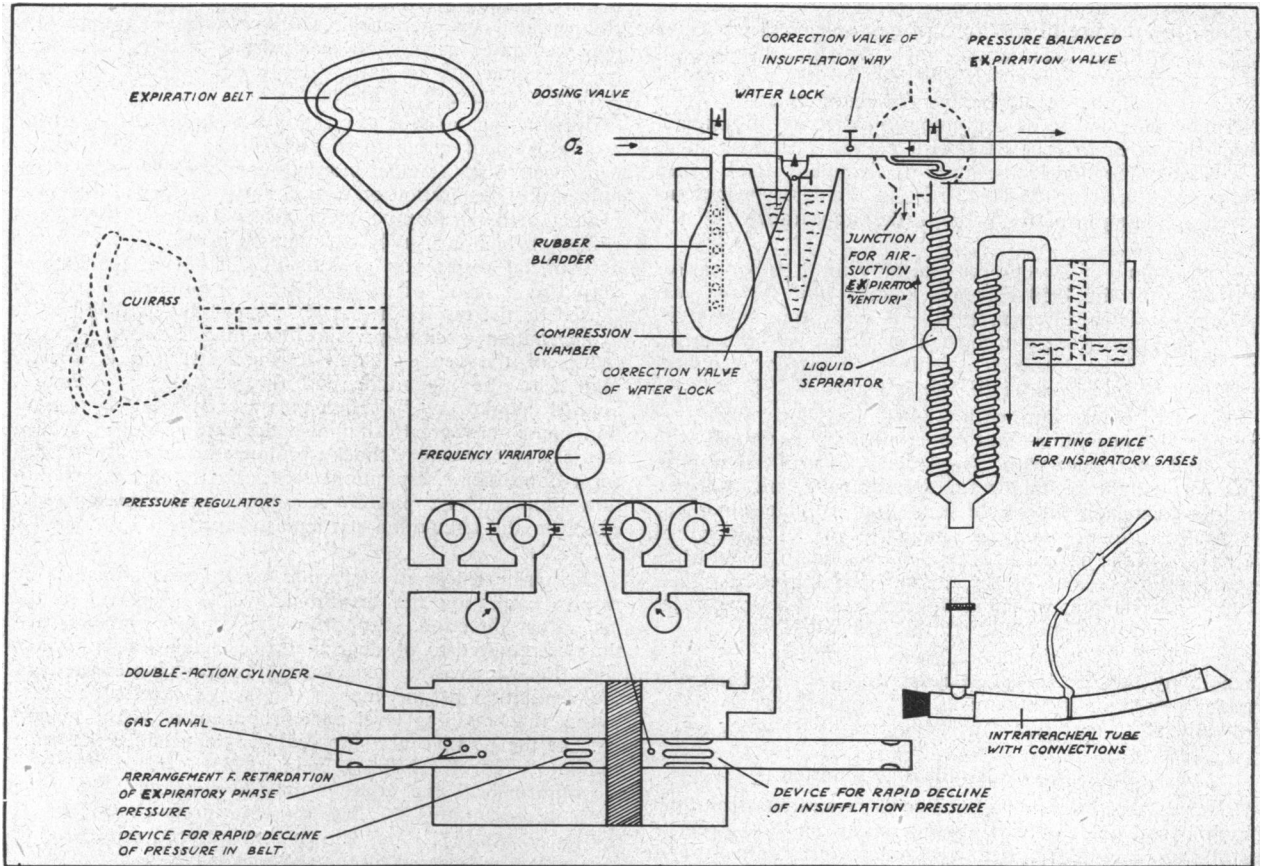
FIG. 2.—Principles of construction of the Engström respirator.

early asphyxia and impending circulatory collapse. Radiologically and clinically, a paralytic ileus was evident, the latter apparently becoming worse through the action of the respirator. Finally, treatment with the Engström respirator in combination with a face-mask and compression of the thorax by a belt was started on December 12, 1951. In this way the ventilation of the patient became immediately satisfactory, meteorism decreased, and his general condition improved so much that he was able to sleep during the following night for five to six hours, with the face-mask in place. After twenty-six hours' treatment his general condition was about the same as before the 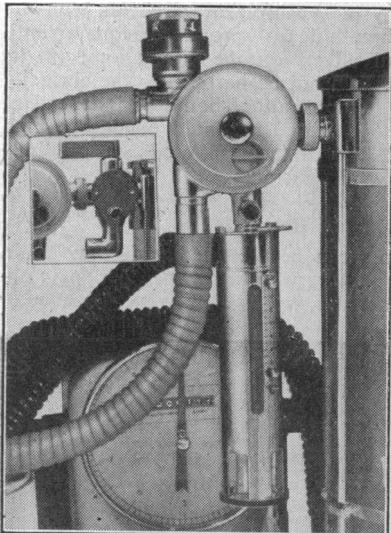onset of the acute complication. However, he wished to have his old respirator again, after which the signs of ileus quickly increased. He died s h o r t l y thereafter in hypoventilatory shock.

Evidently the cuirass respirator had been unable to provide sufficient ventilation in this case ; at the same time, because of its sucking effect on the abdomen, it potentiated the troublesome meteorism which impeded proper ventilation. A vicious circle was thus established.

FIG. 3.—The Venturi suction apparatus for production of an active expiration by negative pressure in the airways.

During the severe poliomyelitis epidemic in Copenhagen in the autumn of 1952, the apparatus underwent further careful clinical trials at the Blegdam Hospital, where a great number of severe poliomyelitic respiratory paralyses were treated at that time. During this epidemic, as is now well known, a special form of intermittent manual positive-pressure breathing, derived from anaesthesiology, was adopted for the treatment of these cases after the usual tank respirators had proved wholly unsatisfactory (Lassen et al., 1953). In this connexion a new technique for the control of the air passages was also developed, consisting of tracheotomy with insertion of a tracheal tube provided with an inflatable cuff. The Engström respirator proved to be the only completely automatic instrument appropriate for the treatment of the most severe cases (Astrup et al., 1954).

1953 Poliomyelitis Epidemic in Sweden

During the severe poliomyelitis epidemic in Sweden in 1953 all 55 cases of bulbo-spinal respiratory paralysis (with one exception) admitted to the Hospital for Infectious Diseases in Stockholm between July 1 and November 15 were treated with tracheotomy and the Engström respirator. The mortality among these cases was 27% (Ström, 1953). All were cases in which respiratory paralysis was regularly accompanied by paralysis of deglutition, often also by central circulatory collapse, coma, encephalitis, or other symptoms of central nervous system involvement. In about 70% of the cases treatment had been started with a body respirator. Working with intratracheal insufflation and compression of the thoracic belt, the Engström respirator was able to produce, even during the most acute stage, an adequate ventilation without any sign of a noxious influence on the circulation. The reported mortality was mainly due to non-ventilatory complications such as hyperthermia, pulmonary infections, and occasionally to lung oedema.

Perhaps the deaths from hyperthermia could have been avoided by the use of the modern neuroplegic drugs which produce artificial hibernation, since the clinical course of this complication showed clearly that the rise of temperature was itself the deadly factor. The fatal cases of hyperthermia ran a course of continuous steady rise of temperature over three to four days with no recognizable sign of a causative infection in the lungs or elsewhere. Only when the temperature reached 41–42° C. did circulatory symptoms appear, leading rapidly, without the appearance of new signs, to death.

In the whole of Sweden the mortality for " bulbar cases " was 38% for the 1953 epidemic against 78% for the year before (Medicinalstyrelsen, 1954). A more careful analysis of the striking decrease in mortality has not yet been made. Treatment of the severe cases with the Engström respirator was largely introduced into the country in 1953.

At many places during this epidemic the treatment—at least in the beginning—was undertaken by personnel who had little experience with the problems of artificial respiration or with the technique for the control of air passages. In this connexion the stable ventilatory volume which the respirator provides and its simple means of control of resistance in the air passages proved very helpful. With the increasing experience of the doctors and nurses and their better understanding of the complications in the air passages and the lungs the mortality further decreased.

Apart from its use in the treatment of respiratory paralysis in poliomyelitis the Engström respirator has also been successfully used in the treatment of respiratory paralysis in polyradiculitis, barbiturate poisoning, skull traumas, etc.

Principles of Artificial Respiration

In assessing the value of artificial respiration from the physiological point of view consideration must be given to its effectiveness in regard to ventilation, quantitatively and qualitatively, and also to its effect on the circulation (Engström, 1953). The ventilatory action must be sufficient to ensure adequate elimination of the carbon dioxide formed in the metabolic processes, otherwise there will be increasing retention of carbon dioxide with consequent lowering of the blood pH and, finally, carbon dioxide narcosis; this phenomenon is often hidden by the simultaneous administration of oxygen preventing the development of cyanosis (Cara, 1954).

Carbon dioxide acidosis is now also a well-recognized clinical syndrome in certain cases of chronic hypoventilation in emphysema, pulmonary fibrosis, and bronchial asthma (Lovejoy et al., 1954; Bühlmann, 1954). In more acute conditions, however, the importance of adequate carbon dioxide elimination is not yet always fully appreciated. Quantitatively the ventilation obtained should be such that the lungs are uniformly ventilated. If there is unequal distribution of the inspired gas, with hypoventilated and hyperventilated regions in the lungs, there will be partial shunting of the blood in the pulmonary circulation. In the presence of a shunt of this kind, and with atmospheric air as the breathed gas, deficient oxygenation of the blood passing underventilated parts of the lungs will not be compensated for by hyperventilation of other parts. There will consequently be a diminution in the oxygen saturation of the arterial blood. As regards the elimination of carbon dioxide on the other hand, the deficient elimination due to

hypoventilated parts of the lungs may to a large extent be compensated by increased carbon dioxide elimination in hyperventilated parts. Anoxaemia may in such cases often be overcome by an extra supply of oxygen, but there is then a great risk of atelectasis.

Even in spontaneous respiration pressure and flow in the respiratory and circulatory systems are intimately related with each other; under normal conditions, however, the influence of respiration on circulation is slight and is readily compensated by adaptive mechanisms (Lauson, 1946). The circulatory action usually encountered in the different forms of artificial respiration consists in influencing the cardiac output as a result of changes in the intrathoracic pressure caused by the respirator. A lowering of the cardiac output in intermittent positive-pressure breathing is due to impeded return of the venous blood to the heart and is directly related to the magnitude and duration of the pressures applied (Werkö, 1947). High pressures and a long inspiration phase may greatly diminish the cardiac output, which can lead to circulatory shock; prolonged treatment with this form of artificial respiration, especially if there is in addition some sort of expiratory resistance, makes this injurious effect on the circulation particularly apparent (Maloney et al., 1951).

In intermittent positive-pressure breathing accompanied by passive expiration the breathing level is displaced in the inspiratory direction. Proportionately greater pressures will thus be required to produce the same changes in volume, a condition which is shown by the pressure-volume curves of the ventilation of the lungs. An active expiratory phase lowers the breathing level and, proportionately, the magnitude of the positive pressure required to produce the same ventilatory effect (Maloney et al., 1953). Investigation of the intratracheal and intraoesophageal pressures—the latter as a representative of intrathoracic pressure conditions (Ferris et al., 1952)—has shown that intrathoracic pressure can in fact be lowered by the application of an active expiration, for instance, by means of suction during expiration (Fig. 4). The effect on the circulation parallels the changes in mean intrathoracic pressure; elevation of this value impedes venous return to the right side of the heart and diminishes cardiac output; as a compensative mechanism the peripheral venous pressure is increased. However, this mechanism depends on the integrity of circulatory control. In shock and in the presence of considerable blood loss it is often deficient.

If a respirator is to have universal application in treating even severe respiratory paralysis, it must satisfy the following requirements: (1) exercise great ventilatory action; (2) produce uniform pulmonary ventilation; (3) act in such a way that no difficulty of synchronization occurs with the patient's spontaneous breathing; (4) produce adequate ventilation without harmful effects on the circulation; (5) its method of operation should not be harmful to the elasticity of the lung tissue; (6) its application should be independent of the patient's posture; and (7) it should produce a high degree of relative humidity in the respiratory gas administered directly into the air passages.

Types of Respirator

In general, respirators can be classified under two main groups. (1) Body respirators with which ventilation is obtained by changes in pressure over the entire body surface or
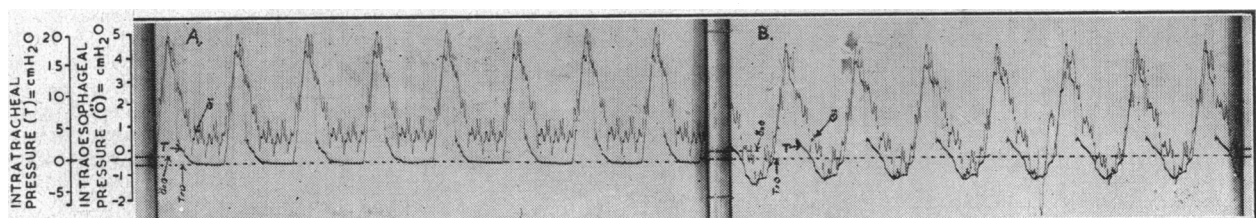
FIG. 4.—A. The intratracheal and intraoesophageal pressures with positive-pressure insufflation only. B. Same pressure curves with application of an active expiration by means of the Venturi suction apparatus. Note conspicuous lowering of level in both curves.

parts of it ; their range goes from " sealed rooms " through the " iron lung " to the chest or abdominal shells and the chest–abdomen cuirass. Body respirators have mainly in-spiratory action ; in some types inspiration can be supple-mented or replaced for a short time by a positive-pressure attachment. (2) This group is represented by insufflation respirators, which may be either positive-pressure appara-tus, giving only active inspiration, or combined positive / negative-pressure machines, giving an active expiration as well. As the body respirators have almost unanimously been abandoned for the treatment of acute and severe cases of respiratory paralysis, this discussion is limited to explain-ing the essential differences between the two types of clini-cally introduced and commercially available insufflation respirators.

In pressure-cycling apparatus (Mushin and Rendell-Baker, 1954) the ventilatory effect depends not only on pressure variation but also on airway resistance and lung compliance. Increased resistance in the tracheo-bronchial tree means diminished efficiency of ventilation ; theoretically ventilation could be made efficient if these factors could be held con-stant. This is, however, impossible in acute conditions. Leakage in the positive pressure phase prolongs inspiration time ; with a big enough leak the valve does not operate, resulting in a constant pressure application (with subcycling values) ; this might rapidly become very dangerous in the presence of certain complications and circulatory lability. Concerning the circulatory effect of such systems, it has been emphasized (Maloney et al., 1953) that it is important to add a negative phase in order to keep the mean intrathoracic pressure at low levels, which will avoid the harmful effect of positive pressure on the circulation.

The Engström respirator, on the other hand, delivers a predetermined volume at a pre-set frequency. That means that the machine furnishes the pressure needed to overcome the resistance, the latter being recorded on a water mano-meter so that any developing impediment can be observed. Therefore, the apparatus represents a time and volume cycling respirator, and is the first of this type used clinically and on a large scale. It ensures a quantitatively sufficient ventilation to the patient with a predetermined volume of any desired qualitative composition.

Conclusion

The severe forms of respiratory paralysis in which signs of central lesions are prominent often constitute a rather complicated therapeutic problem for both physician and nurse. The reported method of treatment has been widely adopted in the Scandinavian countries during the past years, and has led to a considerable decrease in mortality. It must be pointed out, however, that artificial respiration is but one side of the intricate therapeutic problem in these cases ; the rest of the treatment is at least as important, particularly the control of parenteral nutrition, water and mineral balance, and the maintenance of an adequate air-way.

Summary

The Engström respirator is described, and the results obtained with it at the Stockholm Hospital for Infec-tious Diseases in a series of 54 consecutive cases (mor-tality 27%) of acute, severe poliomyelitis with brain-stem involvement are reported. The respirator is suit-able for the treatment of all forms of severe respiratory paralysis, such as may occur in polyradiculitis or barbiturate poisoning, for example.

The principles on which satisfactory artificial respira-tion depend are discussed.

Finally, it is stressed that, in addition to respirator therapy, efficient general medical treatment is essential to success.

REFERENCES

Astrup, P., Gøtzche, H., and Neukirch, F. (1954). British Medical Journal, 1, 780.
Bühlmann, A., Schaub, F., and Rossier, P. H. (1954). Schweiz. med. Wschr. In press.
Cara, M. (1954). Anesth. et Analg. In press.
Engström, C.-G. (1950). Svenska Läkt., 47, 3007.
—— (1953). Ibid., 50, 545.
—— (1954). Ibid., 51, 473.
—— and Svanborg, N. A. (1950). Ibid., 47, 3011.
—— —— (1952). Second International Poliomyelitis Conference, p. 431. Lippincott, Philadelphia and London.
Ferris, B. G., jun., Mead, J. Whittenberger, J. L., and Saxton, G. A., jun. (1952). New Engl. J. Med., 247, 390.
Lassen, H. C. A., et al. (1953). Nord. Med., 50, 1121.
Lauson, H. D., Bloomfield, R. A., and Cournand, A. (1946). Amer. J. Med., 1, 315.
Lovejoy, F. W., jun., Yu, P. N. G., Nye, R. E., jun., Joos, H. A., and Simpson, J. H. (1954). Ibid., 16, 4.
Maloney, J. V., jun., Affeldt, J. E., Sarnoff, S. J., and Whittenberger, J. L. (1951). Surg. Gynec. Obstet., 92, 672.
—— Elam, J. O., Handford, S. W., Balla, G. A., Eastwood, D. W., Brown, E. S., and Ten Pas, R. H. (1953). J. Amer. med. Ass., 152, 212.
—— and Whittenberger, J. L. (1950). Amer. J. Med., 8, 393.
Medicinalstyrelsen (1954). Svenska Läkt., 51, 1232.
Mushin, W. W., and Rendell-Baker, L. (1954). Brit. J. Anaesth., 26, 131.
Sjöberg, A., Engström, C.-G., and Svanborg, N. (1952). Nord. Med., 47, 536.
Ström, J. (1953). Svenska epidemiologföreningens årsmöte.
Werkö, L. (1947). Acta med. scand., Suppl. 193.

THE PREVENTION OF DEFORMITY IN POLIOMYELITIS*

BY

J. M. P. CLARK, M.B., F.R.C.S.

Assistant Orthopaedic Surgeon, Leeds General Infirmary

It is axiomatic to state that it is better to prevent deformity rather than try to correct it after it has occurred. But the idea is commonly honoured only in the breach. It is too often convenient both for the conservative surgeon and for the timid patient to be lulled into a state of hopeful security by the thought that physiotherapy will not only restore strength but will also prevent deformity. Early surgery is often re-garded as interference, and it is usual to recommend that anything more drastic than manipulation ought to be relegated to the stage when muscle recovery is com-plete. Theoretically this interval may extend to two years, but as a practical policy it is fair to consider all worth-while muscle recovery to be achieved by the end of six months from the onset of the disease. Since the orthopaedic requirements for nursing during the acute phase of the disease have become more generally recognized, surgical adjustment of potential deformity depending upon muscle imbalance can usually be safely left until six months have elapsed, by which time a clear assessment of muscle recovery will have been made. But there are other perhaps less potent, but not negligible, causes of deformity that will require atten-tion before the effects of muscle imbalance are likely to become clearly manifest. In any event it seems only logical to treat and to attempt to counteract any con-dition or force that will otherwise inevitably produce deformity in the fullness of time. The need for early recognition of real or potential deforming influences is the strongest argument that can be offered for the in-clusion of the orthopaedic surgeon in the team of experts that the management of poliomyelitis calls for from the very beginning.

Causes of Deformity in the Acute Phase

Pain.—It is too often forgotten that in a relatively small proportion of patients poliomyelitis is a painful disease, and that in a few of these the pain may persist after the febrile attack has subsided, even up to six or eight weeks after the onset of the disease. Pain means immobility on the part of the patient in whatever position may be found to be comfortable. Pain also means that any attempt to carry out passive movements in order to dispel peri-articular

* Read in the Section of Orthopaedics at the Annual Meeting of the British Medical Association, Glasgow, 1954.