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AT A TIME WHEN THE ERADICATION OF pulmonary tuberculosis is heralded as a soon-to-be realized accomplishment, it might seem presumptuous to discuss pneumonectomy for the disease. It is now over 30 years since the first successful human pneumonectomy was performed and almost 20 years since the introduction of specific antituberculosis drug therapy. During the intervening time, much has been accomplished and, often through bitter experience, much has been learned. These lessons should be recorded. Although the series to be presented is small, it represents the total experience in an active hospital devoted to the care of tuberculosis, in which each patient was carefully studied and attended by a rather homogenous staff.

MATERIALS AND METHODS

Between January 1, 1950 and January 1, 1964, 63 pneumonectomies were performed for pulmonary tuberculosis, constituting approximately 0.5 per cent of all pulmonary resections for the disease. According to the classification of the National Tuberculosis Association, 54 had far advanced, eight moderately advanced and one minimal disease. The latter patient had complete atelectasis of the lung which was excised. There were 27 women and 36 men. Thirty-four were in the first four decades, 19 in the fifth, eight in the sixth and two in the seventh. The following concomitant diseases were present, each in one patient: asthma, amyloidosis and glomerulonephritis, carcinoma of the thyroid, diabetes mellitus, gastric ulcer, genitourinary tuberculosis, and advanced silicosis.

Methods of culturing for tubercle bacilli, including *in vitro* drug susceptibility studies have been described,[1] except for ethionamide. Organisms were considered resistant to the latter if there was any growth after two weeks' incubation in Dubos liquid medium containing 5 μg. per ml. Of the 63 patients, only 24 harbored organisms susceptible to streptomycin (SM), para-aminosalicylic acid (PAS), and isoniazid (INH). Two harbored organisms resistant to one drug, 11 to two drugs, and 26 to all three drugs.

Early in this series, patients received short courses of antituberculosis drugs, occasionally singly. On three occasions, no effective drug therapy was given. Later it became customary to employ two or more effective drugs for at least a year postoperatively. The term "effective" drug therapy indicates administration of drug(s) to which the patient's organism proved susceptible *in vitro* by the standards previously outlined. When combinations of SM, PAS and/or INH could not be utilized, cycloserine, ethionamide, kanamycin, thiazolsulfone, pyrazinamide and viomycin were substituted. Details of drug therapy have been previously reported.[1]

After 1954, timed and total vital capacities were performed routinely preoperatively and at intervals postoperatively on all surgical candidates according to methods previously described.[2] These parameters have proved most valuable in following the serial changes which occur in ventilation after pulmonary surgery. In addition, since 1958 pulmonary arterial pressures have been performed at the time of pneumonectomy as previously outlined.[3]

Indications for surgery, of which more than one may have been present in a single patient, may be listed as follows: advanced infectious disease 41, bronchiectasis, five; bronchostenosis, five; extensive pulmonary destruction, 61; severe hemoptysis, two; tuberculous bronchitis, three; and technical difficulties which precluded planned

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subtotal resection, two. Preoperative tuberculous empyema was present in five patients, staphylococcal empyema in one and uninfected pleural effusion in two. These pleural complications do not ordinarily require pulmonary resection unless the underlying lung is affected by disease requiring removal. Twenty-three patients had thoracoplasty prior to pneumonectomy. Fourteen had previous unsuccessful ipsilateral subtotal resections. Three patients had successful contralateral pulmonary resections.

Both prone and lateral decubitus positions were used on the operating table. The type of anesthesia varied considerably in the early cases. However, for several years succinylcholine chloride and minimal amounts of a rapidly metabolized barbiturate have been employed intravenously together with nitrous oxide-oxygen endotracheally. A light plane is maintained, which permits rapid resumption of respirations and coughing postoperatively. Blood loss has been effectively limited by use of the Bovie apparatus.[4] Tracheotomy was employed postoperatively in three patients. The cuirass type of Emerson respirator was employed postoperatively in two patients.

Although the tracheobronchial tree in tuberculosis is usually free of pyogenic organisms, it is possible for the main bronchi to become contaminated by the anesthesiologist's suction catheter. To limit this possibility, the catheter is soaked in a 1:1000 solution of benzalkonium chloride (Zephiran) when not in use. Furthermore, until the bronchus has been sutured, the anesthesiologist is careful not to insert the tip of the catheter beyond the main coryna. We have employed antibiotics postoperatively, most frequently aqueous penicillin. Intrapleural catheters are never irrigated, since this might introduce infection.

Bronchi have been closed with a single layer of suture material, usually interrupted silk. Every effort has been made to cover the bronchial stump with tissue.

All postpneumonectomy pleural spaces were drained by one or two catheters employing three types of apparatus. During the first four years, underwater seal was used in 18 instances. Balanced drainage[5] was used in the next 28 patients. The remaining 17 were treated with continuous suction of approximately minus 40 cm. of water. The occurrence of subcutaneous emphysema has been effectively prevented by covering the wound area with a well padded elastic bandage which is passed about the chest and occasionally over the ipsilateral shoulder. It has not been possible to demonstrate that this type of dressing adversely affects the vital capacity in the intact patient.

Early in this series thoracoplasty was employed to obliterate all postpneumonectomy pleural spaces. Later thoracoplasty was omitted in patients who did not harbor viable tubercle bacilli, after it had been determined that the risk of tuberculous infection is practically nonexistent. The techniques of thoracoplasty varied somewhat. Early, little or no attempt was made to

Table 1—
Complications Following Pneumonectomy

Operative vascular accidents	3
Operative cardiac arrest	1
Bronchopleural fistula without infection	2
Nontuberculous localized pleural infection	3
Mixed tuberculous and staphylococcal pleural empyema	2
Tuberculous pleural empyema	4
Tuberculous bronchial stump abscess	1
Postoperative contralateral tuberculous spread	1
Relapse of tuberculosis (bacteriologic)	2
Total	19

Table 2—
Tuberculous Complications by Drug Therapy

Number of Effective Drugs	Number Treated	Number of Tuberculous Complications
None	3	3
1 "secondary"*	3	2
2 "secondary"	25	3
1 "major"**	2	0
2 "major"	2	0
3 "major"	1	0
PAS, Cyclo, Kana	1	0
Kana, PAS	1	1
Vio, PAS	1	1

*"Secondary"=Drugs other than SM, PAS and INH; **"Major"=SM, PAS and INH; Cyclo=Cycloserine, Kana=Kanamycin, Vio=Viomycin.

TABLE 3—PLEURAL COMPLICATIONS BY THORACOPLASTY AND BACTERIOLOGY

Relation of Thoracoplasty to Pneumonectomy	Harboring Viable Acid-Fast Bacilli	Harboring No Viable Acid-Fast Bacilli
None performed	0	6 (0)
Preoperative	12 (3)	11 (0)
Postoperative	16 (3)	3 (1)
Pre- and postoperative	3 (2)	1 (1)
Preoperative and with pneumonectomy	8 (1)	0
With pneumonectomy and postoperative	1 (0)	0

evacuate the pleural cavity at the time of thoracoplasty. It then became obvious that material in the pleural cavity under thoracoplasty remained a good spawning ground for future infection and various methods were employed to remove it. Subsequently at thoracoplasty the pleura was routinely opened and evacuated. Catheter suction was used until fluid formation decreased to a minimal volume. Whenever thickened pleura was encountered a modified Schede technique according to the method of Grow[6] was used. It is frequently possible to remove relatively short axillary segments of rib when catheter suction is employed postoperatively, as the axillary soft tissues form an effective plomb. By crushing the phrenic nerve near the diaphragm and instituting pneumoperitoneum after pneumonectomy, diaphragmatic elevation is encouraged, thereby further limiting the necessary size of thoracoplasty.

All postpneumonectomy pleural empyemas were treated by thoracoplasty, usually employing the Grow technique. When drugs other than SM, PAS and INH were used it was usually necessary to continue catheter suction for a number of months, until merely a sinus remained and no more viable tubercle bacilli were excreted. The catheter was then gradually withdrawn. The state of healing could be determined radiographically after injecting radiopaque material into the catheter.

Nasal oxygen has been used freely postoperatively especially in the presence of tachycardia or arrhythmia, as there is much evidence that an uneven ventilation-perfusion relationship frequently exists and may lead to hemoglobin oxygen desaturation.[7] Since hypoxia and other stresses during this period may cause even a relatively normal heart to become decompensated, digitalis occasionally has been employed prophylactically.

RESULTS

Complications are listed in Table 1. Serious bleeding occurred on three occasions during surgery. In two instances, it necessitated the performance of pneumonectomy instead of a planned lesser procedure. Two of the three patients died in the early postoperative period. All of these complications occurred prior to 1954. Since that time no serious difficulty has been encountered because of vascular accidents; nor has it become necessary to extend the size of resection for this reason, presumably because of the adoption of precautions previously reported.[8]

There were two bronchopleural fistulas uncomplicated by pleural infection. One patient remained asymptomatic untreated; the other later developed a pyogenic pleural infection which was successfully treated with antibiotics. To prevent further infection, a space-filling thoracoplasty was per-

TABLE 4—RESULTS BY LENGTH OF FOLLOW-UP

	Months										
	0-12	13-24	25-36	37-48	49-60	61-72	73-84	85-96	97-108	109-120	>120
Living non-infectious	6	9	5	4	4	4	5	3	4	2	3
Living infectious	0	0	0	0	0	0	0	0	0	0	0
Dead	7	1	2	0	0	0	1	0	1	0	2

TABLE 5—MORTALITY

Cause	Time Postoperative	Age at Death	Bacteriologic Status
Cardiac arrest	During pneumonectomy	14	Noninfectious
Vascular accident and blood loss	Operative day	42	Infectious
Pulmonary edema	5th day	21	"
Cardiorespiratory insufficiency	24th day	43	"
" "	3 months	40	"
" "	5 "	36	"
Unknown	8 "	31	Noninfectious
Cardiorespiratory insufficiency	17 "	35	Infectious
Amyloidosis and chronic glomerulonephritis	31 "	43	"
Cardiopulmonary insufficiency	54 "	63	Noninfectious
" "	83 "	64	"
" "	98 "	36	"
" "	126 "	43	"
" "	134 "	52	"

formed. Minor air leakage from the bronchus was easily treated by use of balanced drainage.

There were five pyogenic infections of the pleura. Two of these also contained tubercle bacilli. Both patients with mixed infections were treated by modified Schede thoracoplasty with one recovery and one death. The remaining three recovered with drainage alone.

There were eight pure tuberculous complications consisting of four pleural empyemas, one postoperative spread of disease, two bacterial relapses and one stump abscess. One patient developed empyema after leaving the hospital against advice ap-

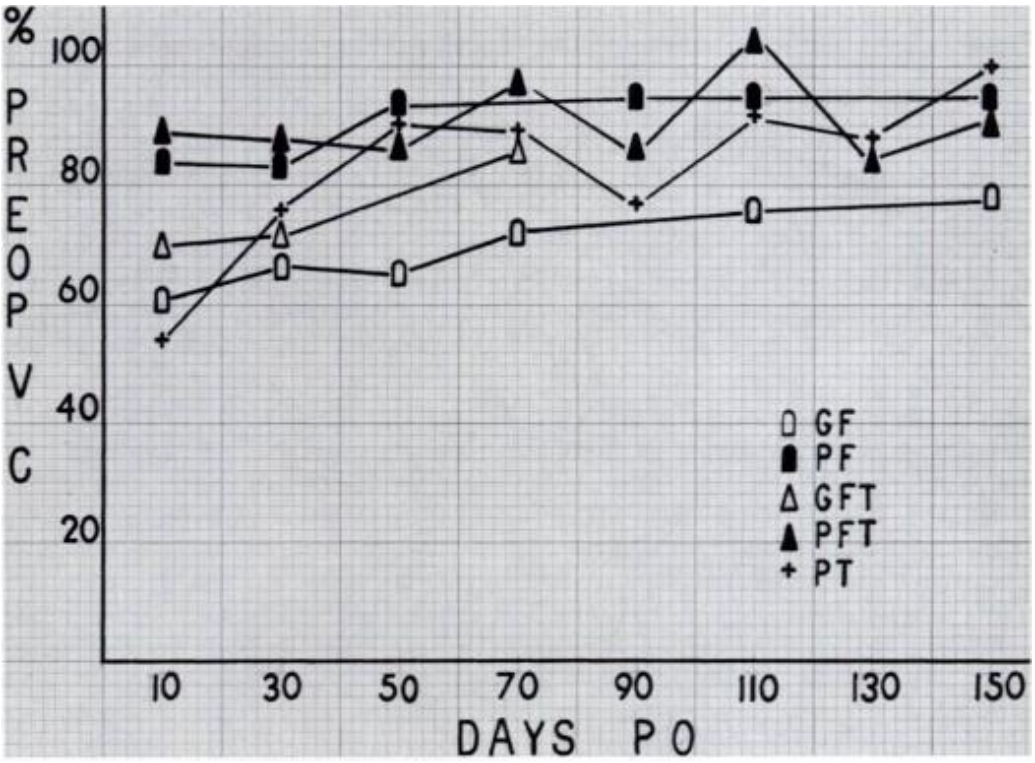

FIGURE 1: Means of 116 observations upon 43 patients who had pneumonectomy. GF=good to moderate ventilatory function in the excised lung; PF=poor to no function in the excised lung; GFT=previous thoracoplasty, good to moderate function in the excised lung; PFT=previous thoracoplasty, poor to no ventilatory function in the excised lung; PT=pneumonectomy and concomitant thoracoplasty. Six of seven patients in the latter category had previous thoracoplasty.

proximately two weeks after pneumonectomy. He received no further effective drug therapy until his death five months postoperatively. The three others with empyema were treated by modified Schede thoracoplasty and drugs other than SM, PAS and INH. Two died and one recovered. All other tuberculous complications were successfully treated with antituberculosis drugs, two receiving combinations of drugs other than SM, PAS and INH and two receiving INH as the only effective drug.

It is not surprising that all complications except one (technical difficulties necessitating pneumonectomy in a planned lobectomy) occurred in patients who had far-advanced disease. It is interesting that eight of the 13 who had infections were operated upon prior to 1955.

Forty-one patients harbored culturable tubercle bacilli at the time of pneumonectomy. All tuberculous complications occurred in this group. These results are in agreement with our experience with all types of pulmonary resection. The relationship of drug therapy to tuberculous complications in patients harboring culturable tubercle bacilli (excluding two who died in the first postoperative week) is summarized in Table 2. Although this series is too small to be of statistical significance, these data confirm what has been common experience, that extensive pulmonary resection must be performed under the protection of antituberculosis drug therapy and that combinations of SM, PAS and/or INH are the most effective.

The relationship of thoracoplasty to pleural complications is summarized in Table 3. Patients who died within the first postoperative week are excluded. Infectious (tuberculous and non-tuberculous) and noninfectious types are included. The number of complications is listed in parenthesis. Empyema did not occur in any case in which the pleura was completely obliterated at the time of pneumonectomy. Creation of an empty pleural space could be avoided by performing an apicolysis and upper stage thoracoplasty preliminary to pneumonectomy when a small number of additional ribs could be removed.

The bronchial stump was covered with tissue in 29 instances. Four of the nine infectious pleural complications and the tuberculous stump abscess occurred in this group. Accordingly, there does not appear to be overwhelming evidence in this group or in our total experience that this maneuver is of critical importance. It appears more likely that infection plays a dominant role.

Although a thorough effort was made to obtain follow-up information on all patients, 22 could not be located. This reflects the large indigent composition of this group. Final results are therefore tabulated according to the time when the patient was last seen (Table 4). At present all living patients are noninfectious. Forty-nine (78 per cent) are living and well and 14 (22 per cent) are dead. The deaths are listed in Table 5. The cardiac arrest and vascular accidents occurred early in this series, and with modern techniques are avoidable. The great majority of these patients died of cardiorespiratory failure which not only reflects the extent of resection, but also the extensive disease.

Physiologic Changes

Figure 1 summarizes the postoperative changes in vital capacity. These mean values are based on 116 observations upon 43 patients. There was some scattering and overlapping of individual values in the various categories, but only ten observations varied by more than ±12 per cent from the mean. The number of ribs removed at prepneumonectomy thoracoplasty generally varied between five and ten. When thoracoplasty was combined with pneumonectomy, rarely more than four ribs were removed. The extent of thoracoplasty in the three categories represented in Fig. 1 was comparable.

The trend of functional changes is obvious. Removal of a lung with relatively good ventilatory function has a greater deleterious effect than removal of one with

poor function. Performance of thoracoplasty at the time of pneumonectomy depresses ventilation by an additional amount for approximately six weeks, after which vital capacity becomes stabilized. This is undoubtedly the length of time it requires for a chest wall to lose its flaccidity. Generally, the curve of the postoperative changes in vital capacity following pneumonectomy (with the exception of pneumonectomy and thoracoplasty) is flatter in the early postoperative period than the curve which has been recorded following subtotal.[8] This may be due to the fact that pleuritic changes affect respirations to a lesser degree when the lung is not present in the hemithorax.

Gaensler and Strieder[9] showed that thoracoplasty over a poorly functioning lung or postpneumonectomy space tends to decrease function further by interfering with chest wall motion. Since there is much evidence in this series that the loss of function is proportional to the extent of thoracoplasty, the operation is now avoided in patients who do not harbor viable tubercle bacilli. When thoracoplasty is indicated, the extent of rib resection is limited as much as possible.

Crushing the phrenic nerve, pneumoperitoneum and intrapleural catheter suction have not appeared to affect ventilatory function adversely, and may spare function by decreasing the size of thoracoplasty. Mediastinal shift to the side operated upon of the degree which is encountered has no effect upon blood pressure or pulse rate. Ventilatory studies before and after removal of several hundred ml. of air and fluid from the postpneumonectomy pleural space on several occasions have consistently indicated that vital capacity can be increased by as much as 100 ml. Furthermore, there is much evidence that distension of the contralateral lung may benefit obstructive disease by dilating the bronchi.[10] Since this could not be verified in this series by comparing pre- and postoperative one, two and three second forced expiratory volumes, it is believed that the changes are probably too subtle to measure by this method. There is no evidence that hyperinflation of the contralateral lung alters arterial blood gas values,[11] increases respiratory dead space or predisposes to emphysema.[12]

Pulmonary artery pressures were determined immediately following pneumonectomy upon 22 patients. Of these, 14 were in excess of 35 cm. of water, which in our experience appears to represent the upper limit of normal. Four of these patients with pulmonary hypertension died of cardiopulmonary failure, two within four months postoperatively. Although mortality in the hypertensives is high, patients may not succumb for a considerable period of time after pneumonectomy (one having survived for seven years).

In nine patients, pre- and postpneumonectomy pulmonary artery pressures were determined. Of six patients who had normal preoperative pressures, two developed elevations following pneumonectomy. It would thus seem advisable to determine pressures before and after occlusion of the pulmonary artery routinely in all candidates for pneumonectomy.

Discussion

Although pneumonectomy may at times be technically the simplest procedure to perform, the high morbidity and mortality which follows the procedure dictates that it be employed only when a more conservative approach is impossible. Every effort should be made to conserve functioning tissue. Indeed, a lung which does not ventilate well may be perfused; and in borderline cases removal of even a small part of the lesser circulation may precipitate pulmonary hypertension.

Pneumonectomy is rarely indicated when viable tubercle bacilli cannot be recovered from the expectorations. Functionless lungs, even when bronchiectatic, are usually well tolerated. Superimposed pyogenic infection usually responds to antibiotic treatment. Rarely, repeated sepsis, localized aspergillosis or severe bleeding may require local excision of cavitary disease.[13] Pneumonec-

tomy may be required for extensive invasive aspergillosis or destroyed lung accompanied by bronchostenosis.

Currently, the most frequent indication for pneumonectomy is treatment of the destroyed lung which harbors viable organisms resistant to SM, PAS and INH. If some of the lung is functioning, pneumonolysis and tube cavernostomy may be substituted. The latter technique has been previously described.[14]

Thoracoplasty is necessary only when viable organisms resistant to SM, PAS and INH are present at the time of pneumonectomy, since the risk of tuberculous empyema is almost nonexistent under other circumstances.

Whenever possible, combinations of SM, PAS and/or INH should be administered. When organisms are resistant to these, a combination of at least two of the more recently introduced antituberculosis drugs should be used. When pneumonectomy is necessary in the presence of active tuberculosis, antituberculosis therapy should be continued for at least a year postoperatively.

Summary

Fourteen years' experience with pneumonectomy in the treatment of pulmonary tuberculosis is reviewed. Sixty-three operations, constituting approximately 0.5 per cent of all resections for tuberculosis, are reviewed. Forty-nine (78 per cent) of the patients are living and well, and 14 (22 per cent) are dead. The most common cause of mortality was cardiorespiratory failure which is believed to reflect not only the amount of tissue removed, but also the extent of the original disease. Bacteriologic, physiologic and clinical data suggest that pneumonectomy, with rare exceptions, should be reserved for the patient with destroyed lung who harbors organisms resistant to SM, PAS and INH.

Zusammenfassung

Es wird eine 14-jährige Erfahrung mit der Pneumonektomie in der Behandlung der Lungentuberkulose besprochen. 63 Operationen, d.s. annähern 0,5% aller wegen Tuberkulose durchgeführten Resektionen werden überblickt. 49 Patienten (78%) der Patienten leben und fühlen sich wohl, 14 (22%) sind gestorben. Die häufigste Todesursache war eine cardio-respiratorische Insuffizienz; man nimmt an, daß diese nicht nur das Ausmaß des entfernten Gewebes, sondern auch die Schwere der ursprünglichen Erkrankung widerspiegelt. Bakteriologische, physiologische und klinische Daten legen nahe, daß die Pneumonektomie, von seltenen Ausnahmen abgesehen, den Patienten mit einer zerstörten Lunge, die gegen Streptomycin, PAS und INH resistente Keime beherbergen, vorbehalten bleiben muß.

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