1939

# Extrapleural thoracoplasty in pulmonary tuberculosis

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# EXTRAPLEURAL THORACOPLASTY
# IN
# PULMONARY TUBERCULOSIS

BY

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SENIOR THESIS

UNIVERSITY OF NEBRASKA COLLEGE OF MEDICINE

OMAHA 1939

# INTRODUCTION

The object in this paper is not to give a statistical review of the literature on extrapleural thoracoplasty but to obtain the present views and opinions of the men doing the most work in this field.

Since most of the original work was reported in foreign languages the history and evolution of thoracoplasty was taken from Alexander's monograph The Collapse Therapy of Pulmonary Tuberculosis. Grateful acknowledgement is made John Alexander for the use of his works which served as a guide in writing this paper.

There will be no discussion of results included, first, because ther are many discrepancies in the report of results; secondly, the value of thoracoplasty is no longer in the realm of controversy. It is now accepted as a definitely valuble procedure.

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## HISTORY

The first attempt to collapse a tuberculous cavity by removal of overlying ribs was made by Cerenville in 1885. His long article published in that year demonstrates that he understood the need of breaking the continuity of the non-yielding bony thoracic cage in order to effect collapse of pulmonary cavities. He stated that his work was based upon empyema studies that had already been made by Simon (1869), Estlander (1879) and himself (1877).

The report of Cerenville includes four operations for apical pulmonary cavity in which he resected portions of each of the second and third ribs anteriorly. He observed definite pulling in of the stumps of the partially resected ribs and a consequent lessening in size of the cavities. This pioneer work of Cerenville was the beginning of an active surgical interest that has gradually evolved the modern thoracoplastic operations.

Approximately the same operation as Cerenville's was performed by Quincke in 1888, and in 1896 he advocated small rib resections for non-cavernous types of tuberculosis as well as for cavernous types.

In 1890 Carl Spengler resected greater lengths of ribs than had previously been done. He called the operation "extrapleural thoracoplasty", the term used today for the standard operation. Turban in 1896 resected parts of the fourth to seventh ribs inclusive, and six months later sections of the sixth to ninth. In 1901 Garre and Quincke in 1903 advocated thoracoplasty for hemoptysis and advised supplementing the operation with an intrapleural or an extrapleural pneumolysis.

Up to this time the results of the operation were unsatisfactory. The costal resections were not extensive enough to compress the lung sufficiemtly to collapse cavities or to bring about other intrathoracic changes upon which the more extensive modern operations depend for their curative effedt.

Brauer was the first to realize that clinical success depended upon obtaining a pulmonary compression somewhat comparable in amount with that obtained by artificial pneumothorax which was already effecting remarkable results. He felt the need for an operation that could be used when artificial pneumothorax failed becuase of pleural adhesions and that would affect the scattered smaller active tuberculous lesions as well as the localized larger ones.

lower lobe. The total length of ribs I to X, inclusive, that were resected ranged from 130-200 cm.

Brauer and Friedrich soon realized that this thoracoplasty was highly dangerous. Three of their first seven patients died from the operation. Later high operative mortality was reported by other surgeons. The shock was terrific; the side of the chest wall operated upon "fluttered" or swung in and out freely with the respiratory movements - the so called paradoxical respiration, thus named for the reason that the chest wall was drawn in during inspiration and blown out during expiration. These movements were shared by the mediastinum and resulted in "mediastinal flutter" and displacement; consequently, the opposite lung was narrowed, respiration became rapid and labored, the circulation was greatly impaired and many patients soon died of acute respiratory insufficiency. The deprivation of one-half of the chest of its bony support, and the paradoxical respiratory movements resulted in great impairment of the coughing and expectorating mechanism, and aspiration and stasis pneumonia occurred frequently. The tuberculous lung of the opposite side was not rested as it was hoped it would be. Because of the "mediastinal flutter"

the lung of the contralateral side was called upon to do more work than was safe for those few tuberculous lesions that it might contain.

In 1909 Brauer published a paper in which he considered the dangers of the operation and proposed methods by which they might be avoided. He also at this time suggested several modifications of the original operation and post-operative management. His suggestions were as follows: (1) to operate at two sittings instead of one; (2) to leave the periosteum to regenerate and fix the chest wall and in the meantime support it with bandages; (3) Limit resections to upper ribs and depend upon artificial pneumothorax for compression of the non-adherent lower lung. This would reduce chest wall flutter; (4) the greatest resections relatively should be made directly over the upper lung and that all or a part of the clavicle and first rib should be resected in those cases in which compression of the apex was especially demanded; (5) Brauer suggests first to resect the upper ribs, then to resect relatively short sections of the lower ribs (anteriorly and posteriorly as in the Kuster - Estlander empyema operation) and to bend the stumps that remained. In this way the lung would be well compressed

and yet the lower chest wall would retain a part of its bony framework to combat chest wall flutter. (6) In considering the advisability of using the Volkmann-Hoffa operation of resection of the "rib humps" in those patients with markedly deformed thoraces. Brauer concluded that, whereas a scoliotic deformity would probably be improved and the lung somewhat narrowed, the lung would not be compressed and rested as much as he believed necessary ; in a non-deformed chest he preferred the original Brauer-Friedrich thoracoplasty; (7) Brauer suggested the use of "positive pressure breathing" postoperatively for those patients with chest wall and mediastinal flutter; (8) He advised cough-quieting drugs to slow the respiration so as to enable the patient to cough effectively and use the non-operated lung for breathing purposes with greater ease.

These suggestions did not result in a sufficient improvement of the original Brauer-Friedrich thoracoplasty to cause it to become very popular.

The thesis of Julien Gourdet published in 1895 was epochal and had far reaching effects upon the development of the surgery of pulmonary tuberculosis. The thesis dealt with the question of the most

effective manner of resecting ribs to narrow the thoracic cavity for pleural empyema. The experimental studies that form the basis of this monograph were stimulated by an operation performed in 1894 by Baiffin. It was done for a large interlobar empyema (which later was discovered to be a complication of an underlying pulmonary tuberculosis) and consisted in the resection of ffom three to six cm. each of ribs II to X inclusive, "at the levels of their angles". It was seen that the diminution in the size of the thoracic cavity was far greater after these short paravertebral resections than it was after extensive resections of the lateral or anterior or anterolateral portions of the ribs. Gourdet showed the importance of removing ribs beyond their angles.

It was Wilms who first demonstrated clinically the value for pulmonary tuberculosis of the experimental work done by Gourdet and by Eden and Robinson. Wilm's operations in 1911 showed that rib resections limited to the paravertebral region had a greater healing effect upon tuberculous lesions of the lung than any operation that had yet been performed and also that such resections avoided the dreaded dangers

of the Brauer-Friedrich operation. Sauerbach had performed a paravertebral thoracoplasty in 1909.

Wilm's first operation (1911) consisted in extrapleural paravertebral resections of from 3-4 cm each of the first to the eighth ribs inclusive . The operation was performed under local anesthesia and with long skin incision, in the depth of which short oblique incisions were made through the muscles in the direction of their fibus at the levels of the second, fifth and seventh ribs; through each of these short muscle incisions two or more ribs were resected. Wilms intention was to remove several centimeters from each of the upper five, six or seven rib cartilages at a later operation in order to increase collapse of the chest wall and lung. The second operation was found unnecessary as the patient's cough and sputum disappeared after the first operation. Later when he considered additional collapse necessary he added parasternal resections from two to six weeks after the first. Sometimes he resected the inner end of the clavicle.

Wilms considered resection of only the upper seven or eight ribs insufficient for cases in which the lower as well as the upper was markedly involved

and so he removed from 6 to 15 cm from each of the lower ribs. In 1912 he operated upon a number of patients in two stages in which he resected the lower ribs as well as the upper ones.

In November 1911 Sauerbruch had performed a similar two-stage operation. He removed from 10 to 5 cm. of ribs X to IV inclusive and five weeks later shorter pieces of the upper ribs. Both Sauerbruch and Wilms used a long vertical incision passing through the skin and muscles to the ribs, over the rib angles down to the lowest rib intended for resection, the incision then went obliquely laterally to the posterior axillary line. Friedrich in September 1911 performed a paravertebral thoracoplasty upon ribs IX to II inclusive in one operation; the patient died the next day from pulmonary edema.

Considering it probable that resection of the upper ribs alone would be enough Wilms preferred to avoid the lower ribs. Later, however, he concurred in Sauerbruch's opinion that the lower ribs should be resected as well as the upper ones in a large majority of cases instead of a few. Wilms insisted upon always resecting the first rib or performing a pneumalysis.

The restriction of the rib resections to the paravertebral region is the distinctive feature of Wilms' exprapleural paravertebral thoracoplasty rather than resections of whole lengths of ribs as was being done by the Brauer-Friedrich operation. Wilms, as early as June 192 , modified the technic of the first few operations he performed in 1911 so that in selected cases as many as 12 cm of the eighth, ninth, and tenth ribs were resected as well as somewhat lesser lengths of the upper ribs.

Sauerbruch in attempting to avoid the dangers of the Brauer-Friedrich operation, felt that removal of the lower ribs was responsible for chest wall flutter. As a remedy he paid particular attention to the first rib. In a case in which the patien's arm was being forcibly elevated in order to expose the first rib for resection, the clavicle was accidentally fractured and as a result there was an excellent compression of the apex of the lung. He devised and used a variety of new operations with very poor results and later concluded that it was necessary to resect portions of the lower ribs, before resecting the upper ones, so as to prevent

aspiration of infected secretions by the lower lung. The results of these operations were more satisfactory. In 1910 Sauerbruch began to divide thoracoplasty operations into two stages - a procedure that Brauer had proposed but not practiced.

In 1912 Sauerbruch operated by resecting ribs ten to two or one inclusive, in one or two stages. In 1913 he stated that resection to the first rib was often not necessary, depending upon the kind of tuberculous lesions in the apex, the position and movability of the first rib, and the need of rapid operation.

Sauerbruch and Elving in 1913 accepted the value of Wilm's localization of the rib resections to the paravertebral region. They pointed out that the best clinical results follow rest and compression of the whole lung; these are attained best when both upper and lower ribs are resected. They advocated, as the first step in practically every thoracoplasty, resection of the lower ribs, including the ninth and tenth,and sometimes the eleventh.

Ochsner and Hedblom first stressed the greater safety of multiple stages. In 1924 Lambert and Miller advised the removal of the upper rather than the lower ribs at the first stage of a thoracoplasty.

In 1925 Alexander called attention to the value of a partial upper thoracoplasty and in 1928, using the multiple-stage principle, began to remove increasingly great lengths of the uppermost ribs as a stage of a partial thoracoplasty as did Walther, Graf, and Salle independently the same year.

During the past decade there has been a tremendous increase in the number of patients with pulmonary tuberculosis who have been treated by rib-resection with an arrest of their disease process. Present day statistics (53) show that from 40 to 60 percent of thoracoplasties are successful in permanently arresting the course of pulmonary tuberculosis. A better knowledge of the pathological lesion which lends itself to cure by surgical methods, together with the use of special types of thoracoplastic operations, has steadily added to the number who have been rehabilitated and returned to normal livelihood.

## RATIONALE OF OPERATION

The rationale of extrapleural thoracoplasty lies in the fact that it accomplishes two things: one, a reduction in the size of the involved lung partly by the collapse of such portions of it as still preserve elasticity, partly by actual compression through the inward spring of the divided rib; two, a diminution in its motion, a reduction in the movements of the lung that accompany each respiratory act favors the natural process of healing (splints the lung) and lessens the likelihood of spread of the disease. A reduction in the size of the lung, facilitates scar tissue, contraction and closure of cavities. The more complete the collapse of that portion of the lung which is involved by the disease, the higher is the percentage of cavity closure. Coincident with the obliteration of the pulmonary cavities there is a reduction or abolition in the amount of sputum. Coughing is lessened and disappears altogether if the collapse has been adequate. Functional rest induced by emmobilization is one of the cardinal

principles of the therapy of any form of tuberculosis. When portions of the ribs are resected the respiratory movements of the thoracic skeleton are abolished: there remains a diaphragmatic movement but this also is very greatly reduced because of the loss of the rib support especially the tenth and eleventh ribs. The result is that respiratory exchange in the affected lung is reduced to a very small fraction of its previous total. The actual reduction in the cubic capacity of the side of the thorax on which a total thoracoplasty has been carried out smounts to well over 50 per cent as is seen with the Xray plates. In some cases the lung is reduced approximately to the size of a somewhat enlarged spleen, the consistency of which it resembles. (7)

The closure of cavities has become the primary objective in the active treatment of tuberculosis. After the disease process has destroyed a certain proportion of the pulmonary tissue, the result is a thoracic cage which is out of proportion to the size of remaining healthy lung tissue. If healing takes place through bed rest alone the scar tissue in the diseased area contracts the remaining lung on that side must expand to occupy the entire hemithorax and the boundries of the hemithorax must move in to decrease the volume of the thoracic cage. As a result the ribs

are crowded closer together, the diaphragm displaced upward and the mediastinum shifted toward the affected lobe. In the event that nature is unable to adequately move in the walls which surround the partially destroyed lung, there then results a discrepancy between the lung size and the thorax size, the actual amount of discrepency being represented by cavities. This is where surgery steps in to mechanically help in the process of cavity closure. Thoracoplasty operation moves in the walls of the hemithorax so that the size of the chest is reduced to that of the underlying lung tissue. When this has been accomplished cavitation ceases to exist. It is believed that it is this factor which is responsible for the rapid disappearance of the toxic effect as seen in fever, rapid pulse, cyanosis emaciation and general malaise: and one explanation given is that compression of lymphatic vessels prevents the absorption of tuberculo-protein and other products of infection. The walls of the cavities are held open by their own stiffness and by the fibrous strands which extend through the lung tissue to the pleura and through an adherent pleura to the ribs, diaphragm and mediastinum. Only by collapse or compression of the lung as a whole can the walls of such cavities fall in and approch each other. So long as a cavity

lined by an infected membrane is held open it cannot heal, but when its walls are brought together it may heal and become obliterated.

Thoracoplasty does good then, by putting the lung at rest, stopping lymphatic absorption and by obliterating cavities.

(3) (7) (61) (39) (64)

## SELECTION OF CASES

General considerations. It is impossible to present a tabulated list of indications for thoracoplasty that can be safely followed because of the many factors which demand individualization in the selection of cases for the operation.

According to Neuhof (61) the best indication for thoracoplasty is the opinion of a well trained physician who has cared for the patient for months or years, has followed the clinical course, has studied the evolution of the pathological process in the lung, and has acquired a knowledge of the resistance to tuberculosis of that patient.

Thoracoplasty should not be considered until a pneumothorax has been undertaken and has proved inadequate, or if any other operation offering a reasonably good chance of success has been tried and has failed. The expert in tuberculosis knows that in the average patient the chance of complete closure of the cavity that has resisted all therapeutic measures except a thoracoplasty is far less than the 80 per cent that it is without a thoracoplasty and that they risk to life from the continuing activity of open tuberculous lesion is far greater than the 10 per cent that is at present

the death rate from the operation of thoracoplasty and from possible post-operative complications and progression of tuberculous lesions in either lung during the year or two following operation. In fact, patients whose cavities have resisted all therapeutic measures except thoracoplasty are almost certain to die from tuberculosis in the near or distant future if thoracoplasty is not used. (2) (64)

In general the patients chosen for this prodedure must be at least in fairly good condition, must have demonstrated considerable resistance against the disease, who have not had a recent exacerbation of the disease, whose cardiac functional reserve is adequate, must present a chronic fibrotic or productive type of lesion. He must possess a good or nearly good contra-lateral lung without too much evidence of fibrosis so that enough available breathing space will remain to carry the patient for the rest of his life.

General Condition: Probably the first consideration should be the general condition of the patient. It is generally considered that elevated temperature and pulse both persisting and remaining high as warning signs to be carefully considered. Sauerbruch pointed out the danger of operating on patients who have evidenced poor resistance and whose general condition does not tend

toward chronicity. On the other hand a thin moderately anemic and moderately febrile patient with abundant sputum does not necessarily present a poor operative risk. Emaciated and chacectic individuals, and those with acute tuberculosis elsewhere are unsuited to undergo major operations. A low vital capacity and even slight dyspnea associated with mild asthmatic condition, silicosis or emphysema, are definite contraindications to operations. Better immediate and distant results can obviously be anticipated if the patient is in good general condition.

Head (48) does not demand that the patient be in good general condition nor that the disease be a chronic and productive one. He abandons careful clinical studies on the basis that if a person needed the operation he had better take the chance. He considers disease in the opposite lung and severe extrapulmonary complications as the only contraindications.

Several writers including Lilienthal (56) have said that no patient should be allowed to reach the terminal stages of tuberculosis without having had the benefit of thoracoplasty, as this offers a very small chance of recovery to patients who otherwise would have none. (69) Most authors do not agree with this. Alexander (2) having used thoracoplasty in a number of

patients with pre-operative dyspnea and evidence of myocardial degeneration came to the conclusion that the high mortality rate and the unsatisfactory degenerated condition of those patients who survive with a closed cavity and negative sputum should contraindicate a thoracoplasty in desperate risk cases. The effect of the high mortality rate would cause the patients for whome the operation was recommended to refuse it even though their condition was good, prognosis excellent, and risk small.

Statistics presented by Crimm (28) bear out the fact that thoracoplasty should not be offered to a patient as a last procedure to cure a wasting systemic disease.

Age: At present there is no one who gives an absolute age limit for thoacoplasty. Most authors agree that the best results are probably obtained in patients between twenty and thirty-five years of age.

While the extremeties of age are ordinarily avoided in thoracoplasty work, there may be individuals in the extreme age groups who present indication for thoracoplasty which may not be disregarded. Kensalla (84) reports a series which range from eleven to sixty-four.

The earliest age at which a thoracoplasty can be done safely on a child is still unknown. The common type of the disease in children is the hilar type or the exudative parenchymal lesions for which the operation is not used. Alexander has perfomred extensive thoracoplasties for chronic tuberculous empyema in several children less than twelve, one being five, with excellent results. However, his youngest patient with pulmonary tuberculosis who presented suitable indications was fifteen.

In the older age groups the chronologic age of the patient is not as important as his apparent age and the condition of the cardiovascular system. Decker (29) has reviewed a series of 154 patients between the ages of 40 and 60 for whom collapse therapy had been undertaken in various ways. Thirty four thoracoplasty operations were performed on seventeen patients. The conclusion was that thoracoplasty is needed and should be utilized but with greater precaution and hesitancy than in the earlier age groups.

Hemoptysis: Hemoptysis may strengthen indication for operation but only if his general condition and his lesions also present proper indications. Thoracoplasty is highly successful in stopping hemoptysis. Pneumo-

thorax may fail because of consolidation surrounding a bleeding cavity prevents its mechanical compression or from pleural adhesions. Thoracoplastic collapse exerts a solid pressure and may succeed when gas compression fails. The operation should be planned so that the ribs overlying the bleeding area shall be resected first. (55)

Thoracoplasty should not be used to check active pulmonary hemorrhage. Wiener and Fishberg (75) performed several thoracoplasties with a view of controlling recurrent pulmonary hemorrhage. Though the general condition was good the results were that the patients still bled, some even more copiously than before operation.

Sputum: General opinion is that the amount of sputum has no effect upon the indication or contraindication for operation except greater care should be taken in those patients with large amounts of sputum in evacuating the secretions before operation.

Archibald (7) believes that the greater the amount of sputum and the more it resembles fluid pus, the greater will be the danger of its running into the healthy parts of the lung during manipulation of the operation and setting up fresh disease.

Right and Left Sides: The results of operations on the left side are much more satisfactory than those upon the right. Bull has stated that the operation is three times more dangerous for right sided than left sided cases. (73)

Jessen in 1932 made a thorough study of the venous pressure in pulmonary tuberculosis and therapeutic collapse of the lung. He reported in collapse of the right side he found 50 per cent higher venous pressure than in operation on the left, probably because the right heart is is more easily compressed than the left heart. This may explain the fact that right thoracoplasties have a less favorable prognosis than the left.

Sex: Apparently there is little uniformity of opinion as to the relationship of sex and mortality rate. In a clinical study of 170 cases of thoracoplasty Coryllos (25) found that the sex of the patient had a decided influence upon the operative result. Females withstood the operation much better than males. Both mortality and morbidity was lower and the percentage of cures higher. His explanation is that the females accepted the operation easier and in earlier stages of the disease than the male. Carters (20) series shows a higher mortality rate for females than for males.

Mediastinal Displacement: Probably the most important preoperative requisite is a fixed mediastinim, which actually means a stiffening of the mediastinal pleura. The most constant indication of a fixed mediastinum is the displacement of the trachea toward the affedted side as seen by x-ray. Removal of the ribs in the absence of a fixed mediastinum is frequently attended by paradoxical movement of the underlying lung, which interferred with the heart action resulting in mediastinal flutter. (73) (41) It has been observed (34) that in many cases of advanced tuberculosis the dyspnea, tachycardia and cyanosis are due to cardiac displacement especially in the extensive and fibrotic left sided lesions and they may be benefited by operation. The decision as to whether such symptoms are due to mediastinal displacement or to organic disease must be made by exclusion of the likelihood of organic disease.

Berck (9) has devised methods of artificially fixing the mediastinum by means of injection of acacia and paraffin oil. These are still in the experimental stage, and as yet have not been used to any extent in man.

Respiratory Function: Unfortunately there is no method of determining a patient's respiratory functional reserve

that can be definitely relied upon. Alexander states that the "most important measure of an adequate reserve of respiratory function is the complete absence of dyspena". Coryllos (25) uses as a test to have the patient go up and down steps. If after this amount of exercise the respiratory rate increases over 35 and the pulse is over 125 the operation is contraindicated or at least postponed. The dyspnea which occurs when the patient gets out of bed is not considered a contra-indication provided he becomes accustomed to being up and is not longer dyspnic after a short period.

A careful examination of the vital capacity should be made before the operation. Patients with low vital capacity are considered good risks provided they are free from myocardial damage. Young patients whose vital capacity is between 900 and 1000 cc may be operated without grave risk. Older individuals past 50 years of age should have a vital capacity of at least 1,500 cc if post operative complications are to be avoided. (27) (64)

Crimm (28) has operated upon a few cases successfully whose vital capacity was as low as 800 cc. Most operators would consider such a low vital capacity a contraindication. Alexander (2) will not operate on a 150 pound patient unless the vital capacity is at least 1,600 cc; he prefers 2000 cc. as a far safer minimal.

Harter, Overholt, and Perkin (46) made pre-operative and postoperative determinations of the lung volume in 32 patients who were subjected to thoraco-plasty for pulmonary tuberculosis. Eight patients showed a greater lung volume after the operation. Twenty four patients showed a reduction in the post-operative lung volume, the per cent change ranging be-tween minus 5 and minus 50.

Clinical impression drawn from their series of cases was that the great mfjority of patients rehab-ilitated by thoracoplasty do very well in respect to pulmonary function. These observations have prevented the authors from becoming unduly alarmed about the possibility of making the patient's condition worse physiologically than it was before.

Lindskog (50) has shonw that the greatest re-duction in lung volume occurs after the first stage which involved resection of the upper three of four ribs. Little decrease was noted after the following operating, in fact, one patient showed a slight in-crease.

Cardiac Reserve: Cardiac reserve is a very important factor when considering thoacoplasty. Years of toxi-city and bed rest reduce the functional capacity of the

heart considerably. Blood pressure reading, pulse and respiratory rates taken before and after mild exercise may give some information as to the condition. Slight cyanosis, tachycardia, "cardiac pallor" when not due to mediastinal displacement are usually considered contra-indications.

Thoracoplasty adds a greater load to the already burdened heart. Aside from the major operation it has been shown (45) that there is always displacement of the heart after operation, there is also direct pressure on the heart, increased resistance to the right heart and the possibility of paradoxical respiratory movement developing after operation.

Cardiac disease as a contraindication is still a relative one. The type of cardiac lesion present and the degree of compensation are important factors. Ensella (53) has performed thoracoplasty successfully and without difficulty in the presence of well compensated cardiac lesions of both congenital and organic types.

Hansen (45) studying the effects of thoracoplasty on the heart states that in his cases there has been no evidence of disturbance in conduction or of myocardial damage in the electrocardiogram.

Duration of Disease: Patients who have had pulmonary

tuberculosis for many years must be approached with caution. If the course of the disease has been mainly atoxic the existence of the disease over a long period may not affect the decision to operate. If there have been prolonged periods of toxemia the outlook is not so favorable. The ill effects of chronic tuberculous toxicity upon the myocardium, kidneys and other organs increases the risk of thoracoplasty. (77)

In the majority the average duration of tuberculosis before operation is three years. (19) (41) Several surgeons will not operate unless the symptoms have been present two years. Those patients whom Graham (96) has operated in which the symptoms have been present for less than a year the results were ungratifying.

Exudative Lesion: The histological reaction in the exudative form, which is always a more or less acute process, consists in the collection of a fibrin containing fluid in the lung parenchyma, along with the usual cell elements, lymphocytes, red cells, and exfoliated cells from the alveolar walls. The amount of fluid thrown out is similar to that of lobular pneumonia. It has been demonstrated that this exudate can be reabsorbed within a few months but this is not the usual

result. Caseation begins in the middle of the exudate, progresses and involves the lung parenchyma with the stroma. Without further progression this may "dry up" and be turned into a scar surrounded by a capsule of fibrous tissue. On the other hand, the caseous focus may break down and the end result is a cavity. If the resistance is strong this may turn into the chronic productive type.

The exudative lesion is interpreted as being exudence of poor resistance or an allergic manifestation. (51) This type of lesion more often shows tendency to progress than to become chronic. It is well agreed that thoracoplasty rarely, if ever, should be performed for extensive exudative lesions. Thoracoplasty may cause rapid progression in either lung by paradoxical respiratory, autotuberculinixation or other temporary harmful effects. It is especially dangerous if there has been any tendency toward progression during the several months immediately preceding the operation. (2) (41)

An analysis with respect to type of lesion by Brunner (17) of 67 patients with productive type operated, 10% died; of 49 patients with exudative lesion 43% died.

Productive Lesions: The productive form leads to the formation of the typical tubercle, with absence of fluted exudate. The tubercle is composed of endothelial cells, which may fuse to form giant cells; these are surrounded by lymphocytes, alveolar cells and proliferated cells from the stroma and vessel walls. A measure of the productive type if considered, the number of giant cells, lack of surrounding fluid exudate, and the relative isolation of the tubercle. Caseation takes place in the center of the tubercle with sloughing out, expectoration and formation of cavities. Frequently, however, a hyaline and fibrous transformation of the whole tubercle into a solid scar takes place, or the formation of a dense fibrous capsule around the caseous mass.

This productive or fibrotic lesion indicates a favorable resistance to tuberculosis. The fibrous tissue tends to close the cavities by progressive contraction. As the contraction takes place it tends to draw the ribs, diaphragm and mediastinum toward it. The extent to which these structures can be drawn may not be sufficient to allow the cavity to close. Thoracoplasty releases the tension on the fibrous tissue allowing the fibrous tissue to close the cavity freely.

Thoracoplasty then should be performed for the lesion which is productive since it favors firm encapsulation and since exudative lesions are made to progress rapidly by the operation. Serial x-ray pictures should show that the exudative lesions present should be stationary or regressive since most patients suitable for thoracoplasty have minimal exudative lesions. Some authors require the serial x-rays to show displacement of the trachea before the patient is suitable for operation. Archibald (7) uses as a working rule "do not operate if the trachea is in mid-line". Most authors do not agree with this, however, and many excellent results have been obtained without this prerequisite. (2) (41) (61)

The "Good" Lung: Since the inception of thoracoplasty the most important single contraindication has been active tuberculosis in the opposite lung. It has been staged many times that the opposite lung should be so nearly normal that physical and roentgen ray examination reveal no abnormalities or only the evidence of limited and arrested disease. Recently, however, surgeons have become far more liberal with regard to the extent of lesions in the better lung. The operation is now performed on the worse lung if the better lung shows moderate productive lesions or even an old cavity,

providing the respiratory function is adequate. There have been many reports of rather extensive active lesions in the good lung favorably influenced and frequently healing of the lesions by control of the more extensively diseased lung. There are two probable explanations for the favorable effect on the unoperated lung:

1. The more extensively diseased lung acts as a source of toxin formation and when this is eliminated or nearly so, by the operation the resistance of the patient against tuberculosis may then be sufficient to control the less extensively diseased lung.

2. The operation releases the tension caused by the poor lung on the mediastinum thereby causing a shift toward the unoperated side relaxing the tension in the better lung which favors healing.

A study of the symptoms, pulse, temperature, serial roengenograms and physical findings during the preceding six months will give valuable information as to the condition of the lesions in the better lung. Even a short period of tuberculous activity within this time should cause the operation to be postponed.

It has been suggested that a preliminary phrenicectomy should be done, achieving some reduction in the size and functional activity of the diseased lung, and

if the lesion in the contralateral lung displays no tendencies to reactivate, thoracoplasty may be done later on. Most surgeons feel that this is of little value because the lesion in the contralateral lung may remain inactive after a phrenicectomy, but flare up soon after the major operation.

According to Young (77) a lesion involving more than about a quarter of the lung should contraindicate the operation. Apical lesions are usually most benign and a fair amount of quiescent disease can be allowed, including small cavities. If the lesion if in the middle or lower lobes the amount of disease allowable is much less and a cavity is a contraindication. Dry pleurisy seldom leads to trouble if there is no x-ray evidence of infiltration of the lung.

The indications for thoracoplasty have been greatly widened through the use of bilateral collapse therapy in many combinations.

Blood Studies: Sedimentation rate and leucocyte counts have been analyzed by Muller (59) and correlated to various factors of pulmonary tuberculosis prior to thoracoplasty and six months after operation. He found that patients with favorable leucocytic index and with normal or practically normal sedimentation rate before

thoracoplasty are likely to respond well to operation. Patients with a marked activity of the disease process as revealed by the leucocytic index and sedimentation rate likewise respond well if the trend of the blood indicates progressive improvement before operation as revealed by serial examination. Patients who show an increase in the sedimentation rate, leucocytic index and a neutrophilic shift to the left, shortly before operation do not derive benefit from the operation and some are made worse.

Extrapulmonary Disease: The contraindication of extrapulmonary tuberulosis is more or less relative depending upon the location and severity, and the age of the lesion present. Tuberculosis of the larynx is not considered a contraindication to operation, infect, the majority improve after operation. However, if it is severe enough to cause interferrence with the coughing mechanism or with sollowing operation may be contraindicated. Intestinal tuberculosis if not severe also do well after thoracoplasty. Tuberulous lesions of bones, joints, skin or ano-rectal region if mild, do not contraindicate operation. Unilateral renal tuberculosis even if progressive is not considered as a contraindication while bilateral renal tuberculosis is

a contraindication.

Extra pulmonary disease contraindicates thoracoplasty in the same degree as any other major surgical operation. Apparently fatal extrapulmonary disease contraindicate the operation whether tuberculous or otherwise, including cancer, advanced renal disease, etc. In this group merely attacking the pulmonary tuberculosis does not alter the eventual prognosis.

The most favorable results are obtained in the "good chronics". Brown and Sampson(15) give the criteria for a good chronic as follows "a cavity at least 2 cm and usually larger in diameter must be present. The general condition must be favorable. The temperature and pulse must be normal during the period of observation of several months. The appetite and strength must be good and the patient must sleep well and be able to take some exercise. Expectoration may be present but not excessive. The number of tubercle bacilli in the sputum is not taken into consideration."

Secondly, the slipping chronics in which group will be found those with quiet but steadily progression of the disease. Moderate elevation of temperature, loss of weight, weakness, easily fatigued, and inability to take exercise. It also includes those patients showing, during the period of observation roentgenologic evidence

of progression of the disease. The group consists of patients with progressive caseous pneumonic disease with cavitation and recent exudative extension. (36)

The bad chronics represent a further stage in the progress of disease. Here is found persistent fever and a marked rise of pulse rate with steady loss of weight and in the lung considerable increasing cavitation. If in these cases favorable resistance is discovered by evidence of previous resistance in contraction, if the disease is chiefly unilateral and if destruction has not gone too far, operation may still be justifiable though with a much greater risk. (7)

Thoracoplasty Combined with Pneumothorax: Thoracoplasty with pneumothorax of the contralateral lung, according to Graham (41) was done on seven occasions by Samson and Freund in 1924 and 1931 respectively. Coryllos reported a series in 1926. In 1938 O'Brien, Tuttle, and Day (63) reported their experience with this method of treatment on 85 patients who had undergone 207 thoracoplasty operations. Aside from the contralateral lung the indications and contraindications were the same as those picked for thoracoplasty. The results are that 27 cases are arrested, 13 quiescent, 23 improved, 2 unimproved, and 18 are dead. They feel

from their results that the use of pneumothorax as a therapeutic measure in treatment of the contralateral lung simultaneously with performance of thoracoplasty is a justifiable and useful procedure.

The work of Wood and Miller (76) shows that the decrease in efficiency of the lung from tuberculous disease does much more to injure the oxygenating function than does a considerable amount of pneumothorax, which may give reason for contralateral control.

## ANESTHESIA

Anesthesia is one of the prime considerations in the operation of thoacoplasty in pulmonary tuberculosis. The success of failure of the operation in a large measure depends upon a wise selection of the anesthetic used. The choice of the anesthetic has been somewhat a matter of individual or national preference. Obviously, patients with tuberculosis in any location and particularly with extensive disease of one or both lungs are below par, and more care should be exercised in choosing an anesthetic for them than in almost any other substandard risk. (62) (74)

The requirements of the idea anesthetic are: (1) a wide margin of safety between the anesthetic dose and the toxic dose; (2) minimal organic irritation to the lungs when given in amounts large enough to produce adequate narcosis; (3) ability to maintain quet, not jerky, respiration, and to retain the cough reflex during complete analgesia; (4) rapid recovery from narcosis so that the patient may voluntarily cough and expectorate immediately after completion of the operation; (5) absence of post operative acidosis; (6) causes minimal nausea and vomiting during and after operation; (7) ease of administration and freedom from

shock. (2) (54)

Gas Anesthesia: Up to 1924 ether or ether-chloroform mixture was used for general narcosis in Europe, sometimes in conjunction with local anesthetic. (3) The danger and irritative effect of ether or chloroform are well known and make them undesirable. Even at that time novacaine-suprorein anesthesia and nitrous oxide oxygen was preferred by Archibald (5) and Hedblom (50), and by other surgeons nitrous oxide alone.

Nitrous oxide fulfills most of the requirements of a good anesthetic and has been widely accepted. It has the advantage in common with other agents producing general narcosis, of dispelling the patient's anxiety during operation. It may be quickly induced and the patient kept in a satisfactory state of anesthesia while maintaining the cough reflex. It permits rapid and complete awakening as soon as the operation is completed. By stopping the anesthetic a minute or two before the operation is completed and giving a mixture of carbon dioxide and oxygen, the patient's awakening will be hastened and it will be possible for him to cough and expectorate immediately. From time to time during the operation it is necessary for the anesthetist to aspirate secretions from the mouth which have gravitated there.

Coryllos (21) used a method of endotracheal anesthesia for thoacoplasties during which bronchial suction is carried on for the removal of the bronchial exudate expressed from the collapsed lung. He used gas (92) at from four to six milimeters pressure through the apparatus. In addition to nitrous oxide and oxygen he gives from 15 to 30 cc of ether and some carbon dioxide in order to hyperventilate the lungs. He used for anesthesia of the pharynx and larynx, local applications of cocaine. The tracheal catheter is introduced as an ordinary brochoscope, gauze is then packed tightly into the throat around the catheter. A rubber of hard gum uretheral cathereter is introduced every five mintues into the intratracheal catheter and pushed down to the bonrchi; by this means a thorough suction is carried out.

This method certainly complicates the operation. It requires in the surgical team a man able to introduce the endotracheal catheter and a more careul anesthesia. The prolonged contact of the catheter with the larynx may cause a tuberculous laryngitis or aggravate an existing one.

Nitrous oxide has the disadvantage of causing loss of water from perspiration and is often followed

by vomiting. It is difficult ot administer the gas and oxygen in the proper proportions to avoid cyanosis from suboxidation but yet to maintain the cough reflex and keep the respirations quiet and regular.

According to Eversole and Overholt (33) nitrous oxide has been responsible for many of the difficulties in carrying thoracic patients through their operation safely. Struggling on the table, deep, forceful respiration, then cyanosis and rising pulse were common experiences with them. It also has the disadvantage of requiring very high concentration of the gas.

Cyclopropane: During the past two years cyclopropane has become the anesthetic of choice by many surgeons doing thoracoplasty operations. It is an anesthetic agent which is effective in low concentration and needs very little absorptive surface in order to reach a sufficiently high concentration in the blood to maintain anesthesia (27). Other advantages according to Weinberg (74) are, "it is not irritating to the tissues of the respiratory organs, it permits minimal excursions of the lung and thoracic wall, it causes almost no alteration in blood pressure and pulse rate and it allows the patient to regain complete comsciousness within a few minutes after it is stopped."

The recovery period from cyclopropane usually varies from 3 to 10 minutes. The cough reflex returns with equal rapidity. Nausea and vimiting occur in approsimately one fourth of the patients in the first three minutes but only one tenth of the patients have subsequent nausea. (33)

Cyclopropane has the disadvantage of being both inflammable and explosive.

Ethylene: Ethylene and nitrous oxide possess about the same advantages. Cabot and Davis (18) cite the added advantages of less sweating and heat loss during the administration. A 15 per cent deeper anesthetic level can be reached with ethylene than with nitrous oxide still allowing the patient an adequate oxygen supply. Its chief disadvantage lies in its odor and explosiveness. Nitrous oxide - ethylene sequence is more desirable than ethylene alone since the induction is more satisfactory to the patient.(38)

Acetylene has been used considerably in Europe and particularly in Germany. In this country it has been most extensively used at the Mayo clinic.(38) It has the advantage of permitting a high concentration of oxygen during administration. It has the disadvantage of requiring a cumbersome apparatus, it has a disagreeable odor and is highly explosive.

**Avertin:** Avertin has been a popular drug for producing anesthesia without inhalation methods. It is easily induced and is comparatively pleasant for the patient in that he falls asleep without any troublesome respiratory difficulties. Quiet breathing on the operating table and freedom from postoperative nausea are other advantages. Newton(62) states that the cough reflex is not abolished as is often mentioned. The disadvantages of avertin are that it is not safe to use alone because the anesthetic dose closely approaches the toxic dose, ticauses marked lowering of the blood pressure, depreses respiration and the effects extend for several hours into the postoperative period.

According to Gale (38) the combination of avertin and nitrous oxide provides a good anesthetic. The dose of avertin can ge greatly reduced thereby assuring complete safety and the induction of the nitrous oxide is much easier. Eversole and Overholt (33) have used avertin as a basal anesthetic supplemented by nitrous oxide and found it very unsatisfactory.

**Evipal:** Coryllos (24) has reported 300 consecutive cases of thoracoplastic operations for pulmonary tuberculosis using evipal anesthesia. He had no deaths from anesthesia. However, respiratory disturbances occurred

in a small number of cases. In all, respiration was restored to normal by artificial respiration and antagonistic drugs. He has been highly gratified by his results and now uses it routinely.

Local and Regional Anesthesia: Almost all chest surgeons use local and regional anesthesia only when an inhalation anesthetic is contraindicated. The routine use of local infiltration and intercostal block has not proved wholly satisfactory. While it possess the advantages of not abolishing the cough reflex and thus lessening the chance of aspiration of secretions nor of producing pulmonary irritation or suboxygenation, it does have definite disadvantages. some of these are; frequently imperfect anesthesia requiring reinforcement with general narcosis, the possibility of perforation of a tuberculous pleura with the injection needle, hypersensitivity to large amounts of novacaine and psychic disturbance or dread of the operation.

The objectionable features of local anesthesia have been minimized by the use of a general anesthetic in conjuncion with it. Less of both agents isethus required.

Spinal Anesthesia: At the present time the majority of writers do not recommend spinal anesthesia for thoracoplasty. Bettman and Biesenthal (10) in 1931 reported five cases which were operated under spinal anesthesia. They employed novacaine dissolved in cerebrospinal fluid and injection of the solution with the patient lying on the side to be operated. They used inhalation anesthesia in one stage and spinal in another; in all cases, and stated that the patients were emphatic in their preference for spinal. Newton (62) employed a similar technic in 28 operations. As a preliminary medication he used morphine and scopolamine in small doses. Newton sums up his report by the statement, "I do not believe in using spinal anesthesia as a routine in thoracoplasty but only in patients with considerable mental poise."

Shields (67)(68) believes that a block which will produce adequate anesthesia for an upper abdominal operation will give ample anesthesia for a lower thoraco- with less circulatory depression. He also states that in any other major operation, in the presence of tuberculosis spinal would be the anesthetic of choice.

Gurd (42) has used this type of anesthesia in nine cases and believes that it has advantages over other types.

## PREOPERATIVE MANAGEMENT

It is advisable to have the patients under observation for severl days in the hospital where the operation is to be performed, the excitement of being transported to a new hospital, the fatigue or exposure on the journey may cause a flare up of temperature and pulse, in the presence of which the added strain of operation might be dangerous.

Graham (40) has observed that patients who have been in bed for too long a time do not tolerate thoracoplasty as well as others. It is his practice to have the patients be up and about for short periods prior to operation. He believes the circulatory system is better for this.

Carter (19) states that practically always the patients ill and toxic for a long time have myocarditis and a treatment with digitalis should be given before operation. He noted a striking contrast with those who had not had digitalis. The majority of surgeons however do not use digitalis.

An important preoperative precaution is to match the patients blood for transfusion. A few writers use blood transfusions routinely before and after operation.

Crimm (28) gives his patients Viosterol 250 D,

(1.5 cc.) per day for approximately two weeks prior to operation.

It is customary to administer a sedative the night before the operation to ensure a good nights rest. Veronal, Amytal, Etc. in small doses. Grimm (28) believes that too much sedative supplements surgical shock. Morphine gr. one fourth is usually given one hour before operation. General opinion is that atropine should never be given before operation.

Emptying the lung before operation is imperative in the prevention of aspiration of secretions. This may be accomplished by volentary coughing and postural drainage. Archibald (7) and Allen (1) recommend setting the hour of operation for a time when, by the patients experience, he has emptied his lung by coughing. This may be in the late forenoon or afternoon.

Fluid requires no treatment other than aspiration previous to operation. However, aspiration of the fluid should continue between stages. In cases where an ineffective pneumothorax is present when a thoracoplasty is decided upon, the air should be allowed to become completely absorbed or be aspirated before the operation.

Special measures: Some authors insist that phrenicectomy should be performed as a preliminary measure in every case of thoracoplasty. These men feel that

phrenicectomy constitutes, in a measure, a test of the functional capacity of the opposite lung, partially initiates the necessary circulatory and respiratory adjustments, and may in itself produce sufficient improvement to make the thoracoplasty unnecessary. The phrenicectomy, too may reduce the toxicity considerably and, by partial closure of cavities, may reduce the amount of sputum, thus lessening the possibility of extension and aspiration. This decreased tendency to aspiration and extension is said to be due to the elimination of the supposed sucking effect of the diaphragm on the lower lobe. It is considered also, that the routine preliminary phrenic nerve operation increases the effectiveness of the thoracoplasty, through added collapse.

Opinion, however, as regards the benefit of preliminary phrenectomy, is not unanimous. Another school of thought agrees that phrenicectomy augments the collapse but advocates that it become subsequent to the rib operation in order to preserve, immediately following the operation, the aid of the diaphragm in coughing. A normal cough mechanism, will naturally reduce the dangers of aspiration.

Position on table: To avoid sputum aspiration the patient should be placed on the table in the head low position. The lateral decubitis is usually chosen. Archibald (7) places a pillow under the chest so that the affected lung is at the top. Urquhart uses a specially constructed mold in order to obtain a satisfactory position of the patient on the table. The mold is made of cork covered with canvas. Strapped to this mold the scapula is thrown forward and outward and any change in position of the arm is prevented. Gale (38) studying the vital capacity in various positions found that the most idea was the supine, all other positions showed a decrease in vital capacity.

## MODERN OPERATION

The technic of thoracoplasty as it is performed today is far removed from the original technic of Cerenville, Brauer, and Friedrich and even of Wilms and Sauerbruch. Narrowing of the whole hemithorax by resection of short segments of a great number of ribs was the object of these authors. The modern operation consists of the resection of only as many ribs as required for complete or complete as possible obliteration of the chest cavity. Rarely are more than three ribs resected at any one operative stage. The posterior and later portions of the uppermost ribs are removed and if necessary the anterior portions.

In the first stage of the operation the second rib, or the third and second ribs are first resected subperiosteally from the tips of the transverse processes of the vertebrae to within a varying distance of the costonchondral junctions. The first rib is then resected to the middle of the costal carilage or to the sternum. The second and third and portions of the first transverse processes and underlying sections of ribs may be removed to obtain maximal collapse of the coastovertebral gutter. The periosteum of the resected

ribs is dried and scrubbed with 10 percent formalin, to prevent rib regeneration.

The second stage is performed approximately three weeks after the first. At the second stage, third, or fourth, if necessary the two or three next upper most ribs and transverse processes are resected.

Many technical aspects of the operation are in dispute. Some authors, including Carter (19) and Archibald (7) prefer beginning with the lower ribs. Neuhof (61) leaves a rib inbetween the first and second stages and excises that rib at a third stage. Many other variations are used.

It is accepted that the individual case must be responsible for the final decision as to the number of stages, number and length of rib resections, interval between stages, etc.

If, after two or three posterior stages have been performed x-ray shows that a pulmonary cavity is being prevented from collapse by the remaining anterior costal stumps and carilages, these may be dealt with by one of the modern types of anterior thoracoplasty which then constitutes a whole stage of the thoracoplasty.

Indications for dividing rib resections into a poster-lateral and an anterior stage are: large amounts

of sputum, retraction of the mediastiminm excessive paradoxical motion after the first stage. In lesions limited to the upper lung maximum selective collapse may be obtained. (2) (43)

Haights(43) technic of anterior thoracoplasty consists of resection of the anterior costal stumps and parasternal dividion of the costal cartilages. Division of the cartilages allows them to hinge at the sternum and swing medially and posteriorly, this is applied to the second third and rarely the fourth ribs, the first having been more easily completely removed at the first posterolateral stage.

For anterior operation Bisgard (11) advocates the subperichondral resection of the costal cartilage with implantation of osteoperiosteal grafts into perichondrial tubes constructed from the residual perichondrium. The implantation of bone grafts into the perichondrial bed results in eventual skeletal rigidity anteriorly, overcoming the disadvantage of the permanently unstable thoracic wall that almost invariably results from the failure of chondrogenesis following resection of cartilages. In resecting the cartilages the cancellous sternum is exposed to that bony union will ensue. The osteoperiosteal grafts are obtained from the anterior costal segments that are resected as part of the anterior stage.

The optimal time to perform an anterior stage is after posterior resection of enough ribs has been done to allow the scapula to fall forward.

Alexander has used both of these methods of anterior thoracoplasty with good results.

## POSTOPERATIVE MANAGEMENT

The patient should be placed in the Trendelenburg positon and maintained until consciousness is regained and preferably for 24 hours. This is very important in the prevention of stasis of pulmonary secretions.

Alexander has his patients lei on their backs, Gale places his on their operated side, O'Brien places his patients partly on their backs and partly on their operated side with their arms strapped to their chests to prevent too great movement of the decostalized thoracic wall.

In order to increase collapse of the remaining stumps of ribs and cartilages a bag of shot may be placed on the anterior chest wall below the clavicle. The number of pounds used variws with the operator. Edwards (32) usus as much as 24 pounds.

The routine use of 15 per cent of carbon dioxide and 85 per cent of oxygen inhalations every two, three or four hours followed after each inhalation by voluntary assisted cough, is advocated as a phrophylactic measure against stasis of pulmonary secretions. (44) Coryllos (22) is of the opinion that under the influence of carbon dixoide the bronchial exudate tends to lose its viscosity and to become transformed into a thin frothy secretion.

When the patient is instructed to cough it is advisable for the nurse to support the painful wound by means of gentle pressure.

Narcotics may be used to prevent excessive pain during coughing, but they should not be given in sufficient amounts to abolish the cough reflex or to cause prolonged sleep. The patient should be especially encouraged to cough as soon as each individual dose of the narcotic has produced its maximum effect.

Steam inhalation with the addition of menthol, and one of the many expectorants may be advantageously employed when the secretions are excessively tenacious.

Intratacheal suction is indicated (44) (25) either because the patient is unable to cooperate due to insufficient strength, unconsciousness or rarely unwillingness. In cases where a single aspiration will probably be sufficient, or when a definite atelectasis is present bronchoscopy is usually preferred. In cases which require suction every four to six hours Haight (44) has devised a method of suction through an intratracheal catheter. He uses a No. 16 French soft rubber urethral catheter which he introduces through the nares. He points out that this not only eliminates much secretions but the presence of the catheter in the trachea incites further coughing which in turn dislodges bron-

chial secretions into the trachea where they are removed by suction.

Of course, other general supportive measures are given routinely.

## COMPLICATIONS

Modern thoracoplasty is no longer accompanied by the tremendous mortality of 75% as in the time of Brauer and Friedrich, but it still presents an immediate mortality of 10% and a late mortality of 20%.

When the literature is reviewed and the causes of death noted they are found to range from the rather general classification of septic state or toxemia to a still more vague and more general post operative causes of death. The majority of the deaths reported are due to pulmonary and cardiac complications. The principle causes of death are reported as shock, heart failure and aspiration or tuberculous pneumonia. Other causes which occur less often are, autotuberculinization, mediastinal flutter, post operative hemorrhage, wound infection, embolism and others.

Post Thoracoplastic Shock: Post thoracoplastic shock is not the same phenomena as typical surgical shock. Yet some of the conditions following the operation may be due to the causitive factors of surgical shock. The lethargy, rapid pulse, low blood pressure, sweating, varying degrees of cyanosis and dyspnea may be due to the pressure on the mediastinum from the collapsed lung, paradoxical movements of the thoracic wall or paradoxical

movements of the mediastinum. Clogging of the bronchi by secretions increase the paradoxical movements, anoxemia and cyanosis. (3) The complication may appear immediately after the operation or during the first week or two following. The typical picture is as follows: the patient suddenly complains of fatigue, becomes restless, repiration is rapid and shallow, the pulse rapid and soft, and the blood pressure drops. The abdomen becomes distended, the tongue is dry, vomiting occurs, eyeballs are sunken, and the extremities are cold and clammy. Briefly there is the clinical picture of rapidly approaching shock. The wound is in good condition, there is no infection, and the lungs are clear. (23)

The delayed appearance of post-thoracoplastic shock is thought to be due at least in part to paradoxical respiratory movements and pressure upon a damaged heart. It is generally accepted that the phenomenon of paradoxical respiration, is due to the removal of the bony support of the chest. During inspiration, as the intrapleural pressure becomes more negative, it draws the chest wall inwards. The latter is deprived of its rigidity following costal resection. Furthermore, in cases with a flexible and mobile mediastinum inspiratory collapse of the affected side causes inspiratory dis-

placement of the mediastinum towards the healthy side because of the greater negative intrapleural pressure in the latter. Conversely, during expiration there is outward bulging of the chest at the diseased side and the mediatinum is displaced toward this side because of a more positive pressure in the healthy side. This phenomenon is known as mediastinal flutter. It is obvious that its immediate results are hampering of inspiratory inflation and expiratory deflation of the healthy lung and consequently with this loss of function there goes a corresponding loss in the vital capacity. The reduction of aeration must affect the heart secondarily. More than this however, the abnormal movements of paradoxical respiration and mediastinal flutter have a direct mechanical effect on the hear t action quite independent of any toxic factors. This is usually seen in an increase of the heart rate up to 100 to 120 which also must tire the heart. The loss of aerating surface is also felt by the good lung which has to work much harder in an effort to compensate and accounts for the severe dyspnea. If, as in the one stage operation as was practiced for some time, the whole of the operated lung was put out of function suddenly, or if even in a two stage operation too much the rib support is removed, the dangers of this complication become all

the greater. This was the greatest factor which made it a general rule to perform the operation in not less than two stages and even more stages in dubious risks. (36) (63) (7)

Coryllos (22) presents a theory explaining the cause of post-thoracoplastic shock. He suggests that stasis of bronchial exudate and especially exudate expressed during operation becomes infected by pneumococcus which increases its viscosity and renders it able to obstruct small or large size bronchi. Massive atelectasis or pneumonias develop which decrease ventilation and increases anoxemia, the resulting shallow rapid breathing further increases anoxemia, causes rapid elimination of carbon dioxide and produces acapnea, which still increases anoxemia. This brings about loss of muscle tone; the latter causes "peripheral vascular failure" peripheral blood stasis, decreases venous return to the heart, drop of blood pressure and "shock" and leads to a more marked anoxemia and to anoxemic crisis.

The treatment of post-thoracoplastic shock resolves itself into the treatment of surgical shock and the other contributing causes, chiefly paradoxical respiration, anoxemia, and accumulation of pulmonary secretions.

The Trndelenburg position and intramuscular ephedeine are used in combatting fall in blood pressure. Various solutions are given intravenously by different writers. A solution of gum acacia, blood transfusions glucose, Ringer's solution, hypertonic salt solution and combinations of these.

It is generally agreed that the most valuable treatment for the effects of paradoxical repiration and anoxemia is inhalation of oxygen. Many are of the opinion that repeated positive pressure breathing with oxygen is the most valuable method of combatting mediastinal flutter. Alexander has used the Drinker respirator in desperate cases with excellent results.

Accumulated bronchial secretions may be evacuated by intratracheal catheter or bronchoscopy, as described under postoperative care.

The presence of air or fluid in the pleural cavity produces a grave form of post thoracoplastic shock by producing a high intrapleural pressure. Aspiration of the fluid or air give immediate relief and may be repeated as often as the symptoms require it.

Tuberculous Pneumonia-Tuberculous Spread

The highest percentage of early deaths is due to pulmonary complications, the chief of which is acute tuberculous pneumonia involving the good side. According to Carter (20) a large percentage of these cases of

acute tuberculous pneumonia in the good lung is due to the aspiration into it of the contents of cavities which are compressed when the diseased lung is collapsed. The mechanism by which this occurs has been described by McCordock and Ballon (60) They state that the development of acute tuberculous pneumonia in the good lung in many cases depends upon the amount of compression obtained and upon the location of such compression. It is the squeezing out into the bonchila tree of the infected contents of the tuberculous cavities and the aspiration of such contents into the already sensitized good lung that produced the tuberculous pneumonia. A considerable amount of edema accompanies this type of pneumonia and on this account many cases are unrecognized and death is attributed to edema of the lungs.

Allen (1) has not had a single case of acute tuberculous pneumonia following thoracoplasty for seven years; He ascribes this to the fact that he had to operate in that particular hospital in the afternoon and by that hour the patients had cleaned their lungs during their morning coughing even better than they could by postural drainage.

Tuberculous spred in the lungs is a frequent complication regardless of the pre-operative care, technnic or type of anesthesia. (31) The mechanism by which this

occurs is probably the same as that of tuberculous pneumonia. The lesions may take the form of small patches of bronchial pneumonic infiltration in previously uninvolved portions of any part of either lung. The base of the lung of the unoperated side ismost often involved. Not all fresh lesions appearing after operation are bronchogenic. A preexisting lesion may be seen to increase in size and have a soft appearance around the periphery. This probably due to increased tuberculous activity from autotuberculinization. The differentiation of lesions from bronchiogenic spread and the reactivation of existing lesions from autotuberculinization lies in the presence or absence of of a previously existing lesion, rapidity of resolution and upon the position and size. The increase of preexisting lesions due to autotuberculinization is usually not great and becomes absorbed in a few weeks. Lesions of bronchiogenic origin are less likely to become absorbed or otherwise healed. Smaller areas without grave toxic symptoms are indicative of a good resistance or relatively small number of innoculating tubercle bacilli; these lesions frequently become quiescent or completely healed, permitting continuation of an uncompleted thoracoplasty. (7) (3) (6)

Autotuberculinization: The type of death described by McCordock and Ballon, in the previous section, is well known and does not cover those cases which die of severe intoxication without signs of sericus disorder in the good lung.

The immediate post operative conditon of the patient is good but at the end of the first day or begainning of the second, the temperature rises, pulse rate increases, there may be slight cyanosis while the repirations are normal. On examination, physical and roentgenological, the lungs may be clear and as a rule are. At this point, in a majority the temperature returns to normal and the cariorespiratory function restored. In fatal cases the temperature increases, pulse becomes rapid, cyanosis and dyspnea become marked. The lungs contain many ralesand ronchi. Death usually occurs in from 48 to 96 hours post operatively. (73) (23) (3)

In 1922 Thjotta suggested that such reactions were due to autctuberculinization. Since that time other independent workers have come to the same conclusion.

It has been reasoned by many that tuberculin from the diseased lung is squeezed into the blood and lymph channels by falling in of the decostalized wall. Coryllos (25) has taken exception to this. He believes that absorption of material containing tuberculin takes place

in the healthy lung following stasis of tuberculous bronchial exudate aspirated during operation or following the early postoperative period when expectoration is still absent.

Most authors agree with Tuttle (72) that the fall of the chest wall upon the lung must of necessity squeeze out varying amounts of tuberculin from the lung into the lymphatic and general circulation and the amount of reaction following operation is associated with that patient's tuberculin hypersensitiveness. He observed that the patients with a high degree of sensitiveness and a relatively exudative lesion had the most marked post-operative reaction. He states that the reaction is one involving the union of antigen and antibody and if severe enough leads to sensitization of the host, the resistance to tuberculosis through the body becomes lessened and a "flare up" occurs.

Bronchial Obstruction and Atelectasis: Numerous authors have stated that every case of thoracoplasty is complacitated with some degree of patchy (or lobular) atelectasis at least in the diseased lobes or the lower love of the same lung. Following collapse of the lung there is a decrease of respiratory movements in the operated side and temporary supression of cough which favors retention of sputum in the small bronchi. (23) The plugging of a large bronchus by heavy tenaceous

secretions may cause lobar atelectasis or even atelectasis of a whole lung. Massive atelectasis simulates pneumonia into which it may develop and it is essential that the diagnosis be made early so that the prope r treatment may be instituted. The onset generally occurs within 24 hours following operation. It is initiated by marked dyspnea, with or without cyanosis, elevation of temperature, rapid shallow breathing, rapid pulse, and fall of blood pressure. Clinically atelectasis is diagnosed by the immobilization and flatness of the affected side, dullness and more or less complete absence of breath sounds. X-Ray shows an opacity of that side with deviation of the diaphragm and displacement of the mediastimum. Paradoxical respiration is usually present.

The treatment consists in the rapid introduction of an intratracheal catheter and aspiration of the bronchial tree. By the use of a soft rubber catheter as described by Haight (44) or a semi-rigid catheter used by Coryllos (22) the common bronchi as well as the secondary bronchi may be aspirated. Coryllos advises that the catheter be pushed as far as possible into the bronchial tree and mild insufflation be carried on. Resuscitation by this method has apparently been spectacular and saved the lives of many patients. Some

authors recommend immediate bronchoscopy in that it is more certain and enables the surgeon to be certain that complete evacuation of the secretions or mucous plug has been obtained.

Dyspnea: Dyspnea is apparently no longer a frequent complication of thoracoplasty. However, one author states (34) that "dyspnea and cyanosis are only exceptionally mild, and never lacking."

Mild or severe dyspnea may be caused by paradoxical repiration it is accompanied by marked reversal of the respiratory movements in the operated side. The chest retracts during inspiration, and expands during expiration. On fluoroscopy it is found that the diaphragm follows the chest in its paradoxical movements.

One explanation of the phenomenon of paradoxical respiration was given with its relation to post-thoracoplastic shock. Coryllos (23) believes that paradoxical respiration is not merely due to the loss of rigidity of the chest wall but that it is also due to retention of exudate in the lung of the operated side, to bronchial or bronchiolar obstruction, and to the consolidation, both atelectatic and inflammatory which follows them. He states that the degree of negative pressure during inspiration is regulated not only by the magnitude of the expansion of the chest but also by the resistance offered by the lung to expansion. A normal lung will

expand readily because of its great elasticity, opposing a very slight resistance to expansion and filling up the expanded chest cavity. As the resistance of the lung to expansion increases, the negative pressure developed in the pleural cavity will increase. Therefore any changes of the lung parencyma which will increase its resistance to expansion and will change the elastic and readily expanding lung to a rigid and inelastic body, will cause a proportionate increase of the negative value of intrapleural pressure.

Dyspnea following thoracoplasty may be due to deficient circulation of air. The operated hemithorax being largely passive after operation, the air leaving the contralateral lung on expiration passes partly into the bronchial tree of the operated side. The latter discharges air into the good lung, in part at least, during inspiration. These rebreathed currents, drifting from one side to the other with respiration are always present in the first period after thoracoplasty and the resultant reduction in the supply of oxygen may be the cause of varying degrees of dyspnea and cyanosis. (61)

Low vital capacity, pre and postoperative, maybe a cause of dyspnea immediately after operation. Impaired

cardiac reserve, spread of tuberculosis, accumulation of bronchial secretions, developing pneumonia or atelectasis are other causes of mild or severe dyspnea following operation.

The treatment of dyspnea is directed toward the causative factor. Neuhof (61) states that the best treatment for respiratory embarrassment after operation is the administration of opiates in large enough amounts and at frequent enough intefvals to give the patient maximal rest. He feels that the fear that the patient will be unable to cough and to expectorate, is unwarrented and that the fear of pain is much more likely to inhibit coughing. Paradoxical respiration may be treated by oxygen inhalation either by positive pressure breathing or by continuaous flow through a nasal catheter. Secretions in the bronchi can be evacuated by methods already described.

Cardiac Death: Graham(41) and Carter(20) believe that there are relatively few true cardiac deaths following thoracoplasty and that many patients whose deaths are ascribed to heart failure,really die of autotuberculinization and acute tuberculous pneumonia. Allen (1) states that he is firmly convinced that patients do not ke of cardiac failure but rather of anoxemia

due to an insufficient vital capacity remaining after operation.

Air Embolism: Air embolism is a possible complication although it is very exceptional. It has happened in Coryllos (23) group of cases twice. The symptoms vary with the location of the emoblus. Coryllos' patients were suddenly seized with convulsions, starting from the face and rapidly becomming generalized. He advises the Trendelenburg positio as a preventitive measure.

Acute Dilatation of the Stomach: Thomas (71) reports four cases of acut dilatation of the stomach following left sided thoracoplasty i which the left hemadiaphragm had been previously paralyzed. Two died, two recovered from the use of Wangensteen suction.

## LATE COMPLICATIONS

Scoliosis; The straightness of the spine is dependent upon the normal balance of the opposing bony structures, muscular forces and tension of the intrapleural negative pressure on the bodies of the vertebra. Rib removal by interference with the normal balance causes a scoliosis with the convexity toward the operated side. (52) (73)

The definite effect of thoracoplasty onthe spinal column was shown by Bisgard (13) In his group of 131

thoracoplasties, 101 were extrapleural and carried out in the treatment of pulmonary tuberculosis. He found that the contour of the spine was always altered but that the contour of the spine was altered but that the alteration was influenced by the preoperative contour.

Fifty one of his cases had straight vertebral columns before operation. These were invariably scoliotic after operation wit the convexity toward the operated side. In 21 in which there was scoliosis with the convexity toward the affected side before operation there was a definite exaggeration of the deformity post-operatively. In 51 with preoperative convexity to the unaffected side 12 were partially or completely corrected by the operation and 39 were overcorrected with resulting opposite scoliosis. Of the 101 only two had straight spines post operatively but the scoliosis was rarely severe.

The development of scoliosis frequently manifests itself within a few weeks after rib resection and active treatment is indicated during this period. New bone formation from the periosteum and the rib ends gives a stabilizing factor which tends to minimize any further deformity. Mild active and passive exercises instutited soon after operation aided by braces are used in preventing lateral curvatures. (8)

Bisgard (12) in making a sudy of methods to prevent the development of permanent scoliosis found that the maintenance of full correction of slight overcorrection while the chest wall is still plastic is a highly effective method. He uses a "posural wedge dompression" by having the patient lie on the affected side immediately after the operation with a pillow rolled beneath his thorax opposite the point at which the apex of the deformity might be expected. This not only exerts a bending force on the spine but increases the collapse of the thoracic wall. (73)

Cleveland (26) reporting cases of thoracoplasty performed on children, concluded that thoracoplasty should be avoided in children who have not reached their rapid growth period as they will almost certainly develop serious deforming curvature.

Fixation of the Scapula: When only five or six upper ribs are removed, tha angle of the scapula may become fixed under the next intact rib. If a wound infection of the subscapular area occurs, the scapula may become fixed to the intercostal tissues by the ensuring scar tissue. This fixation of the scapula may require removal of one or two more ribs (8) or removal of the inferior border of the scapula. Some surteons remove the inferior border of the scapula during an

during an upper thoracoplasty to prevent this complication.

Jumping of the vertebral border of the scapula over the divided ends of the posterior costal stumps occasionally occurs and is called "snapping scapula" Only occasionally does it cause enough discomfort to warrant operation. Steinke (70) resects the medial half of the bone to relieve the symptoms.

Bronchiectosis: Since the advent of lipoidal bronchography the frequent occurrence of bronchietosis in pulmonary tuberculosis has become quite evident. As this procedure is being used more and more it is found that bronchiectosis freqnently occurs after thoracoplasty. Aufses (8) shows radiographs of a widespread bronchiectasis in the lower lobe of a patient whose tuberculosis is confined to a single large apical cavity. Weithout lipoidal bronchography the copius sputum would be attributed to secretions from the cavity.

Graham (41) states that many of the dilatations found in the basal bronchi after thoracoplasty are really associated bonchiectases which are frequently present in cases suitable for thoracoplasty and which are accentuated by compression therapy.

Coryllos, (25) states that although bronchiectasis is a rare complication, a moderate degree of bronchial

dilatation is frequent in tuberculosis and perhaps more so after thoracoplasties. Uncomplicated dilatation in itself is of no clinical significance. It is only when the bronchial mucosa secretes large amounts of mucopurulent sputum that distressing symptoms occur.

The presence of nontuberculous bronchiectasis after thoracoplasty may be the cause of an erroneous diagnosis of persistence of active tuberculous disease. It should always be suspected when the amount of sputum remains high or increases, although it remains constantly negative for tubercle bacilli. It is definitely diagnosed by bronchograms following lipoidal injections.

Cardiac Hypertrophy: Following thoracoplasty a large amount of pulmonary tissue is reduced to a hard fibrotic mass. This offers considerable resistance to to pulmonary circulation and some degree of right sided cardiac hypertrophy is the sequel. The moderate hypertrophy which develops is sufficient to overcome this resistance and an equilebrium is reached, which may continue for many years. Sauerbruch (66) states that enlargement of the right side of the heart occurs during all foms of collapse therapy.

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