Recent Advances in Surgery

CONDUCTED BY ALFRED BLALOCK, M.D.

RIB FRACTURES FROM MUSCULAR EFFORT WITH PARTICULAR REFERENCE TO COUGH

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THE appearance of pleural pain following cough may be the result of fracture of one or more ribs. Although such fractures are not extremely common, they are certainly not rare, and the possibility of their occurence is especially to be considered in the presence of otherwise unexplained pleural pain. Some idea of the incidence of these fractures may be obtained from several investigators. In an interesting study of 500 patients with atypical pneumonia in an Army station hospital made by Harvey[72] in 1942-1943, 19 had recent rib fractures; excluding one with a history of trauma, there remained an incidence of 3.6 per cent. Many of these had been overlooked at the original examination. The serial studies made during the course of the pneumonia would often reveal a callus, and review of the earlier films showed fracture lines at the same site. In several cases reviewed, these fractures were quite apparent, but the attention of the examiner was centered on the more obvious inflammatory process in the lungs. In an analysis[116] of 1,194 incipient cases of tuberculosis, there was one patient with a rib fracture (0.08 per cent); among 601 moderately advanced cases, there were 12 patients with rib fractures (2 per cent); and among 108 far-advanced cases, there were 7 with rib fractures (6.5 per cent). Oechsli,[105] who routinely examined patients for rib fractures, found 22 (0.7 per cent) with such fractures in 3,000 admissions to Olive View Sanatorium. A careful search for fractures of the rib following cough among 64 patients with pleural pain in whom no other cause was apparent was made by Mitchell; of these, 14 (21.9 per cent) had fractured ribs.

HISTORY

The first instance of rib fracture produced by coughing that could be found in the literature is the one reported by Gooch[61] in 1773. His patient suffered from necrosis of a rib caused by a kick. When nearly recovered, he fractured a rib on the opposite side during a paroxysm of coughing. Monteggia[100] in 1802 reported seing a man of about 50 years of age who had fractured a rib while coughing. The sound produced at the moment of fracture was heard by all in the room.

Received for publication, June 30, 1953.

In 1834, R. J. Graves[63] of Dublin reported in excellent detail what he considered to be the first case of this nature.

> A 47 year old woman, tall and unusually strong and muscular for a female, had a violent fit of coughing 5 days previous during which she suddenly felt a stitch in the left side, with a sensation of something snapped or given way. The pain was so severe and so affected her breath she sought professional advice when some leeches and afterwards a blister were applied without relief. Inspiration was painful and pain radiated down to the left kidney and up to the right shoulder. The central point of tenderness was at the midpoint of the 9th or 10th rib and that from which the pain radiated was situated not between the ribs but on one of them. Pressure made at exactly this spot could scarcely be tolerated. She had observed that she was much easier during the days when her stays were on, than at night when she had unlaced and taken them off. A compress and roller over the part affected afforded immediate relief. Altogether the case is instructive not merely for its singularity, but because it affords a useful lesson with regard to the extreme importance of making an accurate examination of every disease before we hazard an opinion concerning its nature.

The following year at Val-de-Grace at the examination of a patient suffering from chronic pneumonia, Broussais[26] found a painless tumor, the size of a pigeon's egg, on the fourth rib; crepitus was elicited and a fracture was diagnosed.

In 1838, the scholarly and erudite surgeon Malgaigne[89] published a most impressive survey of the medieval and ancient medical literature on fractured ribs; he had been able to collect 7 cases. Early case reports were also published by Nankivell (1836),[103] Bérard (1841),[15] Hilton (1852),[74] Denonvillier (1853),[39] and Hérard (1855).[73]

In 1860, Gurlt[67] recorded 14 instances of rib fracture from muscular action; 10 of these were from coughing, 1 from a repressed sneeze, and 1 each from turning in bed, mounting a restless horse, and through an effort to maintain bodily equilibrium.

In 1882, Mazeillé[94] published a series of 24 cases including one previously unreported. In 1890, the list was extended by Tunis[132] to a total of 40 rib fractures from muscular action. In more recent times Wahl[134] (1926) collected 66 cases (including 3 personal cases). Oechsli[105] (1936) reported 22 personal cases and Mitchell[99] (1951), 14 personal instances.

ETIOLOGY

Rib fractures from muscular effort occur as the result of the most varied circumstances but especially following a violent paroxysm of coughing. The most frequently identified cause of the cough in the reported cases has been tuberculosis, but it is likely that the frequency of roentgenographic examination of tuberculous persons accounts for this apparent excess. Thus, Cohen[36] reported 7 such instances, Richardson[116] 30, Oechsli[105] 22, and Webb[135] 3. Richardson[116] stated that there were ten times as many such fractures in patients with advanced as in those with incipient tuberculosis. It is true that as the disease worsens the cough becomes of greater severity and frequency; prolonged bed rest predisposes to osteoporosis.

Mazeillé[94] considered bronchitis the chief cause of rib fractures; certainly a large number of isolated instances have been ascribed to acute or chronic bronchitis, influenza, coryza, infections of the upper respiratory tract, and the like. Bronchial asthma is not infrequently mentioned. Laryngeal irritation from aspirated foreign matter has been the cause of rib fractures in 2 or 3 reported cases. In one young woman, both eleventh ribs were fractured during a paroxysm of whooping cough.

Sneezing has been blamed for the broken rib in several reports in the literature. One concerned the patient of Castella[31] (1861), a powerful 39-year-old Swiss hotelkeeper. Although he did not use snuff, on one occasion he took a pinch of it from a guest. After sneezing repeatedly, he attempted unsuccessfully to suppress the act by expanding his thorax with his mouth closed. A powerful exhalation followed, after which there was a definite crack accompanied by pain and difficulty in breathing. In explaining his case, Wyman[138] (1885) remarked that in the act of sneezing two powerful sets of muscles may be brought into antagonism in such a way as to expend their opposed forces on the ribs, making the fracture simply a mechanical matter. Podrazki[112] reported the case of a strong healthy lady "of some thirty years" who fractured the tenth costal cartilage while sneezing.

It is well known that coughing often follows vigorous laughter. Speed[126] and Palfrey[106] as well as Breslin[23] have called attention to rib fracture under such circumstances. Muscle strain incident to straining at stool or vomiting has also resulted in this accident.

Bones have been broken as a result of intervention of muscles not primarily concerned with respiration; these may act alone or in conjunction with those involved in such physiologic acts as are discussed in the preceding paragraphs. Thus, the patient of Atkinson[10] fractured a rib after coughing while in the act of hanging up his coat; Somerset[124] reported the case of a patient who fractured a rib after coughing while removing her stays; in Seilin's[121] report, the rib fracture followed cough while the patient was attempting to close a window. The patient of Fisk[54] after a sudden violent cough felt a rib break while sitting sidewise on a chair, with his legs crossed, his right arm and his hands clasped on the back of the chair. Groninger's[64] patient made an effort to right himself to prevent falling while walking home, with immediate pain and dyspnea resulting. Aitken and Lincoln[4] reported the instance of a well-developed and -nourished white man aged 29 years who with a cardboard box on his head was climbing a ladder; the box slipped, and to maintain balance he jerked his head suddenly to the right, thereby fracturing the left first rib. Analogous perhaps are those accidents induced by suddenly turning in bed or attempting to mount a restless horse. Rectification of asymmetrical posture seemed operative in the instance of Michael-Phillip's[97] young woman who had been out earlier with her young man. On arising from the bank on which they had been sitting, she felt something snap "like a twig"; a rib fracture was demonstrated roentgenographically.

A frequent complaint of occasional golfers is soreness or tenderness over the lower left ribs and upper abdomen. These might well be symptoms of fractured ribs. Two medical colleagues fractured ribs on the golf links, and a similar accident was at first thought to be due to coronary artery disease (Case 2). Fractured ribs are also said to be common among scullers; Arnold[9] reported a broken rib from a medicine ball workout, and Mandl[91] one from the Telemarkschwung in skiing.

When one is set to perform some action requiring heightened muscular activity which does not eventuate, rib fractures may occur. Chenery's[34] old but active farmer broke three ribs when a root which he was pulling up gave way, causing him to sit suddenly on a rock behind him. Kevin Byrne[28] described a case in which muscular effort alone accounted for six badly fractured ribs, three on each side. His patient was tossing cabbages with a pitchfork, and a particularly heavy forkful slipped off as he started to toss; the anticipated exertion was used on the lightened load. Perhaps the case of Nancrede[102] is parallel. The patient was a healthy vigorous laborer who fractured the second rib while trying to straighten a scythe blade; he was holding it down with one hand while lifting the free end with a monkey wrench held in the other hand when the accident took place.

SEX

There is no doubt that in instances in which these fractures are due to violent muscular action other that that involved in coughing or sneezing, men are definitely more prone to these injuries. Also, men are more often exposed to physical trauma, and fractures of all sorts from external violence predominate in men. This is not the case when the responsible forces derive from physiologic or quasiphysiologic activities (coughing, sneezing, vomiting, straining at stool, parturition). In 140 such instances in which the sex was noted, there were 85 women and only 55 men.

AGE

On a priori grounds, it might be anticipated that increasing age would incline to a heightened incidence of rib fractures. In addition to their greater dependence and helplessness, as a rule there is in aged individuals progressive atrophy of bones resulting from senile osteoporosis. Increasing calcification of the costal cartilages and the tendency to ankylotic fusion of the ribs with the vertebral column lead to reduced elasticity of the thoracic cage. Moreover, the wasting with senescence of muscles which formerly protected the ribs exposes them especially to indirect as well as to direct violence. The fact seems to be, however, that this very decrease in muscularity precludes the development of stresses adequate to break the now more predisposed ribs.

On the other hand, in youthful individuals the elasticity of the ribs affords a significant measure of protection. In quite young people, rib fractures from muscular action alone must be extraordinarily rare. One exception must be made. Cough develops in patients with progressive rickets, and this

cough may occur in paroxysms. In a study of 32 children, ranging in age from 8 months to 4½ years, who suffered from severe rickets, Park and Howland[109] found rib fractures almost regularly present. In one case, 20 were counted. Although these fractures were often not apparent on physical examination, the roentgenograms of the patients studied by Park and Howland characteristically showed remarkably slender porous-appearing ribs. Pospischill[114] described a "dozen" instances of fractured ribs in autopsies of children who died from whooping cough; perhaps they also had rickets. In the 113 reported cases in which the age was specified, the youngest was a 16-year-old girl; 3 were 18-year-old and two 19-year-old women. The majority of the remainder occurred in patients in the third to sixth decade. Thus, the likelihood of rib fracture from muscular action is greatest from 20 to 50 years of life, that is, when the resiliency of extreme youth is lost but the feebleness of advanced years is not yet apparent (Table I).

TABLE I. DISTRIBUTION OF RIB FRACTURES BY AGE AND SEX

	AGE (YEARS)							TOTAL
	10-19	20-29	30-39	40-49	50-59	60-69	70-79	
Men	2	5	8	12	6	4	4	41
Women	6	18	16	14	10	6	2	72
Totals	8	23	24	26	16	10	6	113

PREGNANCY

In the literature there are reports of 24 rib fractures during pregnancy, all of which occurred in the last trimester, but only two during labor. Ahern's (1894)[3] patient, a strong, healthy woman in labor with her third child, sustained a fracture of the left sixth rib a little in front of the anterior axillary line when she was seized with a violent fit of coughing during a severe pain accompanied by powerful expulsive efforts. Freeland's (1895)[57] case, which seems to have escaped general attention, is quoted because of its interesting features: "A black woman of Herculean frame, who in a long pain during parturition fractured the eighth and ninth ribs on the left side. I was present when the accident occurred, and the loud report I heard when the bones gave away proves, I think, that although the ribs were large, solid, and fixed they were not strong enough to resist the powerful action that was being exerted by this unusually muscular woman."

Reference to Table II will show, as noted by Paulley and co-workers,[111] that in these cases the fractures occur late in pregnancy, tend to be left-sided, and affect chiefly the lower ribs. Paulley and co-workers also pointed out that multiple fractures are exceptional under such circumstances, but this observation is not confirmed in the present series.

Cazeau[32] asserted that there is an increase of fragility of the ribs in pregnancy because of fetal demands on maternal calcium. This idea has been alluded to repeatedly by later writers on the subject, but it was first studied critically by Paulley and co-workers. Their comparisons of bone density with controls of the same sex and age revealed slight osteoporosis in only one case; blood calcium and phosphorus estimations were within normal

limits. Barr (1949)[13] is of the opinion that some degree of decalcification may be present late in pregnancy although it is not revealed by roentgenographic or blood chemistry studies. Lachmann and Whelan[82] experimentally removed calcium by acid and studied roentgenographically the bones before and afterward. It is clear from their results that normal roentgenograms do not exclude osteoporosis, for only under favorable circumstances can decalcification of less than 20 per cent be diagnosed roentgenologically. In most bones, including the ribs, the calcium loss, in order to be visible, must be in the vicinity of 20 to 40 per cent.

TABLE II. SUMMARY OF REPORTED RIB FRACTURES DURING PREGNANCY

SOURCE	AGE (YR.) AND PARITY	DURATION OF PREGNANCY	SITE OF FRACTURE (RIB)	EXCITING CAUSE
Adkins (1949)	36	1 week before confinement	Left 7th and 8th	Cough
Ahern (1894)	Multipara	In labor	Left 6th	Coughing paroxysm
Barr (1949)	26	36 weeks	Left 11th	Coughed while rising from bed
Benoît		9th month	Left 9th	Coughing fit from chronic bronchitis
Blanc (1908)	37	End of pregnancy	Multiple	Cough
Brookhouse (1879)	36	Late pregnancy	Left 6th	Coughed while sitting sideways
Chenery (1878)	23			Coughing fit
Dogadkin (1885)	27; multipara	10th month	Left 8th	Bronchitis
Evans (1949)	Late 20's; multipara	8th month	Left 8th and 9th	
Freeland (1895)		In labor	Left 8th and 9th	Straining with hard pain
Hérard (1855)	22	7th month	Mid ⅓ of left 11th	Violent cough from chronic bronchitis
Inglima (1938)	29	Last of pregnancy	Left 9th	Coughing fit (acute bronchitis)
Miall (1871)	29	7th month	10th	Violent paroxysm of coughing
Paulley, Lees, and Pearson (1949)	21; primipara	36 weeks	Left 10th	Coughing fit (chronic bronchitis)
	25; multipara	38 weeks	Left 9th and 10th	Coughing mildly
	36; multipara	40 weeks	Left 11th	Lifting and coughing
	25; multipara	29 weeks	Left 11th	Coughing after previous choking
Telhouni (1937)	40; multipara	8 months	Left 11th	Asthmatic attack
Trillat and Pizzera (1932)	34; primipara	8 months	Left 10th	
	27; multipara	8 months	Right 11th and 12th	Bronchitis
	32; multipara	4 days before delivery	Right 11th and left 7th	Bronchitis
	35; primipara		Left 11th	
Vidal (1894)	32; multipara	7th month	Left 10th	Bronchitis
Wynn-Williams (1951)	28	6 months	Right 6th	Coughing from respiratory tract infection

In any case, gestation does not retard consolidation in spite of the classic conception to the contrary; in the case reports in which comment was made, healing was noted to progress normally even before delivery.

The presence or absence of increased fragility of bones in late pregnancy would in no way explain the left-sided preponderance of these frac-

tures. It has been suggested that the position of the liver seems to protect the right ribs, the net effect of the blow being delivered against the lower left ribs. Paulley and co-workers considered that the laterality was favored by the bulky uterus being driven violently upward and backward with forceful contractions of the abdominal muscles in coughing or sneezing. They further called attention to the posteral alterations in the pregnant state: compensatory to the backward thrust of the head and shoulders is a lordosis with increased tone of the sacrospinalis. In their view, incoordinate action in association with depression of the lower ribs by the iliocostalis could provide conditions for a shearing stress sufficient to fracture a lower rib. Telhouni[128] commented on the exaggerated distension of the abdomen in advanced pregnancy and on the derangements provoked thereby in the last ribs; thus the direction of forces generally applied by the ribs is modified, at times deleteriously. None of these speculations is satisfactory, and it may well be that the explanation can be found in a combination of these with as yet unappreciated factors.

SITE AND NUMBER OF THE FRACTURES

Fractures resulting from cough have been reported in every rib, but rarely occur in the uppermost and lowermost ribs. The first rib is, however, frequently the site of fracture from muscle stress unrelated to cough. Most fractures are found in the fifth through the tenth ribs (Table III). As a rule (102 of 142 instances), a single rib is involved. In 15 patients, two ribs were broken; in 12 patients, three ribs; four and six were broken in four instances each; and eight were broken in one person. There are a number of reports in which it is clear that in multiple rib fractures not all of the ribs break simultaneously. Edgecombe's[49] patient sustained a fracture on the left side; one week later a second break took place on the right. The second fracture in Halliwell's[68] case occurred sixteen days after the first. Evans'[51] patient felt the second rib crack with a subsequent bout of coughing about twenty minutes after the first. In the case reported by Swineford and McKinnon[127] there were eight independent rib fractures during one single bout of upper respiratory tract infection.

TABLE III. DISTRIBUTION OF RIB FRACTURES BY SITE INVOLVED

LOCATION	RIB												TOTALS
	1	2	3	4	5	6	7	8	9	10	11	12	
Right side	0	0	1	2	9	15	19	10	9	4	5	1	75
Left side	1	1	0	2	7	21	18	16	14	8	6	0	94
Totals	1	1	1	4	16	36	37	26	23	12	11	1	169

Analysis of the location of fractures in the cases reported in the literature suggests that those in the first rib seem conditioned by the attachment of the scalene muscles as well as by the subclavian groove. There were too few fractures in the second, third, and fourth ribs to elaborate on this point. There was a definite increase in incidence of fractures between the anterior and posterior axillary lines from the fifth through the ninth ribs.

They were less commonly found mesiad to this area and were definitely rare adjacent to the cartilages and vertebral column.

Reference to Table III shows that in those instances in which the side involved was noted, there was a moderate preference for the left. In the 134 case reports in which this point was recorded, 7 patients had bilateral fractures, the remainder (approximately 93 per cent) having but one side involved. The discrepancies in the various totals stem from the lack of detail in many instances.

PSYCHOSOMATIC FACTORS

The old-fashioned fault of carelessness and its counterpart carefulness have been replaced in more modern circles by accident proneness and compulsive behavior. Much has been written on accident proneness as a cause of fractures.[30, 45, 46] Only one reference was found to emotional or psychosomatic factors in the reported cases of rib fracture. In a letter to the editor of the *British Medical Journal,* Harold[70] wrote: "A young female, after some months estrangement from her boy friend met him again, was lovingly embraced, and soon after experienced what she described as a sharp pleuritic pain in the chest. Medical opinion was nonplussed for three days when an x-ray revealed a fractured lower rib. Could this, sir, be etiologically ascribed to emotional trauma?"

THEORIES

It is generally agreed that muscular contraction can fracture healthy ribs, but there is no unanimity either as to the precise muscles involved or to their method of action. In general, it is supposed that the accident takes place by virtue of opposed forces. Seilin[121] invoked the simultaneous contraction of the diaphragm and the upward pull of the latissimus dorsi. Tunis also believed that the diaphragm was a major factor, together with the other powerful muscles attached to the ribs. Oechsli,[105] whose views are most widely accepted, excluded the diaphragm from consideration because the attachments of this muscle do not correspond to the location of the fractures. In his cases, these fractures were found in a line extending from a point 4 cm. from the costochondral articulation of the fourth rib obliquely caudad and laterally to the ninth rib in midaxillary line. This line, he stated, corresponds to the interdigitations of the external oblique and the serratus anterior. The contrasting contractions of these muscles, in his view, produce the fractures.

Malgaigne[89] invoked torque: "in powerful inspiration preceding cough, slight torsion which the elevation of the sternum produces on ribs is not completely executed because of ossification of cartilages; bones are ruptured because they cannot yield." Telhouni[128] also favored the concept of torsion. Parenti[108] thought that the site of the fractures was conditioned by the moment of curvature which is greatest posteriorly near the region of the angle, and anteriorly near the costochondral junction.

Sustained tetanic contractions are quite capable of breaking bones; such fractures may appear in 35 per cent of patients subjected to electric shock

therapy,[95] or in 23 per cent of those treated with Metrazol.[47] Fractures have also been reported in tetanus: in the ribs and vertebral column,[84, 117] elbow,[125] femoral neck,[12] and forearm.[137]

Moreover, it is by now well established that repeated subminimal trauma may produce fracture, particularly of weight-bearing bones. Large numbers of such fractures have been reported under various names (March fracture, March foot, Deutschländer's disease, Pied forcé, fracture de recrue) ever since World War I, although they were known earlier.[22] This mechanism has been called on to explain rib fracture from coughing, a view which has been championed especially by Zur.[140] He doubts that such fractures come about from a particularly strong cough, feeling it more likely that they are instances of "schleichende Frakturen" (creeping fractures). Alderson,[6] too, considered stress from repeated contraction of the scalenes to be a plausible explanation of breaks of the first rib appearing after strenuous physical training. The constant location of the fracture line in relation to the insertion of the scalene muscle is invoked as the explanation of rib fractures following thoracoplasty in the report of Guggenheim and Cohn.[65] They analyzed 208 cases of thoracoplasty in which fractures of the first or second rib or both occurred on the contralateral side in eight patients. After operation, the pull of the muscles on the first and second ribs is unopposed by similar muscles on the side operated on. The fractures did not take place during or immediately after the operation. The authors commented that it was noteworthy that all fractures with one exception occurred in the area of greatest muscular stress and where the bone structure was thinnest due to the subclavian grooves. Further reference to these points is made in the structural analysis section.

STRUCTURAL ANALYSIS OF RIB FRACTURES FROM MUSCULAR CONTRACTION

Before the structural analysis is discussed, it is considered best to define, from an engineering standpoint, those terms which may be used differently in other fields. When a force is applied to an object, the object is subjected to *stress;* the fundamental stresses may act singly or in combination. The diagrams in Fig. 1 illustrate these stresses, which are called *tension, compression* (direct stresses), *shear,* and *bending.* As a result of these stresses the object undergoes *deformation;* this deformation is called *strain. Enlongation* is the strain which results from tensile stresses; under compression the body is shortened; as a result of shearing stress, one part of the body tends to slide past the other. When one prunes a branch in his garden, he is subjecting the branch to a shearing stress.

In order to facilitate and simplify the engineering analysis, an object is isolated from its surroundings by means of a *free body diagram* which permits the application of vectors to those points at which forces are acting. This principle is shown in Fig. 2.

A moment, mathematically defined, is $\int (x\text{-}a)^k dm$, where dm is the differential of measure over the appropriate portion of space. In engineering

it is customary for k to be 1 or 2, that is, for the first and second moments only to be used. The first moment is the moment of a force; the second is the moment of inertia.

The *moment of a force* (''moment'') with respect to a point is the tendency of the force to turn or rotate about the given point. This tendency to rotate is expressed as the force times the perpendicular distance from the line of action of the force, as illustrated in Fig. 3. In this analysis, three basic

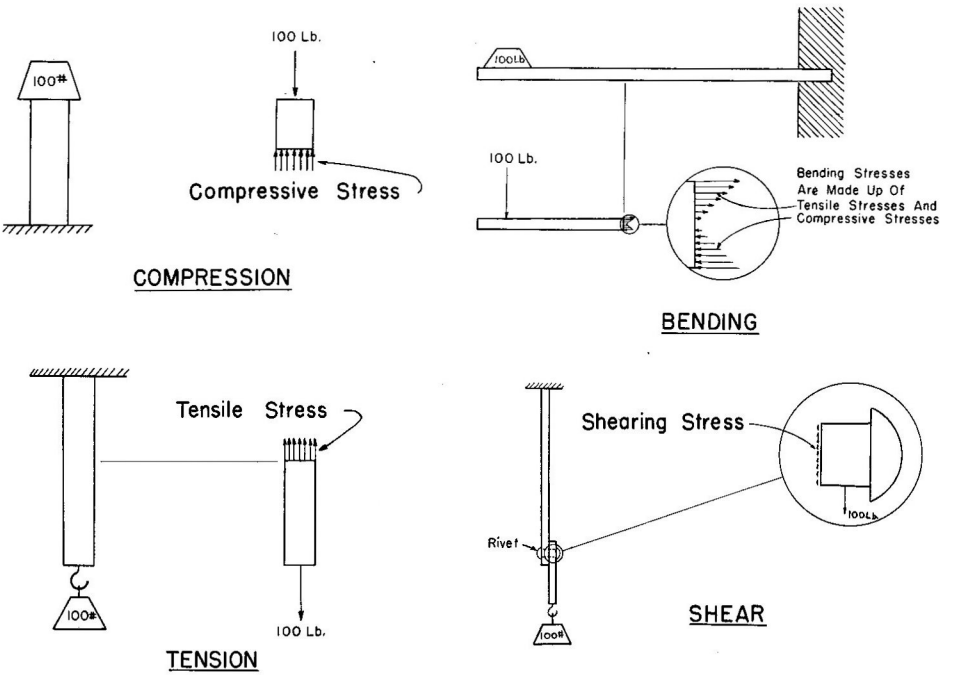

Fig. 1.—The fundamental stresses.

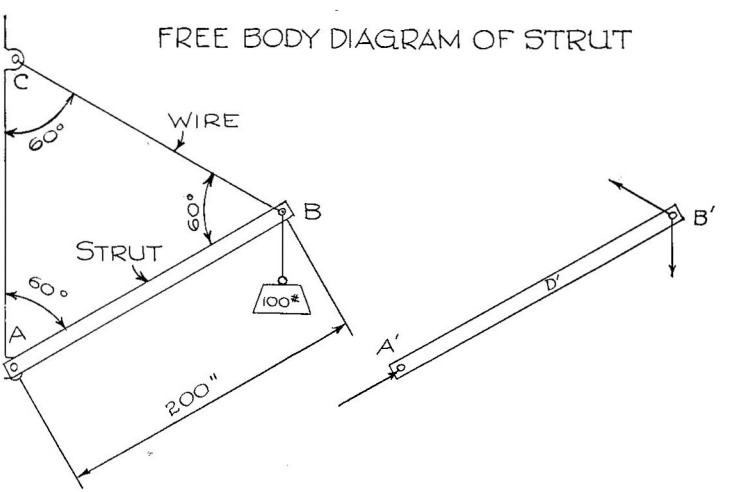

Fig. 2.—Free body diagram of strut.

laws of static equilibrium have been used: (1) summation of horizontal forces acting on a free body equals zero, $\Sigma F_x = 0$; (2) summation of vertical forces acting on a free body equals zero, $\Sigma F_y = 0$; (3) summation of moments of forces acting on a free body about any point in the free body equals zero, $\Sigma M = 0$. In the free body diagram of the strut, which represents a condition of static equilibrium, these principles can be applied to solve for the unknown forces acting on the body as shown in Fig. 4.

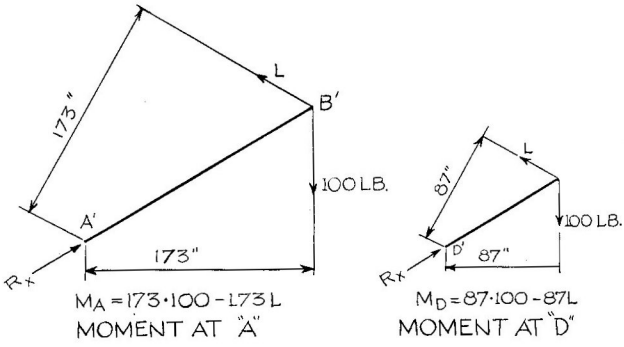

Fig. 3.—Example of computations of moment of a force with respect to points "*A*" and "*D*."

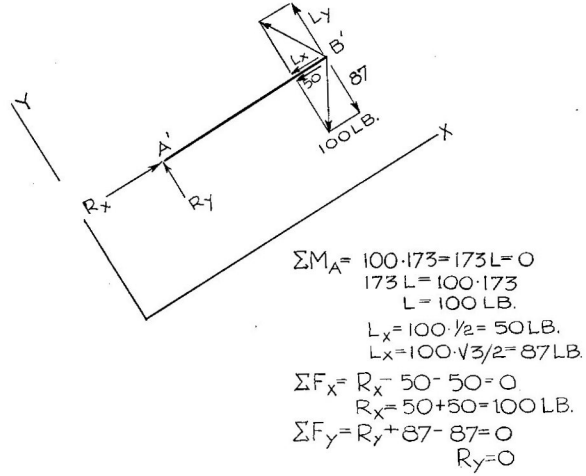

Fig. 4.—Computation of unknown forces. R_X and R_Y are reactions with respect to the x and y axes; L_X and L_Y are components of L with respect to the x and y axes; F_X and F_Y are the resultant forces on the x and y axes.

Of the reported rib fractures from muscular action, the sixth rib was involved the greatest number of times and, therefore, this one was selected for the structural analysis. The first step was to draw a free body diagram of this rib and solve for the reactions. (See Fig. 5.) *Reactions* in this sense are resultant forces at the supports of the ribs, that is, the costochondral junction and vertebral column due to muscular action. At various points along the rib, imaginary cross sections were established and stresses were computed at

these points. These stresses consisted of shearing stresses, tensile stresses, compressive stresses, and bending stresses. For example, in order to compute the stress in Section 4, a free body diagram was established for the portion of the rib extending from the vertebral column to Section 4. The free body diagram and computations of stresses at Section 4 are shown in Fig. 6. Bending stress was computed from the formula $f = \frac{M}{S}$ in which S is the *section modulus,* M the moment at the section, and f the extreme bending stress. The section modulus is the *moment of inertia* divided by ½d. For

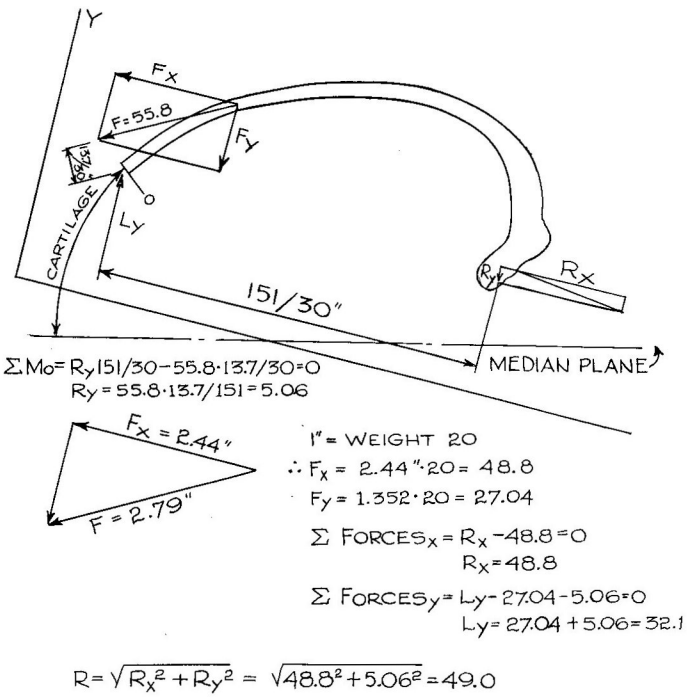

Fig. 5.—Free body diagram of sixth rib with calculations of reactions at costochondral and costovertebral junctions.

the purposes of calculating stresses, the rib sections were assumed to possess properties of equivalent ellipses. Table IV summarizes the values obtained from computations at the various sections indicated. It should be noted that direct stresses and bending stresses at the same section are additive. In Fig. 7 is shown the variation of the combined direct and bending stresses along the rib. The variation of shear stresses is shown in Fig. 8. In each case the relative magnitude of the stresses at the various sections is represented by the distance from the center line of the rib to the curve. Sites of reported fractures are indicated on the ribs themselves. The incidence of fractures in each zone is indicated by encircled numbers. Fractures are

of greatest frequency in those areas where bending stress is greatest; they are of least frequency where shearing stress is maximal. Torsion is not believed to be present, but if there were any torsion present it would be in the portion

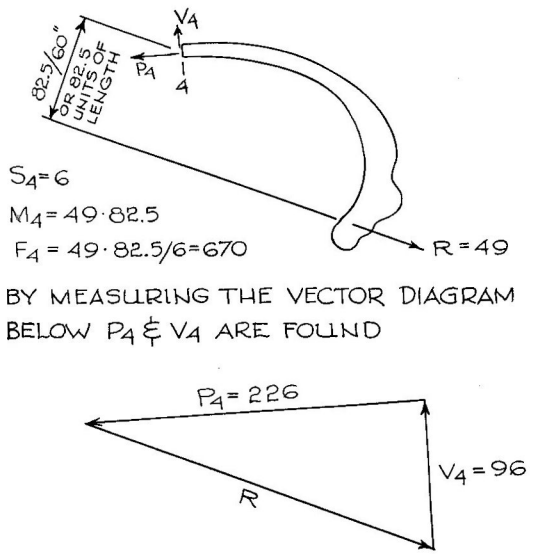

Fig. 6.—Free body diagram with computations of stresses at Section 4.

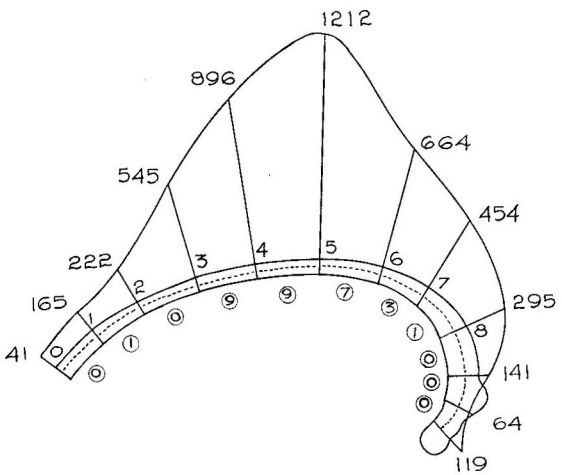

Fig. 7.—Variation of combined direct and bending stresses along the rib. See text.

of the rib extending from Section 7 posteriorly; fracture produced by torsion in this portion would tend to assume a helical path.

The actual fracture may be the result of a gradual failure of the rib due to a progressive cracking across a given section. Even though the stress at this section may be computed to be below the *elastic limit,* stress concentrations

in minute regions occasionally exceed the elastic limit. The elastic limit is the maximum stress to which a material can be subjected without any permanent deformation. Prior to the development of a crack, there is a period of inelastic deformation which is graphically illustrated in Fig. 9. Cracks are

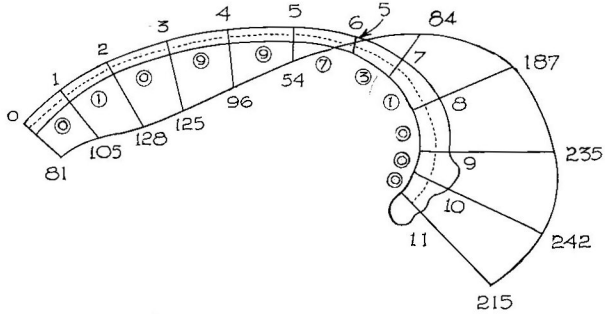

Fig. 8.—Variation of shear stresses. See text.

thus started which reduce the cross-sectional area resulting in an increase in maximum stress, as illustrated in Fig. 10. This cycle is repeated with progressive reduction in area of intact bone, which may suddenly snap. Throughout the failure, the region of high stress has always been so small that the deformation does not extend sufficiently to become apparent. This mechanism is illustrated by those patients in whom a definite localized area of tenderness persists for several days prior to audible fracture at this site.

TABLE IV. VALUES OBTAINED FROM STRESS COMPUTATIONS AT DESIGNATED SECTIONS OF SIXTH RIB

SECTION	S*	y*	M*	f*	P*	A*	p*	f + p*	V*	v*
0	18	0	0	0	141	1	141	141	81	81
1	18	22.5	735	40.9	124	1	124	165	105	105
2	14	52.5	1710	122	100	1	100	222	128	128
3	9	61.5	3000	333	212	1	212	545	125	125
4	6	82.5	4020	670	226	1	226	896	96	96
5	5	98.6	4860	972	240	1	240	1212	54	54
6	12	103.0	5030	419	245	1	245	664	5	5
7	21	96.5	4710	224	230	1	230	454	84	84
8	27	76.0	3710	137	158	1	158	295	187	187
9	30	44.0	2150	72	69	1	69	141	235	235
10	30	20.5	1000	33.3	31	1	31	64	242	242
11	30	0	0	0	119	1	119	119	215	215

*Symbol notation:
S = Section modulus,
y = Perpendicular distance from center of section to the line of action of the reaction at support,
M = Bending moment at section,
f = Maximum bending stress at section,
P = Direct force on section,
p = Direct stress on section (p = P/A),
A = Cross-sectional area of rib, which is taken as 1 since it is practically constant at all sections,
V = Shearing force on section,
v = Shearing stress on section.

In the foregoing analysis, certain assumptions were made initially.

1. The weight of the rib was assumed to be negligible. This would not have altered the location of the maximum stress.
2. The support of the rib at the vertebral column was assumed to act as a hinge joint.

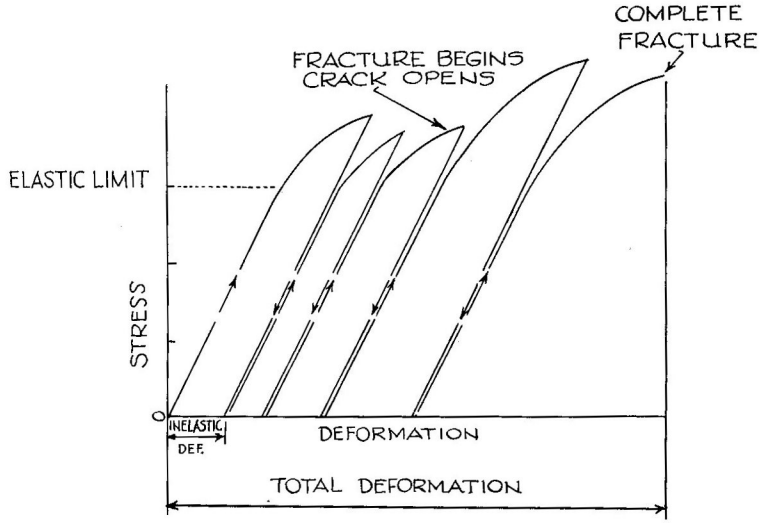

Fig. 9.—Stress-strain diagram. In coughing, the rib returns to its initial dimensions, the zero position, as long as the elastic limit is not exceeded. When the elastic limit is exceeded, it no longer returns to the zero position but a certain small amount of permanent set takes place which is indicated by *inelastic deformation.* Each time the elastic limit is exceeded, the inelastic deformation is increased. Ultimately the rib breaks.

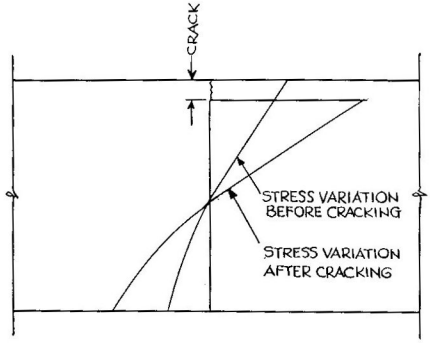

Fig. 10.—Example of change in stress variation caused by small crack in rib. The parallel horizontal lines represent the upper and lower margins of the much enlarged rib. It will be seen that prior to the crack the displacement of the stress line from the vertical is considerably less than after the cracking has begun. As the depth of the crack increases, the maximum stress in the remaining intact bone is progressively increased. Finally, complete fracture results.

3. The anterior support was taken to be at the costochondral junction; the moment induced by the cartilage was considered to be negligible.
4. It was assumed that the rib was supported only at its extremities.
5. It was assumed that there was no chance of failure in a vertical plane because of the uniform action of the intercostals and also because of the ratio of the depth of the vertical plane to the depth of the horizontal plane of the rib. Strength varies directly with the cube of the depth.

6. It was assumed that the section modulus was proportional to the outside dimension of the rib, that is, that the ratio of the cross-sectional areas of the compact bone to the cross-sectional areas of the cancellous bone did not vary and that the cancellous bone trabeculae were uniformly distributed. Consequently, stress units are of arbitrary dimension.
7. It was considered that muscle force is directly proportional to its effective cross section,[50] and that in addition the Muskelkrafteinheit of Fick[53] (10 kg. per square centimeter) is valid in so far as it permits contractile forces of various muscles to be compared. This force has been estimated by Franke[55] to be 11 kg. per square centimeter.
8. It is clear that a number of variables are also involved in the area of cross section of the respiratory muscles, variations not alone from age, sex, and muscularity of the individual, but also from the effect of the incident disease. As a standard, the *Cross-Section Anatomy* of Eycleshymer and Shoemaker[52] was employed.
9. A mean position of the rib was assumed. A series of roentgenograms was taken on full inspiration and expiration in the hope of deriving information useful to this analysis. Extent of thoracic expansion and degree of costal or diaphragmatic breathing varied not only from person to person but also in the same person at different times.
10. Other stresses, such as radial stresses, have not been discussed, as they are negligible.
11. Bending stresses were assumed to vary along a straight line instead of hyperbolically as they actually vary. It is realized that this assumption yields inaccurate stress calculations, but since the ratios of the radii of curvature to their corresponding depths are not of great magnitude, the variation of maximum stresses along the rib would be similar to that obtained by virtue of this assumption.

The criticism might be offered that an analysis based on so many assumptions could not produce valid results. Rashevsky[115] pointed out that the study of such nonreal idealized systems does lead to practical results, at least within certain limits; within these limits the real things have common properties with the fictitious idealized ones. "Only a superman could at once grasp mathematically all the complexities of a real thing. We ordinary mortals must be more modest and approach reality asymptotically, by gradual approximation."[115] Finally, there is a close correspondence of the predicted and actual zones of greatest likelihood of fracture.

THEORY OF RIB FRACTURES DUE TO VIBRATION

Whereas many rib fractures are probably the result of stress concentrations and progressive cracking, as has already been explained, some fractures may be caused by a sudden muscular contraction that is repeated at a frequency which corresponds to the natural frequency of vibration of the rib. Under such a condition, the stresses and strains are tremendously increased. This can best be seen by inspecting the equation of motion of a spring under forced vibration,

$$\frac{W}{g}\frac{d^2x}{dt^2} = W - (W + kx) + P \sin t,$$

together with the magnification factor curve in Fig. 11. W is the weight acting on a spring, g is the acceleration of gravity, k is a physical property of

the spring called the spring constant, x is the deflection of the spring at time t, and the term P sin t is known as the disturbing force and is related to the magnification factor.*

Of course, the preceding equation pertaining to a spring is not directly applicable to the action of ribs, but the magnification curve for rib vibrations would take a similar form, and even though the vibration of a rib would be subjected to some damping, due to contiguous tissues, stresses and strains in excess of the elastic limit (and sometimes in excess of the ultimate strength) would be reached. This is due to the fact that the magnification factor approaches a limit of infinity at $\omega/p = 1.0$.

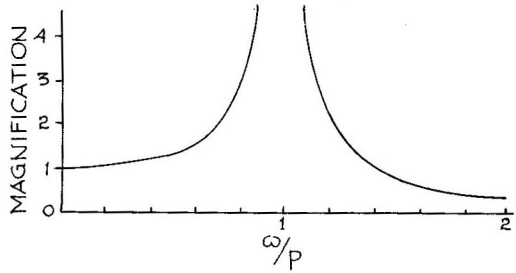

Fig. 11.—Magnification of forces results when coughing occurs at the natural frequency of vibration of the rib. At the time when $\omega/p = 1$, the force approaches infinity.

It should be pointed out that the probability of rib vibrations occurring at the natural frequency of a rib is extremely low; however, such a condition must have occurred, when one considers the periodic function of a coughing seizure and the billions of people who have had many coughs during their lifetimes.

PATHOLOGY

In those instances in which fractures produced by muscular action have been examined pathologically, essentially normal features have been revealed grossly and histologically. Hérard[73] reported a case of fracture of the eleventh rib on the left side which at autopsy showed rich callus at the fracture site; the tissues of this rib and of the other bones as well were normal. Matthes and Thelen[93] excised two such fractures which were initially thought to be malignancies; biopsy showed new formation of bone and cartilage and no tumor but "reactive changes in the sense of callus formation." In the third case of this paper, the biopsied fracture disclosed essentially normal rib including bone marrow. Finally, Bodenheimer's[19] case showed little beyond osteoid formation with low-grade perichondritis.

It may be relevant to cite here the results of post-mortem examinations of vertebrae fractured during convulsions of tetanus. Eberstadt's[48] patient was a 29-year-old soldier. The autopsy disclosed in the third and fourth thoracic vertebral bodies numerous shattered, broken, and collapsed bone trabecu-

*For a complete explanation of this equation and graph see S. Timoshenko's Vibration Problems in Engineering, Chapter 1, D. Van Nostrand Company, Inc.

lae, which comprised a rather disordered group. In many places, the medullary cavity was replaced by an edematous vascular fibrillar marrow, which contained some plasma cells and round cells with much protoplasm. There was limited new bone formation with irregular calcification. There was no evidence of pre-existing bone disease.

Autopsy of a powerful boy, 15 years of age, in whom tetanus developed following a foot injury showed the fifth thoracic vertebra to be compressed and to project into the spinal canal. The fourth intervertebral disc was infiltrated with blood. Aside from the mechanical disorder, microscopic examination revealed completely intact bone.[11]

CLINICAL PICTURE

The symptomatology of rib fractures produced by muscular action does not differ from that produced by trauma. At the moment of the accident, many patients have felt something break or give way in the side; certain of these fractures have been accompanied by noises which at times could be heard across the room.[3, 7, 8, 38, 40] The noise is generally likened to that produced by breaking a stick, fagot, or twig. Pain is not an invariable symptom, especially in breaks of the uppermost ribs; thus, of Alderson's[6] 35 patients with fracture of the first rib, only 5 volunteered significant symptoms or history. The patient of Brewster[24] felt something snap in the chest but experienced no pain; three days later a small tender swelling was noted at the fracture site. The onset of pain may be sudden; 3 of Wynn-Williams'[139] 9 patients and 5 of Mitchell's[99] 14 reported development of abrupt pain. Patients stated, for example, that for days they had had aches in the side which suddenly became stabbing pains. Once present, the pain is usually intense and sticking or cutting in nature. All movements of the thorax, especially coughing, sneezing, or deep breathing, intensify the pain. Movement of the arm of the affected side, contracting the serratus magnus, or moving the trunk may similarly worsen the discomfort. The pain is accompanied by an instinctive restriction of respiratory motion and often by a splinting of the ipsilateral muscles of the thorax, particularly in instances of multiple fracture. If coughing continues, the pain will ordinarily interfere greatly with sleep. Severe pain persists from two days to two weeks. Some degree of discomfort probably persists for about three months. In a number of the reported cases, pain was present after six months. Just as with traumatic fractures, immobilization affords relief; Graves'[63] patient felt better in her stays and Mitchell's[99] patient was more comfortable when lying with the painful place pressed against a hard pillow.

The pain usually is localized in the area contiguous to the fracture site, but not infrequently it is referred along the distribution of the involved intercostal nerve. Particularly in fractures of the lower ribs, pain may extend to the hypochondrium, mediated through the anterior cutaneous branches of the sixth through the eleventh intercostal nerves. Pain may extend above as well as below the fracture site because of the superior and inferior branches of these nerves. Two instances of paradoxical referred pain have been re-

ported. Ginsburg's[60] patient complained of an aching pain in the right side of the neck; roentgenogram showed a recent fracture of the left first rib. Because the pain was on the wrong side, another roentgenogram was made and it confirmed the fracture site. Webb's[135] patient felt no pain at the termination of the ninth intercostal over the abdomen on the same side as the fracture, but had severe pain on the opposite side in this area of distribution.

Moderate to exquisite tenderness may be elicited by finger point pressure over the fracture site. Pressure on the rib at some distance from the site of injury causes pain in patients with rib fracture but not in those with contusions or muscular injury.

Innumerable instances of crepitus, at times audible at a considerable distance, are reported after rib fractures produced by coughing. Crepitation naturally is to be expected only in complete fracture; it is ordinarily not elicited in infractions or in insignificant separation of the fragments from one another. When present it is usually quite clear and may be felt with the palpating hand during ordinary respiration or heard with the ear or stethoscope applied to the chest. It is often apparent to the patient.[38, 104, 135] Gurlt[67] noted that crepitation could at times be elicited by applying pressure with the fingers of both hands placed on either side of the suspected fracture site. In order to appreciate the sound with the stethoscope or feel it with the applied palm, pressure might be exerted on the rib at a greater distance or the patient might be asked to cough.

At times, palpation immediately after the fracture might reveal a deformity produced by overriding of the displaced fragments.[7, 8, 10, 37] Later the callus may be palpable as a somewhat indistinct ridge; gradations from this finally include definite tumors as large perhaps as 2.5 by 2 cm. The discovery of crepitation, abnormal mobility, or callus is difficult when the broken ribs are covered with unusually thick soft parts, as in significant obesity or location under a large breast or under powerful muscles such as the pectoralis major and sacrospinalis. The patient should be in the optimum position for examination, that is, standing erect or in the dorsal decubitus. The seated position, especially in fat people, is the most disadvantageous.

The similarity between the pain of pleurisy and that caused by rib fracture has led to the diagnosis of many rib fractures as pleurisy. There are several reported cases, however, in which rib fracture led to pleural friction rub either from the fragments irritating the pleura or from localized hemorrhage. Hilton[74] reported the first such case. Wahl[134] reported 2 cases in which pleurisy developed at the fracture site. There was a suggillation the size of a Viennese thaler in Podrazki's[112] patient. The hemorrhage may be extensive as in the patient of Bodenheimer,[19] a man 67 years old, in whom the hemorrhagic spot over the fracture site was the size of the palm of the hand. The hemorrhage continued to spread until it involved the entire surface of the left half of the thigh. There was otherwise no bleeding tendency and the excised fracture site showed only perichondritis. Browning[27] reported the case of a patient with advanced tuberculosis who suffered from generalized

emphysema secondary to two rib fractures with displacement of the fragments following severe coughing. This seems to be quite rare after cough fractures but is well known to occur after trauma to the chest.[62, 88]

Roentgenography.—Occasionally, the roentgenogram shows definitely less density than normal, but usually there is no radiographic evidence of decrease of bone density. The ease with which early rib fractures might be overlooked in roentgenograms has been commented on repeatedly. The initial line of fracture is quite delicate, and because of the tendency for crowding of the ribs laterally, fractures in this zone may be missed. At times when callus has formed, reviewing of the earlier films may disclose the initially undiscovered break.

The need for oblique views was stressed by Mitchell[99]: of 14 fractures, 8 were seen only in the oblique views. However, Wynn-Williams[139] was unable to find fractures in lateral or oblique views which were not obvious in the anteroposterior position. It is our belief that not only should oblique views be taken but the film should also be exposed for bone detail (including use of Bucky diaphragm) rather than for soft tissue information, as is usually done in views of the chest.

CASE REPORTS

CASE 1 (Rib fracture simulating pleurisy).—Mrs. W. R., white, 55 years of age, had suffered from bronchial asthma since childhood. Within three or four days after development of an infection of the upper respiratory tract, moderately severe asthma associated with a persistent nonproductive cough appeared. Several days later she complained of intense pain over the right hemithorax anteriorly in the region of the seventh and eighth ribs which was aggravated by deep inspiration and particularly by coughing. Physical examination disclosed sibilant râles but no friction rub. It was thought that the patient had pleurisy, but a roentgenogram revealed definite linear fractures in the eighth and ninth ribs in the anterior axillary line on the right side.

CASE 2 (Rib fracture simulating angina).—D. G. R., a white attorney, 54 years of age, had suffered from "asthma" for the past two years. The asthma never awakened him at night. He had an intermittent nonproductive cough and exertional dyspnea which was worse shortly after arising. While playing golf one afternoon he had a paroxysm of coughing almost simultaneously with teeing off the ball. This was followed by severe precordial pain, radiating to the left shoulder and left hypochondrium, and severe dyspnea. He was barely able, with the help of friends, to return to the clubhouse. The pain persisted and was accompanied by some nausea. His physician had him hospitalized for the exclusion of a myocardial infarction. Numerous electrocardiograms were within normal bounds, and after two weeks' observation he was discharged. Roentgenogram of the chest had not been made. One week later, examination at the Ochsner Clinic disclosed obstructive emphysema plus callous formation over the fifth left rib near the costochondral junction.

CASE 3 (Rib fractures confused with metastatic carcinoma fractures).—Mrs. W. M. Y., a white housewife 43 years old, had had a left mammectomy elsewhere because of possible carcinoma of the breast. She had an attack of unrelieved coughing followed by generalized thoracic pain. A roentgenogram of the chest revealed slight accentuation of the pulmonary markings at the right base and multiple fractures involving the sixth and eleventh right ribs and the sixth through the eleventh on the left side with faint rarefaction of the bone on the region of several of these. In view of the multiplicity of the fractures with slight rarefaction and absence of trauma, these were considered to represent pathologic fractures secondary to metastases. Rib marrow aspiration disclosed no abnormality. Rib biopsy was

performed. The periosteum over the ninth rib was incised after palpation had failed to disclose the fracture site. A rather fresh fracture was found; the rib was cleaned off and this segment excised. Microscopic examination revealed essentially normal rib, marrow, and early callus. No metastatic tumor was present.

DIAGNOSIS

The diagnosis of rib fracture may be obvious, or not even suspected. Rarely does one think of a fractured rib if there has been no fall or blow to the chest or if the patient has heard no sound of fracture or felt anything give way. Sudden pain in a circumscribed region of the thoracic wall following cough is a daily occurrence; it is frequently a sign of minimal muscle damage or pleural irritation, and therefore one may easily pass over a fracture and attribute the pain to much more frequent occurrences of this sort. The ease of dismissing these lesions is illustrated by Tunis'[132] (1890) patient, who felt something snap in her side following a cough. "Not believing it possible she could have fractured a rib in this fashion, I gave her a sedative cough mixture and told her to apply a turpentine stupe. The next day she was complaining bitterly so *she was then examined* and a definite fracture discovered." (Italics mine.)

The clinical manifestations of rib fracture may be indistinguishable from pleurisy, in which case the diagnosis must be established roentgenologically. At times intermittent thoracic pain, often diagnosed pleurodynia, may precede the onset of pleural effusion by three to six months; in such cases the radiograph is usually normal. This was true in 10 per cent of 200 cases of tuberculous pleurisy with effusion studied by Sibley.[122] In epidemic pleurodynia there is usually no difficulty in making the diagnosis, for the triad of pain, fever, and headache is pathognomonic. According to Locke and Farnsworth,[86] the pain varies from mild pressure or discomfort to the extreme degree described as having an intense cutting or knifelike quality; in its severe form it may be paroxysmal and quite overwhelming. Locke and Farnsworth added other characterisitc features of the pain: (1) It is directly related to sneezing, laughing, coughing, deep breathing, and especially exercise. (2) Commonly the victim is leaning over a table or chair in a fixed position, or sitting or lying in a relaxed state. If relieved in this manner, motion of any sort is likely to precipitate a paroxysm of pain. (3) The patient walks slowly and deliberately, bent over with the body held rigidly. (4) Referred pain may be located anywhere on the trunk but the commonest sites are along the lower or lateral portion of the abdomen or chest in areas about three inches in diameter. (5) In the epidemic studied by Locke and Farnsworth the onset of fever was coincident with the pain and showed a sharp rise to a maximum of 104° or 105° in very severe cases. Prostration is at times extreme, but most cases subside promptly.

Pre-eruptive herpes zoster of one of the intercostal nerves may also present a clinical picture indistinguishable from pleurisy or rib fracture. With the appearance of vesicles, the differentiation becomes obvious.

Bone changes not produced by muscle action but rather by systemic disease must also be borne in mind when rib fractures are discovered on roentgenography. There is a large number of conditions in which pseudofractures mimic true breaks in bone. Camp and McCullough[29] listed the following conditions in which transverse zones of rarefaction may appear in various bones including the ribs: osteomalacia, rickets and late rickets, renal rickets, celiac disease, chronic idiopathic steatorrhea, Gee's disease, nontropical sprue, sprue, early and late osteogenesis imperfecta, fragilitas ossium, hyperparathyroidism, hyperthroidism, osteitis deformans or Paget's disease, adrenal-pituitary bone dystrophy, severe chronic acidosis or hyperglycemia, congenital syphilis, osteomyelitis, osteopetrosis (marble bones, osteosclerosis fragilis generalisata), states of overloading of bone (march fracture, insufficiency fracture), and certain blood dyscrasias. In referring to this list Albright, Burnett, Parson, Reifenstein, and Roos[5] pointed out that the bone disturbance in the first eight of these conditions is rickets or osteomalacia, depending on the age of the patient, and that the disturbance in the next two may be osteomalacia or rickets. They believed that "the ribbon-like zones of decalcification which occur in otherwise normal appearing bone, which last for months or years without regressing, and which exhibit a marked tendency to be symmetrical, occur only in osteomalacia or rickets." Looser[87] first described these under the term "Umbauzonen" (zones of transformation) in an extensive essay which appeared in 1920.

Milkman's syndrome derives from a carefully studied case first reported under the title "Pseudofractures" (1930); a second report entitled "Multiple Spontaneous Idiopathic Symmetrical Fractures" appeared in 1934 after the death of the patient. This patient exhibited "fractures" of the ribs as well as other bones. Although Albright and co-workers[5] established the identity of this condition as a variant of osteomalacia, they believed it should be retained as a separate entity because of the coexistence of pseudofractures and a skeleton which otherwise is not definitely abnormal as judged by roentgenograms. LeMay and Blunt[85] demonstrated that one factor determining the location of pseudofractures in osteomalacia is the position of the main arteries which lie on the bones. In their patients with rib lesions, it is surmised that these were at the site of branches of the intercostals; vessels were found in these areas in one of three cadavers examined by them.

Another "new" syndrome closely related, in the opinion of its discoverers Guichard and Lehmann,[66] to Milkman-Looser syndrome, has recently (1952) been reported under the name of costal fissures in chronic pulmonary disease. The reproduced roentgenograms certainly resemble those of rib fractures produced by cough; no indication is given of the status of the blood calcium, phosphorus, or alkaline serum phosphatase which would be useful in differentiating osteomalacia, osteoporosis, and osteitis fibrosa generalisata. Since there were no other bone anomalies than those noted in the ribs, it is believed that there is no validity for considering this syndrome as a separate entity.

Rib fractures have been considered to be malignancies either from the roentgenographic appearance or on physical examination. Wynn-Williams[139] remarked that if the rounded area of callus lies over the pulmonary field, it may be taken for an intrapulmonary shadow more easily than is generally realized. He saw two instances in which a callus around a rib fracture was temporarily diagnosed disease in the lung. I know of a patient who narrowly escaped operation for a cough fracture initially diagnosed malignancy. Case 3 (Mrs. W. M. Y.) had had a breast removed for suspected carcinoma. Because of slowly growing, slightly painful masses over the osteochondral junction of the second or third ribs, four patients were referred to Matthes and Thelen[93] with diagnosis of chondroma, sarcoma, osteochondritis, or tuberculosis. They were men between 20 and 35 years of age in good health with rather delicate bony structure but powerfully built musculature. Physical examination revealed a clearly visible mass ranging from the size of a pigeon's egg to that of a plum, and extending perhaps 0.5 cm. above the surface of the chest; it was in firm union with the rib, of the consistency of cartilage, and unattached to the overlying skin. On palpation the masses were slightly painful. Biopsy in 2 patients disclosed callous formation. In all 4 patients, questioning revealed that the fractures were probably caused by excessive physical exertion.

PROGNOSIS

The outlook in rib fractures is favorable for complete recovery with rich callus binding the rib ends together. In many cases the callus appears exuberant, especially with anterior or lateral fractures, probably because of the greater movement of this portion of the costal arch and hence the greater irritative stimulus exercised on the periosteum.[119] These fractures are rarely followed by any of the numerous complications of traumatic fractures of the ribs.[16] There are isolated reports of pseudoarthrosis (Wahl's[134] patient had pseudoarthrosis involving four ribs), of hemoptysis,[33] of extensive emphysema,[27] and of subcutaneous hemorrhage.[19, 112]

TREATMENT

The standard treatment for fractured ribs is strapping with adhesive. Blades[17] advised encirclement of the lower costal margin with a single four-inch strip of adhesive plaster regardless of the level of the fracture. The strapping should remain in place for at least three weeks. Christopher[35] recommended application of a tight circular muslin bandage around the entire chest; it gives much relief, does not irritate the skin, and can be changed easily and painlessly. Harmon[69] found that the use of a local anesthetic with prolonged action (eucupine hydrochloride) eliminated the necessity of strapping the thoracic wall and of excessive use of sedatives.

SUMMARY AND CONCLUSIONS

Rib fractures due to muscular action are not uncommon; in patients with infections of the respiratory tract the incidence of such fractures ranged be-

tween 0.08 and 6.5 per cent. The first instance of rib fracture from coughing was reported by Gooch[61] in 1773.

Muscular effort induced by coughing, sneezing, laughter, vomiting, straining at stool, or parturition may lead to broken ribs. Women are somewhat more prone to such accidents than men, approximately in a 3:2 ratio. Although these fractures occur at all ages, they occur most commonly in persons between 20 and 50 years of age. There are reports of 24 of these accidents in pregnancy; all occurred in the last trimester but only two occurred during labor.

Cough fractures have been reported in every rib but are quite rare in the uppermost and lowermost ribs. The first rib is, however, frequently the site of fracture from muscle stress unrelated to cough. Most fractures are found in the fifth through the tenth ribs, with a moderate preference for the left side. Ninety-three per cent of the reported cases were unilateral, and in 102 of the 142 reported instances only a single rib was involved.

The symptomatology or rib fractures produced by muscular action does not differ from that produced by trauma. At the moment of the accident, patients may feel something break or give way in the side; some fractures have been accompanied by a cracking sound. Pain is often intense and worsened by movements of the thorax.

Crepitation is common, and at times deformity may be palpated. The fractures are easily overlooked in the roentgenograms, especially if these are made before callus has formed.

The diagnosis may be simple, or not even suspected. The clinical manifestations may be indistinguishable from pleurisy; epidemic pleurodynia and preeruptive herpes zoster also have features in common. Rib fractures should also be distinguished from the pseudofractures seen in osteomalacia and other states. Rib fractures have at times been considered malignancies.

In those instances in which fractures produced by muscular action have been examined pathologically, essentially normal features have been revealed.

A structural analysis was made of the sixth rib using engineering principles to study the relative importance of various stresses. It was concluded that the incidence of fractures is greatest where bending stresses are greatest and shearing stresses least, and contrariwise, fractures occur least often where shearing stresses are greatest. Many rib fractures are probably the result of stress concentration and progressive cracking. Fractures may rarely be produced by sudden muscular contractions that are repeated at a frequency which corresponds to the natural frequency of vibration of the rib.

The outlook is favorable for complete recovery. Treatment consists in immobilization and/or local anesthesia.

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