Analysis of the deformations is most important. For instance, the dropping of metatarsal heads may be secondary to cavus induced by an uncorrected calcaneus deformity. Dropping of the first metatarsal head is a very common deformity which will inevitably produce a cocked hallux (Fig. 2) with its painful friction areas, plantar callus, and ruinous wear on the shoe sole.

Perverted Action of Normal Tendon

Two prime examples of this are to be seen in the foot. One has already been noted in the discussion of the calcaneus deformity. The posterior tibial muscles, in the presence of a weak triceps surae, will attempt to take over the function of the weak group. If the calcaneum is already dorsiflexed then the action of the posterior tibial muscles will exacerbate the deformity and the need to transfer the posterior tibial muscles to the tendo Achillis is paramount.

FIG. 3.—Gross valgus foot with perverted action of extensor digitorum longus tendons and peroneus tertius.

The other example in the foot is the action of the extensor digitorum longus tendons and peroneus tertius on a valgus foot resulting from a weak tibialis posterior (Fig. 3). If this action is allowed to persist the foot will assume a bow shape and the long toe extensor tendons will act as the bow string. Mistakenly the peroneal tendons may be used to counteract the deformity, but it will persist if the true deforming agent be not perceived. The foot can only be corrected by shifting the toe extensor tendons to the medial side of the foot to act as a supplement to the weak tibialis posterior.

Summary and Conclusions

The causes of deformity during each phase of poliomyelitis are considered. In the acute stage the effects of pain and muscle spasm are discussed, the contracture of fibro-elastic tissues is detailed, and methods of its control are outlined. In the stage of potential recovery the mechanics of uncorrected fibro-elastic contractures are elaborated and methods of correction are recommended. Muscle imbalance as a cause of deformity is expounded and the surgical correction by tendon transposition is explained as a means of anticipating common deformities. The perverted action of normal tendons caused by paralysis or weakness of other muscles is instanced and its correction is described. The thesis is that surgical anticipation of deformity is more logical and easier to perform than surgical reconstruction, and the results are better.

It is not claimed that all deformities can be controlled by preventive surgery, but it is maintained that patients can be halted in a steady deterioration which would otherwise yield an intractable problem. In poliomyelitis it is the surgeon's duty to anticipate rather than to reconstruct.

REFERENCES

- Bennett, R. L. (1952). *Papers and Discussions Presented at Second International Poliomyelitis Conference*, p. 261. Lippincott, Philadelphia.
 Seddon, H. J. (1947). *British Medical Journal*, 2, 319.
 Soutter, R. (1914). *Boston med. surg. J.*, 170, 380.
 Yount, C. C. (1926). *J. Bone Jt Surg.*, 8, 171.

POSITIVE-PRESSURE INFLATION IN RESPIRATORY PARALYSIS OF POLIOMYELITIS

BY

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During the 1952 epidemic of poliomyelitis in Denmark the iron lung type of respirator used in cases of bulbar respiratory paralysis requiring tracheotomy was replaced by a different method of artificial respiration. Instead of the application of negative pressure to the chest wall manual rhythmic positive-pressure inflation of the lungs themselves was performed. It was carried out, by means of an apparatus specially designed by Dr. B. Ibsen (Lassen, 1953), through a cuffed endotracheal tube led into the tracheotomy opening.

Since that time various other methods of artificial ventilation in these cases have been described. Macintosh (1953) redesigned the bellows part of the Oxford vaporizer as a separate unit which he called the Oxford inflating bellows and which are operated by hand. Mushin (1953) added to these the Cardiff inflating valve which automatically allows deflation and prevents re-breathing. Russell and Schuster (1953) constructed a respiration pump which drives the Oxford bellows automatically. Others constructed automatic respirators for inflation where volume, speed, and pressure were either set according to the needs of each case or steered by the intrapulmonary pressure of the patient (Pask, 1953; Beaver, 1953; Bang, 1953; Macrae *et al.*, 1953).

I have utilized the original Oxford vaporizer fitted with a Salt valve (Wislicki, 1953). Its use for two different purposes is described in this paper.

Case 1

A builder aged 29 was admitted to the local infectious diseases hospital on October 29, 1953. For four days he had suffered from poliomyelitis which had resulted in paralysis of both legs and retention of urine. His temperature was 102.6° F. (39.2° C.). During the next two days external eye muscles and pharyngeal muscles became affected, causing diplopia and difficulties in swallowing, respectively. Large amounts of mucus accumulating in his mouth and pharynx necessitated tracheotomy (Dr. A. Fraenkel). On November 1 partial respiratory paralysis of bulbar origin developed. Manual artificial respiration was applied, but his condition deteriorated and little hope was held out for his survival. I was then called in.

On arrival I found a patient of muscular build, in a good state of nutrition, but cyanosed, restless, and with a very anxious expression. His respirations through a tracheotomy opening were laboured, irregular, and shallow. It was decided to try artificial respiration by means of the Oxford vaporizer. As no cuffed endotracheal tube was available the inner tracheotomy cannula was removed while the outer one was left in position. A Magill endotracheal tube No. 5, shortened to 10 cm., was inserted into the cannula until it made a tight fit. The tube was connected by a Rowbotham connexion and a short piece of wider rubber tubing to the Salt valve and from there to the Oxford vaporizer. Rhythmic inflation with air only was started. After a few minutes oxygen at the rate of about 2 litres a minute was led into the vaporizer. Suction was performed by taking the rubber tube out of the tracheotomy cannula and introducing the suction catheter instead. The mouth and pharynx were also cleansed by suction when secretions accumulated.

Within ten minutes improvement in the patient's condition was striking. Cyanosis and restlessness had decreased considerably, and he indicated that he felt much easier. Inflation and suction were continued for one hour, and then auxiliaries were trained to continue artificial respiration at the rate of 20 a minute. An hour later the patient was asleep and of excellent colour.

He was kept on constant manual inflation of the lungs for forty-eight hours. His bulbar paralysis receded gradually and he could then be left on spontaneous respiration for ten minutes out of every hour. At the beginning of each period his respirations were deep and satisfactory, but they weakened gradually, and he asked then for renewed inflation. After a further twelve hours he could be left on spontaneous respiration for two hours, and about eighty hours after artificial ventilation had been started no further help was required. His temperature fell gradually to 99° F. (37.2° C.) and the power of swallowing returned. On November 6 the tracheotomy cannula was removed. He continued with subfebrile temperatures for a few days. There was no recurrence of respiratory embarrassment. At the beginning of December he was generally very well, with normal vision, and had regained control of his bladder. Unfortunately, his legs were still paralysed, with only slight movements in the right leg.

Case 2

A man aged 25 had been in the iron lung for several days suffering from poliomyelitis with paralysis of all limbs, intercostals, and diaphragm. Swallowing was impossible, and almost constant oral suction had to be applied because of continuous outpourings of large amounts of mucus. Tracheotomy had not been performed. On November 2 I was asked to pass an endotracheal tube in order to suck out his trachea and bronchi. Respiration in the iron lung had become unsatisfactory, he was in great distress, and it was thought that mucus had entered his respiratory passages. Oral intubation under local analgesia with 5% cocaine was performed. Though the air passages were found to be almost clear, intubation resulted in immediate relief. Ventilation had become inefficient because the entrance to the larynx had been partly closed by the tongue, which had fallen back owing to partial paralysis of the muscles inserted at the hyoid bone. The endotracheal tube pushed the tongue forward and provided an open airway. The patient's condition improved, he slept for five hours, but then the tube started to disturb him and had to be removed. Obstruction of the airway did not recur.

Two days later several attempts were made to introduce a stomach tube with the help of a laryngoscope in order to feed him. They failed because, owing to paralysis of the pharyngeal constrictors, the tube was not guided down the oesophagus but rolled itself up in the pharynx. It was then decided to make a feeding gastrostomy. He was again intubated under cocaine analgesia, and the tube was connected to the Oxford vaporizer. At first, respiration through the vaporizer was synchronized with that of the iron lung, as it was thought advisable to continue in the rhythm to which the patient had been used. The motor of the iron lung was then switched off and the effect of inflation with air was tried. It became clear at once that this was not enough. The patient's colour deteriorated and he showed air hunger. As no cuffed endotracheal tube was available to close the trachea, too much air returned along the wall of the ordinary tube without reaching the lungs, and the part which reached the alveoli did not provide enough oxygenation. A pharyngeal pack was ineffective because it became soaked through with mucus after a few moments. Oxygen was led into the vaporizer in increasing quantities, and at a very high rate of flow the patient could be kept in a fairly satisfactory condition.

Gastrostomy was performed (Dr. W. Nissel) under local analgesia. It was carried out in three stages, as the iron lung had to be closed twice during the operation in order

to give the patient a more thorough ventilation. By this manoeuvre it was possible to complete the gastrostomy. He recovered quickly from the operation and has been fed through the opening now for four weeks. At the time of writing his general condition was still very poor.

Discussion

Both of these cases are instructive. In Case 1 manual inflation was carried out with very crude means, as a sudden and unprepared start had to be made. It showed that a cuffed tube is not essential for inflation through a tracheotomy opening. The shortened endotracheal tube pressed into the outer cannula fitted tight enough to carry out artificial inflation over a protracted period. The cannula itself blocked the trachea effectively against secretions from above. As no suction on the thorax was applied, and air under positive pressure entered only below the larynx, secretions from the mouth and pharynx were not forced past the cannula, while oral and pharyngeal suction sufficed to prevent a trickle down the trachea. The system adopted out of necessity actually proved an advantage. A cuffed tube would have been unknown to the available personnel and most likely some accident would have happened. But they were used to performing suction through a tracheotomy cannula and no difficulty was experienced.

It took about half an hour to train auxiliaries. They were only shown how to press the bellows and close the valve simultaneously at a given rate. Once the technique was understood inflation proceeded smoothly. Although the Oxford vaporizer is practically fool-proof, frequent medical supervision is essential. On one occasion it was noticed that air could hardly be forced into the lungs. Below the inset rubber tube the cannula was blocked by inspissated mucus as suction had been omitted. To prevent a recurrence suction had to be carried out from then on at regular intervals whether mucus was present or not. Another time the original valve of the Oxford vaporizer—which has to be kept screwed down—had opened through friction against the bed-clothes, with the effect that most of the air did not reach the patient but escaped through the valve. It is preferable to remove the expiratory valve and to connect the rubber tubing direct to the Salt valve.

The Cardiff valve will no doubt replace the Salt valve, as only one hand is needed for inflation, and it will then be so easy to work the bellows that unskilled personnel can be employed.

The question is bound to arise whether manual or automatic inflation is preferable. It seems that both have their advantages and their drawbacks. During extensive epidemics, when many cases are gathered in one hospital, an automatic device will be very useful. It will save personnel and their training. Constant volume and speed of automatic inflation might be an advantage over manual inflation, which is bound to vary in intensity. Medical supervision can be carried out constantly in a large institution; experts are there to regulate volume, speed, and pressure of the machines, technicians can be called upon to adjust or repair them, and compressed air or nitrogen-oxygen mixtures are easy to obtain. But the single case in a cottage hospital without all these facilities is probably served much better by the almost fool-proof combination of the Oxford inflating bellows with the Cardiff inflating valve. No adjustments or repairs are needed, air and an oxygen cylinder are always available. Should there be any resistance to inflation, and the person working the bellows has been forewarned of such an occurrence, no undue force would be applied which might cause damage, while a machine would continue with its set pressure unless a safety valve was fitted. The bellows unit is portable and can be taken to the patient's home if he cannot be moved. It seems advisable to fit all small country hospitals with such a unit, which can also be used for any other case requiring artificial respiration.

The second case indicates a way in which patients without tracheotomy can be taken out temporarily from the iron

lung for more thorough nursing, massage, or any other treatment which is difficult or impossible to carry out through its windows. Rovenstine and Strauss (1946) intubated, inflated, and anaesthetized a patient who had been kept in a Drinker respirator, in order to perform a caesarean section. Intubation has to be performed on the conscious patient under local analgesia, but his co-operation is easily obtained once the procedure and its necessity are explained to him. In these cases a cuffed endotracheal tube is essential, otherwise inflation will not provide the same degree of oxygenation as the iron lung. Any anaesthetic machine can be used for that purpose, delivering pure oxygen. For short periods this will not cause any harm to the patient and no arrangements are needed for adding air or nitrogen. If the apparatus used is not fitted with a non-rebreathing device like the Salt or the Cardiff valve, carbon dioxide absorption will have to be employed.

The Danish team has demonstrated the analogy between respiratory paralysis produced deliberately by the anaesthetist by means of a relaxant drug and the paralysis caused by the poliomyelitis virus. By transferring a technique applied every day in anaesthesia to the treatment of a pathological process with similar manifestations the same results are obtained—namely, to tide the patient over a period of respiratory paralysis by means of artificial inflation. The difference, apart from the additional complicating symptoms of poliomyelitis, lies in the length of time during which this inflation has to be carried out. Succinylcholine wears off after about five minutes, tubocurarine after forty-five minutes; Case 1 lasted for less than four days, but some of the Danish cases required inflation for more than three months.

Once the similarity of muscular relaxation during anaesthesia and of paralysis of poliomyelitis is realized more analogies become apparent. Case 2 could not be ventilated efficiently because of partial obstruction of the airway by the patient's tongue, a picture familiar to any anaesthetist but one that is outside the range of observation of a physician who has spent years dealing exclusively with the treatment of infectious diseases. Most likely there will be a number of cases in which insertion of an airway—covered with an analgesic ointment like cinchocaine—which keeps the tongue forward will greatly improve ventilation by the iron lung.

Collaboration between physician and anaesthetist in the treatment of respiratory paralysis of poliomyelitis has resulted in the saving of many lives during the Danish epidemic, and more can be saved, as Case 1 of this report has shown. In our age of increased specialization in medicine it may be worth while to contemplate that close connexions exist between fields apparently as unrelated as, in our instance, poliomyelitis and anaesthesia.

Summary

Successful positive-pressure inflation by means of the Oxford vaporizer in a case of bulbar respiratory paralysis of poliomyelitis is described.

A method is outlined, and its application described, showing how poliomyelitis patients whose respiration is paralysed can be taken out of the iron lung temporarily.

The analogy between deliberately produced muscular relaxation during anaesthesia and paralysis of poliomyelitis is pointed out.

REFERENCES

- Bang, C. (1953). *Lancet*, 1, 723.
 Beaver, R. A. (1953). *Ibid.*, 2, 200.
 Lassen, H. C. A. (1953). *Ibid.*, 1, 37.
 Macintosh, R. R. (1953). *British Medical Journal*, 2, 202.
 Macrae, J., McKendrick, G. D. W., Claremont, J. M., Sefton, E. M., and Walley, R. V. (1953). *Lancet*, 2, 971.
 Mushin, W. W. (1953). *British Medical Journal*, 2, 202.
 Pask, E. A. (1953). *Lancet*, 2, 141.
 Rovenstine, E. A., and Strauss, H. (1946). *Amer. J. Obstet. Gynec.*, 51, 213.
 Russell, W. R., and Schuster, E. (1953). *Lancet*, 2, 707.
 Wislicki, L. (1953). *British Medical Journal*, 2, 393.

A PNEUMOFLOTOR ATTACHMENT TO BOYLE'S MACHINE

BY

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The need for automatic mechanical devices for maintaining controlled respiration during anaesthesia has been fully discussed by Mushin and Rendell-Baker (1953, 1954). This apparatus is a further development of the prototype described previously in a preliminary report (Williams, 1952), and differs in certain important respects from other mechanical respirators.

The apparatus consists of a small device which can be attached to the outlet of any standard Boyle's machine. In principle, it converts the continuous flow of gases into an intermittent one so that Boyle's machine is made suitable for performing automatic rhythmical inflation of the lungs. The prototype has been in daily use for the past five years, and has proved useful and effective in over three thousand patients, many of whom were undergoing major thoracic procedures. The apparatus is really intended, however, for anaesthesia in general surgery in circumstances in which controlled respiration is thought desirable. It can be quickly brought into use for varying periods of time, and whenever the anaesthetist is called upon to set up a transfusion or otherwise attend to the apnoeic patient.

The attachment has the following salient points: (1) It forms an integral part of Boyle's machine, and is therefore immediately available for use. (2) Soda-lime is not required, so that trichlorethylene may be used to supplement the gases if necessary. (3) The motive power for operating the mechanism is provided by the compressed gases within the cylinders. It is therefore independent of electric motors and has no inherent risk of electrical failure or explosion. (4) A safety valve prevents lung pressures rising above approximately 30 cm. of water. (5) A built-in valve allows air to supplement the gas mixture if spontaneous respiration unexpectedly returns and the inspiratory demand is greater than the gas-flows supplied by the machine. (6) A small lever projects through the detachable lid of the apparatus, and its rhythmical movement provides both visual and audible evidence of function. When this lever is held in the inspiratory position the lungs may be kept inflated momentarily if so required by the surgeon. Periods of deflation of the lung are obtained by temporarily opening the normal expiratory valve at the facepiece. (7) The rate and depth of respiration can be varied between adequate limits by the use of two controls only.

For efficient operation a flow of 15 litres a minute is required during the inspiratory phase. This is easily obtained from Boyle's machine, having an oxygen flowmeter graduated to give 5 litres a minute and a nitrous oxide flowmeter graduated to 10 litres. During expiration, however, the gas flow is cut off so that the actual consumption of gases is little more than half the above amount—that is, 8–9 litres a minute. In practice it is found that with continuous running a 20-cu. ft. (0.57 m.³) cylinder of oxygen and a 200-gallon (910-litre) cylinder of nitrous oxide both last for approximately two and a quarter hours before depletion.

The gas mixture is delivered to the patient by means of a narrow-bore (3/16 in. (4.8 mm.) internal diameter) rubber tube which is attached to the apparatus by means