500 cc.) is still the most effective therapeutic agent in combating the disease.

4. Prompt isolation of infected patients, preferably in a contagious division or a contagious hospital as soon as the epidemic is recognized, offers the best hope of limiting its spread.

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POSTOPERATIVE PULMONARY COMPLICATIONS

II. CARBON DIOXIDE AS A PREVENTIVE IN A CONTROLLED SERIES

DONALD S. KING, M.D.
BOSTON

The surgical service of any large general hospital is still faced with the problem of prevention of postoperative pulmonary complications. The numerous studies made during the past fifteen years have consistently shown the frequency of these complications. Many theories have been proposed regarding the etiology and treatment of them, but none have been accepted as entirely satisfactory. Certain facts, however, are becoming definitely established and an intensive study, made at the Massachusetts General Hospital during the past two years, has given new emphasis to some of these points. Statistical observations are published in another article,[1] but in the main they have shown that: an overwhelming majority of postoperative pulmonary complications occurs after laparotomy and herniorrhaphy (14.0 per cent); they are especially frequent after operations on the stomach, gallbladder and intestines (40.2, 18.8 and 20.8 per cent, respectively); they occur at least twice as frequently in men as in women, and, further, the patient's general condition and sepsis or perforation play a definite part. Statistically, the type of anesthesia bears no relation to the development of complications.

It is true that, although sex, general condition and sepsis are important, the abdominal operation itself is the one practically constant factor in the development of pulmonary complications. Consequently, studies have been made to determine to what extent interference with respiration, following abdominal operations, leads to pulmonary pathologic changes. It has been shown that these operations produce marked reduction in vital capacity[2] and that respiration becomes more rapid and shallow and that total lung volume is decreased. A recent study made in this hospital by Beecher gives new information on these points. In short, after abdominal operation, the lung assumes the position of normal expiration, or what Henderson[3] calls the "acapnial" position. This condition of "hypoventilation"[4] apparently allows the collection of secretion in the bronchi and atelectasis or pneumonia may result.[5]

The type of complication that follows such interference with the respiration develops almost invariably in the first three postoperative days and is usually accompanied by fever, leukocytosis, cough and purulent sputum. It has been variously diagnosed as bronchopneumonia, "pneumonitis"[6] and collapse (or atelectasis). The percentage of cases that can be diagnosed as true bronchopneumonia is very small, as is also the percentage of cases that can be diagnosed as typical massive collapse with involvement of the greater part of one lung. Between these two apparently definite entities lies a great majority of cases which are either pneumonia, pneumonitis or partial collapse and which cannot yet be satisfactorily classified. It has not seemed wise, therefore, in this study to separate pneumonia from collapse. Furthermore, cases of definite pulmonary embolus, exacerbation of pulmonary tuberculosis, empyema and the like have been excluded because they do not belong to the group of complications that occur soon after operation and seem to be associated with interference with respiration. In the pneumonia and collapse group, however, interference with respiration is at least partly responsible for the complication, and restoration of normal respiration had seemed to offer a reasonable hope for its prevention or cure. Of the various methods available, Henderson's[7] recommendation of hyperventilation by the inhalation of carbon dioxide has received most attention and has been employed to a greater or less extent by many investigators.

Scott and Cutler[8] compared a series of 1,000 patients at the Strong Memorial Hospital, who had had carbon dioxide inhalations during or after operation and in only 0.2 per cent of whom postoperative massive collapse developed, with another series of 2,000 patients at the Lakeside Hospital, in whom hyperventilation was not employed (and who were consequently used as a control series) and in 0.6 per cent of whom massive collapse developed. Conclusions cannot be drawn from such a study, since the control group is in a different hospital, in a different year and the complications include definite massive collapse only and not "pneumonia." Scott[9] later reported on 2,850 patients, in 85 per cent of whom hyperventilation was employed with only 3 cases of massive collapse, while in 15 per cent hyperventilation was not employed, with 4 cases of collapse. Shatzky[10] reported 38.5 per cent pulmonary complications in a series of 320 untreated patients in 1926-1927, as compared with 22 per cent complications in 264 patients who had hyperventilation induced by carbon dioxide postoperatively in 1927-1928. Sise, Mason and Bogan[11] cite a much smaller series of cases in which 4.2 per cent of 48 patients, treated with carbon dioxide inhalations, developed postoperative pneumonia and 2 per cent of 49 patients, not treated,

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Study made in the Surgical Services of the Massachusetts General Hospital by the author, a member of the medical service, aided in part by the Delamar Mobile Research Fund of Harvard University Medical School.

1. King, D. S.: Postoperative Pulmonary Complications: I. A Statistical Study Based on Two Years' Personal Observation, Surg., Gynec. & Obst., to be published.

2. Churchill, E. D., and McNeil, Donald: The Reduction in Vital Capacity Following Operation, Surg., Gynec. & Obst. **44**: 483-489 (April) 1927. Head, J. R.: The Effect of Operation on the Vital Capacity, Boston M. & S. J. **197**: 83-87 (July 21) 1927. Powers, J. H.: Vital Capacity, Its Significance in Relation to Postoperative Pulmonary Complications, Arch. Surg. **17**: 304-323 (Aug.) 1928.

3. Henderson, Yandell: Acapnia as a Factor in Postoperative Shock, Atelectasis and Pneumonia, J. A. M. A. **95**: 572-575 (Aug. 23) 1930.

4. Muller, G. P.; Overholt, R. H., and Pendergrass, E. P.: Postoperative Pulmonary Hypoventilation, Arch. Surg. **18**: 1322-1345 (Dec.) 1929.

5. Coryllos, P. N.: Postoperative Apneumatosis (Atelectasis) and Postoperative Pneumonia, J. A. M. A. **93**: 98-99 (July 13) 1929.

6. Whipple, A. O.: A Study of Postoperative Pneumonitis, Surg., Gynec. & Obst. **26**: 29-47 (Jan.) 1918.

7. Henderson, Yandell; Haggard, H. W., and Coburn, R. C.: The Therapeutic Use of Carbon Dioxide After Anesthesia and Operation, J. A. M. A. **74**: 783-786 (March 20) 1920.

8. Scott, W. J. M., and Cutler, E. C.: Postoperative Massive Atelectasis: II. The Effect of Hyperventilation with Carbon Dioxide, J. A. M. A. **90**: 1759-1763 (June 2) 1928.

9. Scott, W. J. M.: Massive Atelectasis and Postoperative Pneumonia, J. A. M. A. **93**: 101-103 (July 13) 1929.

10. Shatzky, A. V.: The Use of Carbon Dioxide with Some Anesthetics and in Postoperative Complications, Vestnik Khir. **14**: 219-224, 1928.

11. Sise, L. F.; Mason, R. L., and Bogan, I. K.: Prophylaxis of Postoperative Pneumonia: Preliminary Report of Some Experiments After Upper Abdominal Operations, Anesth. & Analg. **7**: 187-190 (May-June) 1928.

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developed complications. This group, although well controlled, is small but is an argument against rather than for the use of carbon dioxide. Fischer [12] observed only 7 cases of bronchitis and 1 of pneumonia following 300 gynecologic operations, in patients who had been given carbon dioxide inhalations. He, however, had no control series. Aza [13] reported a series of 48 patients having abdominal operations, followed by routine carbon dioxide inhalations, none of whom developed pulmonary complications.

Other authors [14] report good results from the use of carbon dioxide inhalations as a preventive measure for postoperative pulmonary complications, stating with apparent conviction that its use has materially reduced the incidence of complications among their patients who were operated on. They, however, cite no definite series of cases. Still others [15] make only casual mention of the prevention of postoperative pulmonary complications among the many uses of carbon dioxide inhalations. Brunn and Brill [16] make a general statement in regard to the benefit of the method, observing that their records showed an increase in pulmonary complications during the use of carbon dioxide inhalations, but they also state that this apparent increase was due to more careful studying and recording of complications. They do not have a control group and so have not reported figures. Briscoe [17] decries hyperventilation with carbon dioxide as drawing secretion deeper into the lungs and as being unpleasant to the patient.

In addition to the unsatisfactory evidence presented in these articles, three partially controlled series, observed at the Massachusetts General Hospital, had given the impression that carbon dioxide did not reduce the percentage of pulmonary complications. In one of these series, carbon dioxide was given to all patients before they left the operating room, and in the other two groups hyperventilation was induced several times a day for the first three postoperative days. This early experience was therefore disappointing, but the method still seemed the most reasonable one at our disposal, and we determined to study an absolutely controlled and very carefully followed series in order that definite conclusions might be drawn.

12. Fischer, Erich: Die intraoperative und postoperative Kohlensäureinhalation, eine wertvolle Unterstützung der Inhalationsnarkose, Zentralbl. f. Gynäk. **52:** 2010-2013 (Aug. 11) 1928.

13. Aza, Vital: Hiperventilacón pulmonar postoperatoria, Med. ibera **2:** 149-151 (Aug. 9) 1930.

14. Graham, E. A., in discussion on Muller, Overholt and Pendergrass (footnote 4, p. 1342). Doppler, Karl: Die Anwendung der Kohlensäureinhalation im chirurgischen Betrieb, speziell bei Schädigungen der Atemzentrums und beim operativen Shock, Deutsche Ztschr. f. Chir. **219:** 308-317, 1929. Henderson, Yandell, and Haggard, H. W.: Hyperventilation of the Lungs as a Prophylactic Measure for Pneumonia, J. A. M. A. **92:** 434-436 (Feb. 9) 1929. Henderson, Yandell: The Physiology of Atelectasis, ibid. **93:** 96-98 (July 13) 1929. Lidzki, A.: O wdychiwaniu CO_2 jako środku leczniczym i zapobiegawczym, Polska gaz. lek. **8:** 496-497 (June 30) 1929. Mouzon, J.: L'inhalation de gaz carbonique: stimulant et régulateur de la fonction respiratoire, Presse méd. **37:** 68-71 (Jan. 16) 1929. Fuller, C. J.: Analysis of Postoperative Pulmonary Complications, Based on Cases at University College Hospital, London, in One Year, Lancet **1:** 115-121 (Jan. 18) 1930. Moore, J. A.: Postoperative Pulmonary Atelectasis, J. Michigan M. Soc. **29:** 182-190 (March) 1930. Coryllos, P. N.: Postoperative Pulmonary Complications and Bronchial Obstruction: Postoperative Bronchitis, Atelectasis (Apneumatosis) and Pneumonitis, Considered as Phases of the Same Syndrome, Surg., Gynec. & Obst. **50:** 795-827 (May) 1930. Overholt, R. H.: Postoperative Pulmonary Hypoventilation, J. A. M. A. **95:** 1484-1489 (Nov. 15) 1930. Mogilew, M.: Bedeutung der Kohlensäure in der Prophylaxe der postoperativen Komplikationen, Zentralbl. f. Gynäk. **54:** 2015-2019 (Aug. 9) 1930.

15. Lundy, J. S.: Carbon Dioxide as an Aid in General Anesthesia, J. A. M. A. **85:** 1953-1955 (Dec. 19) 1925. Dzialoszynski, A.: Apparatus zur Kohlensäureinhalation und bildliche Darstellung der Kohlensäureanwendung am Kranken, Deutsche Ztschr. f. Chir. **205:** 22-27, 1927. Hewer, C. L.: The Therapeutic Value of Carbon Dioxide, China M. J. **41:** 852-858 (Oct.) 1927. Van Allen, C. M., and Lindskog, G. E.: Obstructive Pulmonary Atelectasis, Arch. Surg. **21:** 1195-1213 (Dec.) 1930.

16. Brunn, Harold, and Brill, Selling: Observations on Postoperative Pulmonary Atelectasis, Ann. Surg. **92:** 801-837 (Nov.) 1930.

17. Briscoe, Charlton: The Mechanism of Inflation of the Lungs and the Influence of Deflation on Postoperation Complications, Lancet **2:** 513-520 (Sept. 5) 1931.

SELECTION OF CASES

Previous studies had made so clear the high incidence of pulmonary complications following abdominal operation and hernia repair that in selecting cases for treatment the present study was confined to this group. Further, since the sex of the patient and the type of abdominal operation play so important a part, the patients were divided according to sex and then grouped according to the type of abdominal operation. Every other patient, in the subgroups of each sex, was treated. This alternation gave, for instance, a group of men who had had operations on the stomach and who had had hyperventilation induced, to compare with an equal number of men who had had operations on the stomach but who had not had hyperventilation induced. These groups could in turn be compared with female patients, treated and untreated, who had had operations on the stomach. Thus, statistics were available for male and female cases, treated and untreated, in the different groups of abdominal operations and hernia repair.

At the Massachusetts General Hospital the general surgical services perform between 90 and 120 operations for abdominal conditions and hernias each month. During our period of study, which ran from Dec. 1, 1930, to Dec. 15, 1931, 648 treated cases were available to compare with 667 controls. From August 1 to 15, no treatments were given. From August 15 to September 8, special intensive treatment was given in a particular group of cases to ascertain whether frequent and prolonged hyperventilation would make a difference in the percentage of complications in the so-called bad risk group; namely, male patients who had had operations on the stomach, gallbladder and intestine.

TREATMENT SCHEDULE AND PERSONNEL

The carbon dioxide inhalations in our series were given as a postoperative routine for three days, beginning after the patient had returned to the ward. Previous to this controlled series, carbon dioxide inhalations had been given for seven months in the operating room after every laparotomy and operation for hernia. During this period the pulmonary complications in this group reached 13.1 per cent. This was a higher percentage than had ever been noted before, but more careful observation and recording were probably responsible for the apparent great increase. However, it was evident that the "de-etherization" in the operating room was not materially reducing the percentage of pulmonary complications, and the possibility existed that carbon dioxide inhalations, given while the patient's cough reflexes were still abolished by the anesthetic, might cause a deeper inhalation of bronchial secretion and so perhaps do harm. In this study, therefore, it seemed best not to give the inhalations until the patient was back in the ward and at least partially recovered from the anesthesia.

A full time graduate nurse administered the carbon dioxide. The same nurse was employed, during the day, throughout the entire period of the study, insuring uniformity of treatment and the same careful observation and reporting of pulmonary symptoms, in both the treated and the untreated groups. During seven of the twelve months, a second full time graduate nurse worked at night.

APPARATUS AND DOSAGE

Four different methods of giving carbon dioxide were employed. The first was the use of a rebreathing tube with a mouthpiece and nose clip, by means of which the patient rebreathed his own carbon dioxide

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and thus saved the expense and trouble of using tanks of either carbon dioxide or carbon dioxide and oxygen mixture.[11] This method was the suggestion of Dr. J. H. Means.[11] The tubes used were of the size and texture of those used with the ordinary spirometer. Their diameter was 1¼ inches, their length was from 8½ to 9 feet, and their capacity was approximately 1,500 cc. Of course, the use of such a tube lowers the amount of oxygen in the inspired air, and there is danger of partial anoxemia. Rebreathing was stopped, however, at the first indication of cyanosis. A short insert of metal tubing allowed the removal of the first 2 feet of the rubber tubing so that it could be boiled with the mouthpiece after each treatment. The remainder of the tube was kept by the bedside of the patient during the three days of the treatment and was not used for any other patient during that time. In some cases an ordinary anesthesia mask was attached to the rubber tube instead of the mouthpiece. The apparatus could then be used for a patient who could not, or would not, keep his lips tightly closed over the rubber mouthpiece.

With the length of rebreathing tube used, most patients could not keep up the hyperventilation comfortably for more than three minutes, and practically all patients would breathe with increasing depth for the first half minute and then maintain a maximum level for about two minutes. During the first four months, treatment was given in this way three times a day for the first three postoperative days and only during the daytime. During the next three months similar treatment was given every four hours, day and night. During the following month, the night nurse was omitted and the number of treatments was again dropped to three, during the day only.

The second method was the use of small tanks of either pure carbon dioxide or carbon dioxide and oxygen mixture of from 5 to 25 per cent carbon dioxide. This gas was given by means of a funnel held at varying distances from the patient's nose. This method of hyperventilation was employed with a few patients who objected to the mouthpiece and nose clip and others who could not hold the mouthpiece. With this method, hyperventilation could be induced from five to ten minutes either three or six times a day. These small tanks were also used on certain patients during the last three months of study because the large tank could not be conveniently transported to a distant ward. The total number of cases, however, was small, only thirty-nine patients having been treated in this way.

The third apparatus used was the original Henderson inhalator,[7] in which carbon dioxide is mixed with room air rather than with pure oxygen. This apparatus, used in the Massachusetts General Hospital previously by White,[18] was employed during the last three and a half months of the study. The treatment was given at least six times a day and, in most instances, eight or ten times. Some patients could take the inhalations for only five minutes at a time, but most could tolerate them for ten minutes. The amount of carbon dioxide used with this inhalator was left to the discretion of the nurse who was giving the treatments because, as noted by other observers, different patients demonstrate varying responses to a given percentage of carbon dioxide. Our studies with the next type of apparatus to be described, however, showed that these patients were receiving, for the most part, a mixture containing about 8 per cent carbon dioxide.

18. White, J. C.: Deetherization by Means of Carbon Dioxide Inhalations, Arch. Surg. 7: 347-370 (Sept.) 1923.

The fourth method employed was the use of separate tanks of oxygen and carbon dioxide with a Foregger flow-meter[19] on each tank, so that the mixture of oxygen and carbon dioxide could be regulated to meet individual requirements. This apparatus was cumbersome and the expense of oxygen and carbon dioxide tanks high; consequently, this method was used only long enough to determine the approximate percentage of carbon dioxide being given with the original Henderson inhalator. It was found that in most cases the best hyperventilation for a ten minute period was given by a mixture of 8 per cent carbon dioxide and 92 per cent oxygen. The amount of hyperventilation induced by this mixture was apparently the same as that induced by the Henderson apparatus as previously described. (Gas analysis determined that, when the flow-meters were set to give a 10 per cent mixture of carbon dioxide, the actual amount delivered to the masks was 8 per cent. Similarly, when the flow-meters were set for a 5 per cent mixture, the patient was actually getting 4 per cent.) It should be noted that in many postoperative cases cough and expectoration required the removal of the mask at intervals, so that it would be an error to assume that all the patients were constantly inhaling an 8 per cent carbon dioxide mixture. Of the eight cases treated with this apparatus, a complication developed in one case, giving the usual 12.5 per cent of pulmonary complications.

TABLE 1.—*Methods of Carbon Dioxide Administration*

Period of Time and Method Used	Treated: Number of Operations	Treated: Postoperative Pulmonary Complications: Number	Treated: Postoperative Pulmonary Complications: Per Cent	Untreated: Number of Operations	Untreated: Postoperative Pulmonary Complications: Number	Untreated: Postoperative Pulmonary Complications: Per Cent
December, 1930, through March, 1931 Rebreathing tubes used for an average of two minutes, three times a day	206	25	12.1	211	45	21.3
April through June, 1931 Rebreathing tubes used for an average of two minutes, six times a day	177	24	13.6	185	13	7.0
July, 1931 Rebreathing tubes used for an average of two minutes, three times a day	56	6	10.7	65	6	9.2
Sept. to Dec. 15, 1931 Henderson carbon dioxide inhalator used for an average of five to ten minutes, six to ten times a day	209	25	12.0	206	23	11.2
Totals						
Rebreathing tubes	439	55	12.5	461	64	13.9
Carbon dioxide inhalator	209	25	12.0	206	23	11.2

RESULTS

For the purposes of this report, all cases demonstrating definite parenchymal involvement have been recorded as pulmonary complications. With few exceptions, clinical signs have been checked by x-rays and only cases showing definite roentgen evidence have been included. Cases were omitted if the roentgen evidence was doubtful or could be explained by the taking of the film while the lungs were in the position of expiration.[4] ("Bronchitis" is not reported in this study as a complication except in the one table in which it is recorded separately.)

Table 1 shows the number of cases treated by each of the different methods and the percentage of pulmonary complications that have occurred in each of these

19. This apparatus was kindly lent to us by Dr. C. C. Lund.

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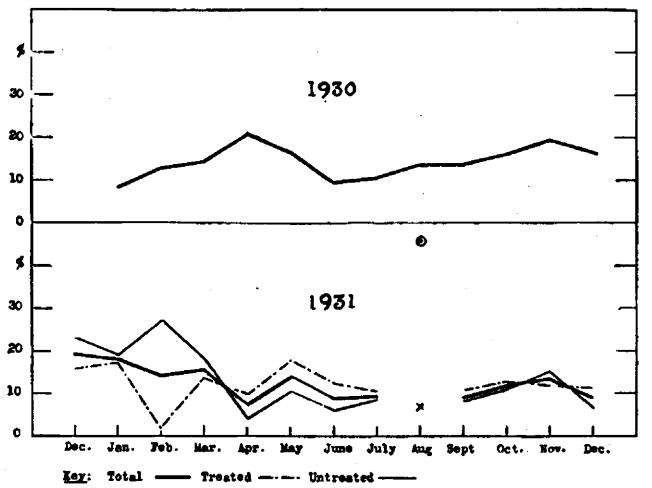
groups. These percentages are, in turn, compared with the untreated cases for the same period.

The accompanying chart represents graphically the monthly percentage of pulmonary complications occurring in the treated and untreated groups, and, as a mean between them, the monthly percentage of the series as a whole.

A study of this table and chart brings out the following points:

1. During the first four months, when two-minute hyperventilation was being induced three times in twenty-four hours, there was a definitely smaller percentage of complications in the treated group. This was particularly noticeable in February, when the incidence in the treated group was 2 per cent as opposed to 27 per cent in the untreated group. No amount of study has been able to explain this unusual month. It is still true, however, that in each of the first four months there was a lower percentage of complications in the treated group.

2. During six of the seven months of the experiment, when the patients were getting six short treatments by the rebreathing tubes, or eight or ten longer



Monthly percentage of pulmonary complications following all laparotomies and hernia operations in 1930, and following the same type of operation included in the carbon dioxide study in 1931.

treatments with the Henderson inhalator, the percentage of complications in the untreated cases was less than in the treated group. (As will be noted from the table, during the month of July the number of treatments was again reduced to three, but without a return of more favorable results in the treated cases.) This unexpected reversal was due, not to an appreciable increase in the percentage of complications in the treated group, but to an extraordinary drop in the percentage of complications in the untreated group.

3. An entirely satisfactory explanation of this drop cannot be given. We have studied the problem from all angles and believe that the only change in the care of the patients of this untreated group lies in the fact that after the first few months of our special study of pulmonary complications attention was being focused on the need of adequate bronchial drainage. Because of this, patients were having postural change (a method which has been advocated by other authors [20]) every one or two hours.

20. Hurxthal, L. M.: The Use of Postural Drainage in Postoperative Pulmonary Complications, S. Clin. North America **8**: 115-117 (Feb.) 1928. Rouillard, J.: Le collapsus aigu du poumon; complication postopératoire, Presse méd. **37**: 36-38 (Jan. 9) 1929. Overholt (footnote 14); Brunn and Brill (footnote 16).

4. As already noted, the definite alternation of treatment was not carried out in August and early September, and the curve in the chart is broken at this point. The dot, however, denotes that the percentage of complications in the group treated was very much higher than in any other month. This is explained by the fact that during this period fifteen cases of the group that our past experience had shown to be very bad risks—the male patients who had had operations on the

Table 2.—*Abdominal and Hernia Operations: Treated Series*

Type of Operation	Total: Total Operations	Total: Postoperative Pulmonary Complications: Number	Total: Postoperative Pulmonary Complications: Per Cent	Male: Total Operations	Male: Postoperative Pulmonary Complications: Number	Male: Postoperative Pulmonary Complications: Per Cent	Female: Total Operations	Female: Postoperative Pulmonary Complications: Number	Female: Postoperative Pulmonary Complications: Per Cent
Stomach and duodenum	47	21	44.7	34	18	52.9	13	3	23.1
Gallbladder	76	10	13.2	14	5	35.7	62	5	8.1
Intestine	44	12	27.3	27	11	40.7	17	1	5.9
Appendix	198	19	9.6	99	14	14.1	99	5	5.1
Hernia	94	7	7.4	77	7	9.1	17	..	....
Gynecologic laparotomy	137	8	5.8	..	..	....	137	8	5.8
Miscellaneous laparotomy	52	3	5.8	30	3	10.0	22	..	...
Total	648	80	12.3	281	58	20.6	367	22	6.0

stomach, gallbladder and intestine—were treated with carbon dioxide inhalations for about ten minutes every two hours during the day. In spite of this intensive treatment, however, complications developed in 46.6 per cent of this group just as they had in the past. This observation is important because it shows again that the percentage of complications depends, to a very great extent, on the type of operation and the sex of the patient. In the 168 untreated patients who were operated on during this period only 7.1 per cent developed complications, as indicated by the cross on the chart.

Table 3.—*Abdominal and Hernia Operations: Untreated Series*

Type of Operation	Total: Total Operations	Total: Postoperative Pulmonary Complications: Number	Total: Postoperative Pulmonary Complications: Per Cent	Male: Total Operations	Male: Postoperative Pulmonary Complications: Number	Male: Postoperative Pulmonary Complications: Per Cent	Female: Total Operations	Female: Postoperative Pulmonary Complications: Number	Female: Postoperative Pulmonary Complications: Per Cent
Stomach and duodenum	43	15	34.9	35	14	40.0	8	1	12.5
Gallbladder	75	14	18.7	13	5	38.5	62	9	14.5
Intestine	51	10	19.6	32	5	15.6	19	5	26.3
Appendix	206	22	10.7	105	19	18.1	101	3	3.0
Hernia	95	9	9.5	82	8	9.8	13	1	7.7
Gynecologic laparotomy	146	14	9.6	..	..	...	146	14	9.6
Miscellaneous laparotomy	51	3	5.9	28	2	7.1	23	1	4.3
Total	667	87	13.0	295	53	18.0	372	34	9.1

Tables 2 and 3 give an analysis of the total operations for the period of the study with a percentage of complications for each sex and each type of operation. A study of the tables brings out the following points:

1. Taking the series as a whole, there is a very slight decrease in the percentage of the total number of complications occurring in the treated group.

2. In the so-called bad risk group (men who have had operations on the stomach, gallbladder and intestine) there is a definite increase of complications in the treated group following both gastric and intestinal operations and a very slight decrease following gallbladder

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operations. In each instance, however, the number of cases is small.

3. There is an increase in the percentage of complications in the treated group of women who have had operations on the stomach, but a very marked reduction in the case of women with intestinal operations.

4. Women having had operations on the appendix have shown a very low percentage of complications in both the treated and untreated groups. The figures, however, run slightly higher in the treated group.

5. Following gynecologic operations, the treated group shows a definitely lower percentage of complications.

6. Table 4 gives an analysis of the total complications occurring in the treated and untreated groups from the standpoint of the severity of the complications. It will be noted that if all the complications, including bronchitis, are considered, the percentage of complications in the treated and untreated groups is practically the same. If, however, bronchitis is omitted and only the definite pulmonary complications are considered, there is a slightly smaller percentage in the treated group. If the moderate and severe complications are considered, there is a more marked showing in favor of the treated group. It must be remembered, however, that practically all of this improvement came in two months, namely, December, 1930, and especially February, 1931, and that comparative improvement did not continue when frequent postural change had been instituted in the untreated group.

TABLE 4.—*Postoperative Pulmonary Complications*

		Postoperative Pulmonary Complications					
	Number of Operations	Including Bronchitis		Not Including Bronchitis		Moderate and Severe Only	
		Number	Per Cent	Number	Per Cent	Number	Per Cent
Treated	648	135	20.8	80	12.3	48	7.4
Untreated	667	137	20.5	87	13.0	70	10.5

7. During the period of study, typical massive collapse has not been observed in either the treated or the untreated group, although in both groups, the x-rays have shown many cases of collapse of all or part of one lobe. I believe that the attention given to bronchial drainage is responsible for the prevention of the massive collapse cases, and, on the basis of observations and statistics to date, I consider that carbon dioxide is effective in preventing postoperative pulmonary complications only so far as it encourages coughing and raising secretion. However, frequent change in position is, in my opinion, fully as effective a method of prevention.

8. The study of the chart and the tables which show a constant and rather low percentage of complications in the treated group and a dropping percentage in the untreated group (due, in my opinion, to postural change) would lead one to believe that the percentage of complications in the total series of cases included in this study in 1931 would be below the percentage of complications which were recorded in 1930, in which series carbon dioxide inhalations and postural change were not as carefully given. It is rather disappointing, however, to find that the percentage of complications for the period of the carbon dioxide study in 1931 are only slightly below the complications as reported in our study for 1930. It is true, however, that in 1931 the complications were observed and recorded somewhat more carefully than they had been in 1930, because the special nurse in charge of the carbon dioxide treatment made the daily visit with the surgical staff and reported all cases in which there was even the least suggestion of a pulmonary complication in order that these cases might be roentgenographed and personally studied by me. It is also apparent, from a study of the curve of total complications, that the last six months of 1931 show a distinct improvement over the last six months of 1930; which improvement, in my opinion, can be maintained by frequent postural change without the use of carbon dioxide. In the Massachusetts General Hospital, therefore, the routine use of carbon dioxide as a preventive measure against postoperative pulmonary complications has been discontinued and the search for a more effective method is still being pursued.

SUMMARY

1. A study is outlined in which 648 patients who had had laparotomies or hernia repairs received carbon dioxide inhalations from three to twelve times in each twenty-four hours for the first three postoperative days.

2. The percentage of pulmonary complications of the type including "bronchopneumonia," "pneumonitis" and "collapse" is recorded for the total group, for the two sexes and for the different types of abdominal operations.

3. The results in this treated group are compared with the percentage of complications developing in 667 carefully alternated cases which were used as controls.

CONCLUSIONS

1. During the first four months a comparison of the percentage of complications in the treated and untreated groups seemed to show a marked reduction in favor of the treated group, especially a reduction in the percentage of "moderate and severe" complications as compared to the total group including the "mild" cases.

2. In the last eight months of the study, however, the percentage of complications, while more nearly equal, has been definitely less in the untreated group.

3. The percentage of complications in the treated group has been fairly constant, no matter what the method of administration of the carbon dioxide or its frequency or duration. The amazingly low percentage in February came in the period when the least treatment was being given.

4. A striking observation has been the marked reduction in the complications in the untreated group. The explanation offered for this reduction is a change in the postoperative nursing care, providing frequent change in position, favoring bronchial drainage.

5. It is believed that better bronchial drainage, either by postural change or by carbon dioxide inhalations, has practically eliminated massive collapse.

6. No method of treatment, either postural change or carbon dioxide inhalations, has materially affected the percentage of complications occurring in the so-called bad risk group, composed of males with operations on the stomach, gallbladder and intestine.

7. In 1931, the use of carbon dioxide with one group and postural change with another has resulted in only a slight reduction of the percentage of total pulmonary complications as compared with that of 1930. Were it not for the better observation and recording of complications in 1931, the figures would undoubtedly show a greater reduction.

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8. Given according to the methods described in this article, carbon dioxide inhalations are of no greater value in preventing postoperative pulmonary complications than frequent change in position of the patient.

9. Progress in routine postoperative care has been made, but a real preventive for postoperative pulmonary complications has not been discovered.

205 Beacon Street.

SURGICAL STIMULATION OF BONE GROWTH BY A NEW PROCEDURE

PRELIMINARY REPORT

ALBERT B. FERGUSON, M.D.
Roentgenologist, New York Orthopaedic Dispensary and Hospital
NEW YORK

Many surgeons believe they have observed cases in which a bone has recovered some of its length after a fracture with shortening. This phenomenon does occur and is in accordance with a general principle of bone physiology which has not received the attention it deserves. The principle is that during the period of epiphyseal growth interruption of the medullary blood supply to the metaphysis without interruption of the periosteal blood supply to the end of the shaft produces an increase in the speed of longitudinal growth of the metaphysis affected.

This article presents examples of the operation of this principle and a surgical method of applying the principle to secure stimulation of growth.

THE PRINCIPLE

In a study of the factors influencing bone growth it was observed that after osteotomy of the tibia in children the upper end of the fibula was short relative to the tibia except in rare instances. This suggested that interruption of the medullary blood supply of the tibia had stimulated growth. A review of various cases in which the medullary blood supply of a bone had been interrupted confirmed this opinion. However, comparatively few cases provided sufficient data for thorough study because of various factors, such as both legs being operated on, only one leg being roentgenographed, the full length of the bone not being shown, or examination not being continued after union occurred. When any deductions could be drawn there was constantly the suggestion of an increase of growth rate after interruption of the medullary blood supply in children. Because of the frequent incompleteness of the data the cases are not tabulated, but the following examples are given:

A child had an ununited fracture of the tibia with the whole leg underdeveloped at the age of 5. In the following seven years the two fragments of the tibia grew 6¼ inches, while the fibula grew only 3¾ inches, a gain of more than one-sixth inch per epiphysis annually for the tibial metaphyses whose medullary blood supply was interrupted. At the age of 8 a graft was inserted, more of it being in the upper fragment. Thereafter the upper fragment grew faster than the lower. At the age of 10 a graft was inserted, more of it being in the lower fragment. Thereafter the lower fragment grew faster than the upper.

Most processes that increase the growth rate at the epiphyseal disks result in premature union of the disks, so that the final result may actually be shortening. Hence it is worthy of note that in the case cited, at the age of 12, after seven years of abnormally rapid growth, the epiphyseal lines in the fractured tibia revealed no evidence of a tendency to premature union as compared with other epiphyseal lines in the legs, nor has a tendency to premature union of epiphyseal lines been noted after osteotomies.

Another patient had an amputation through the upper half of the tibia and fibula at the age of 12. In two and one-half years the fibula grew three-fourths inch from the one remaining epiphysis, and the tibia more than three-eighths inch, how much more being undetermined as there was considerable absorption of the end of this bone. The growth of the fibula from its one remaining epiphysis equaled its normal growth at this age from two epiphyses.

A child had an osteotomy of each tibia at the age of 6. In the following twenty-one months each tibia gained three-eighths inch on the fibula, which is 50 per cent more than the normal gain of the tibia on the fibula at this age.

A child had an osteotomy of the tibia in the upper third at the age of 7. In nineteen months the tibia gained one-fourth inch on the fibula (30 per cent more than normal at this age), and examination of transverse lines in the bone showed that the excess growth was all at the upper metaphysis, the one affected by the osteotomy.

Correlation of such examples in cases of fracture, osteotomy, prenatal fracture, bone cyst, abscess and amputation led to the conclusion that interruption of the medullary blood supply to a metaphysis results in about 30 per cent increase of longitudinal growth rate at that metaphysis. During the rapid growth period of adolescence this is the equivalent of about one-eighth inch annually for each epiphysis affected. Such an increased growth rate continues for an indefinite time, probably at least three years, and more rapidly in the first year after operation than subsequently.

THE OPERATION

An obvious suggestion from the phenomenon stated is that growth of tubular bones can be stimulated to gain about one-eighth inch for each epiphysis annually during the growing period by the simple process of drilling into the bone half way from the epiphyseal line or lines to the middle of the bone, inserting a knife or curet and disrupting the continuity of the medullary substance.

Such an operation was done at this hospital in April, 1932, in a case of poliomyelitis with the right leg 1¼ inches short at the age of 10. The medulla was sectioned in the upper and lower third of the right tibia and fibula and in the lower third of the femur.

The operation is done as follows: The bone is approached through a short incision, anteriorly for the tibia, laterally between the muscles for the fibula or femur. The periosteum is divided by a small crucial incision. A hole is made through the cortex with a three-sixteenth inch drill. The medulla is divided transversely by means of a curet. The wound is closed in the ordinary manner.

Such an operation has been done in sixteen cases in which there was a short leg, up to October, 1932. Seven bones operated on in four cases were examined from three to five months after operation. In each bone roentgenograms showed a gain in length of from one-sixteenth to one-eighth inch on the corresponding bone of the opposite leg.

Whenever medullary section is done on the tibia, it is done also on the fibula. The upper end of the femur is not used unless the shortening is great. The order of preference is (1) lower end of femur, (2) upper end of tibia and fibula, (3) lower end of tibia and fibula,

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