disintegrate and re-form in a random way throughout the suspension (Special Plate, Fig. B). The phenomenon only occurs when the suspension is dense—that is to say, when the number of spermatozoa per millilitre is high and when the spermatozoa are very active. The causes of wave formation are imperfectly understood, but, as it is correlated with sperm density and activity, it might be a measure of the fertilizing capacity of the suspension. Wave formation cannot itself be measured, but it causes or is associated with changes in the electrical properties of the suspension which can be. When an alternating electric current, sufficiently small not to affect or harm spermatozoa, is passed through a dilute suspension or one containing dead spermatozoa, the alternating current resistance or electric impedance is constant. If, however, the suspension is dense and the spermatozoa are active, the impedance varies up to 100 or so times a minute (Fig. 6). As in the case of wave formation, the size and frequency of the impedance changes are proportional to sperm density and activity. The impedance change frequency of bull semen is quite a good index of its fertilizing capacity—as good, I think, as any of the other methods of assessment, such as rate of fructolysis, methylene-blue reduction time, or scoring by eye. Human semen does not exhibit impedance changes, because the number of spermatozoa per millilitre is too low, being about one-tenth of that in bull semen. It would be interesting to see whether human semen exhibits wave formation and impedance changes after concentration of the spermatozoa by centrifugation to 1,000 million per ml., the average value in bull semen.

Stirring the Medium

When bull semen is examined under the microscope the impression is gained that the whole suspension is in a state of turbulence and is being vigorously stirred. Even at low magnification the microscope may deceive one because it magnifies distance but not time. A spermatozoon swims at only just over a foot an hour. How much, in fact, do spermatozoa stir the medium in which they swim? A few years ago I was interested in this question because I was doing some experiments on bull spermatozoa in the absence of oxygen. Their container was in communication with the air through a narrow tube, and I wanted to know whether oxygen would diffuse from the air at its normal very slow rate down this tube, or whether the spermatozoa stirred the medium sufficiently to accelerate normal diffusion to a

FIG. 6.—Impedance changes in ram semen (top) diluted 1:1 with Ringer solution, 37° C. The same semen (bottom) containing dead spermatozoa. The white vertical lines are 30 seconds apart.

significant extent. I thought it best to put this question to two specialists in fluid dynamics, who both came to the conclusion that bull sperm tails would have little effect on the diffusion coefficient of oxygen in water. They might, in fact, cause an increase of about 13%. About a month ago I put a suspension of bull spermatozoa into each of two differential manometers and shook one manometer in the usual way at 100 cycles per minute and left the other one stationary. To my surprise the oxygen uptake of both suspensions was the same. If the same experiment is done with a suspension of yeast, the unshaken suspension respire at a much lower rate than the shaken one. Such experiments can be used to determine the effective diffusion coefficient of oxygen in water being stirred by sperm tails. So far from causing an increase of 13%, it is not difficult to show that the tails cause an increase of more than 600%. This result shows that a suspension of spermatozoa, even when diluted, as in such experiments, to an extent which precludes wave formation occurring, cannot be considered as an assemblage of spermatozoa each of which behaves as it would if it were on its own. The most probable explanation of the discrepancy between theory and practice is that there is a degree of order in a sperm suspension—they are not just like gas molecules moving at random.

(To be concluded next week)

CLOSED ABDOMINAL INJURY

BY

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At a time when the accident services of the country have come under national review it seemed appropriate to study the cases of abdominal trauma treated in this hospital in recent years.

The peacetime experience in abdominal traumatic surgery of any one general surgeon, excepting those in specialist accident units, must of necessity be limited. With increasing mechanization in industry, density and speed of road traffic, and an ever-present and healthy adventuresomeness in youth, however, this experience is likely to be increased.

Although the literature abounds with records of recovery after operation for massive trauma and reviews of series of cases of injury to a single viscus, it seems more than likely that many failures in diagnosis and treatment may fail to reach the record books, and there are few published records of personal series of unselected cases of abdominal trauma.

While the injured abdomen may present lesser problems in diagnosis and treatment to the older surgeon, perhaps with an extensive wartime experience to draw upon, it is commonly the less experienced surgeon who is confronted with the immediate problem of the abnormally injured patient. His is clearly a heavy responsibility.

The diagnosis of the patient with an intra-abdominal injury is not always the simple matter standard textbooks suggest. Unlike disease, trauma has a total disregard for artificially created systems, and multiplicity of injury is common. Associated head injury, perhaps with conscious level seriously depressed or even absent, a not uncommon association with an alcoholic state,

previous administration of morphine in the control of pain and shock resulting from bony injuries, and the presence of various major orthopaedic injuries all may make the diagnosis or exclusion of an intra-abdominal injury difficult.

Nor is the management of the patient with an intra-abdominal injury straightforward. Multiplicity of injury in one victim and superspecialization within surgery have raised new problems, and indeed introduced a new hazard to the patient—surgery by a committee with diverse views on priority in treatment and no unified control of resuscitation, diagnosis, and treatment.

Whatever the administrative view of final responsibility in an accident service the role of the abdominal surgeon will remain an important one. Abdominal surgery for trauma is urgent and life-saving, and the general surgeon's experience will contribute much to the comprehensive management of the injured patient.

It is with all these points in mind that this experience of closed abdominal injury is presented.

During the period under review, 1954-61, 23 cases of proved intra-abdominal injury have been admitted to this hospital; details of these cases are presented in Table I.

Road transport, sport, athletics, coal-mining, "play," and miscellaneous hazards at work have all contributed to the toll of the injured, with road accident clearly the most common single cause (Table II).

The liver has been the organ most commonly damaged, with the urinary bladder the next most common. Injury to a single viscus occurred in 18 patients, while damage to two or more viscera was present in five patients (Table III). Fig. 1 shows the summation of the visceral injuries in the 23 patients in this series.

Associated bony injury, regarded as within the province of the orthopaedic surgeon, has been present

in 12 patients (52.5 %), maxillo-facial injury in two cases, and rib fractures in two patients. Four patients had also suffered concussion.

TABLE II.—Cause of Intra-abdominal Injury

Road accident	11	Sport or athletics	2
Coal-mining	3	Miscellaneous work hazard ..	4
At play	3		

TABLE III.—*Injuries to Viscera (Total 23)*

Spleen alone	..	..	..	..	..	1
„ with liver	..	..	..	..	..	1
„ „ kidney	..	..	..	..	..	1
Liver alone	..	..	..	..	..	5
Stomach with testis	..	..	..	..	..	1
Small bowel alone	..	..	..	..	..	2
„ „ with mesentery and colon	..	..	..	..	..	1
„ „ „ „ bladder	..	..	..	..	..	1
Mesentery alone	..	..	..	..	..	1
Bladder alone	..	..	..	..	..	4
Colon alone	..	..	..	..	..	1
Haemoperitoneum—cause not disclosed	..	..	..	..	..	1
Kidney alone	..	..	..	..	..	2
Diaphragm alone	..	..	..	..	..	1

FIG. 1.—Summation of injuries.

TABLE 1.—*Details of Cases of Injury*

Case No.	Sex	Age	Viscus Injury	Mechanism of Injury	Associated Injuries	Treatment	Complications	Result
1	M	19	Spleen	Football	Kidney contusion	Splenectomy	—	Recovered
2	M	34	„ liver (L. lobe)	Car accident	Concussion	„ suture, drainage	—	„
3	M	9	Liver (R. lobe)	Falling masonry at play	Fracture radius, ulna	Suture of liver, drainage	Hepato-renal syndrome, subphrenic abscess	„
4	M	2	Undisclosed	Car accident	—	Laparotomy, removal of blood	Chest infection	„
5	M	49	Colon	„ „	Fracture tibia, concussion	R. hemicolectomy	—	„
6	M	27	Liver (R. lobe)	„ „	Fracture nose, rib	Suture of liver, drainage	—	„
7	M	50	Mesentery, small bowel, bladder	Mining accident	Fracture femur, ulna; concussion	Bowel resection, cystostomy, repair of bladder	Wound sepsis; incisional hernia	„
8	F	15	Kidney (R.)	Car accident	Concussion	R. nephrectomy	—	„
9	M	60	Bladder	Mining accident	Fracture pelvis	Cystostomy and repair	Urethral stricture. Bladder calculus	„
10	M	10	„	At play	„ „	„ „ „	—	„
11	M	36	„	Motorcycle accident	„ „	„ „ „	—	„
12	M	41	Small-bowel, mesentery	Car accident	Fracture femur, tibia, patella, maxilla	Repair of mesentery	Shock	Died
13	M	23	Liver (R. lobe), testis	Motorcycle accident	Fracture radius	Conservative	Tubular necrosis	Died
14	M	25	Diaphragm	Mining accident	—	Thoracotomy, repair of diaphragm	Massive collapse of lung	Recovered
15	M	19	Stomach, testis	Motorcycle accident	—	Suture of stomach, repair of testis	—	„
16	M	23	Liver (R. lobe)	„ „	Lumbar spine, kidney (left)	Suture of liver	Tubular necrosis—hypertension	„
17	M	51	Small bowel	Fall (carrying posts)	—	Repair of perforation, drainage	Wound sepsis	„
18	M	16	Kidney (R.)	Athletics (running)	—	Conservative	—	„
19	M	14	Spleen	Fall at play	Fracture rib	Splenectomy	—	„
20	M	65	Small bowel, mesentery, colon	„ from height	—	Exteriorization colon. Repair small bowel and mesentery	Peritonitis (pre-operation), paralytic ileus	Died
21	M	63	Small bowel	Tree-felling	Fracture pelvis	Repair of perforation	—	Recovered
22	M	63	Bladder	Car accident	„ femur, pelvis	Repair of tear. Cystostomy	Paralytic ileus, pulmonary embolism	Died
23	M	40	Liver (R. lobe)	Fall from height	Bilateral Colles fracture	Suture of liver, drainage	—	Recovered

Two cases of retroperitoneal haemorrhage and one case with haemorrhage around the ligamentum teres have also undergone laparotomy. Other cases with transient and minimal haematuria due to renal contusion treated conservatively are also not included in the table.

Problems of Diagnosis

Two questions immediately pose themselves to the surgeon faced with the case of possible intra-abdominal injury. What viscus injury is present, and is laparotomy essential? While slovenliness in abdominal diagnosis is to be deprecated and the importance of the first question is far from academic, it is the correct answer to the second which will save lives. The decision whether exploration of the abdomen is required should be made at the earliest possible time. This is particularly so where urgent treatment of other injuries—for example, orthopaedic—demands general anaesthesia. Clearly, anaesthesia may further compromise the making of an abdominal diagnosis, and it is also highly undesirable that a second anaesthetic should become necessary for the purposes of laparotomy within a matter of a few more hours. Except where such circumstances apply, it is not incumbent upon the abdominal surgeon to pronounce upon the integrity of the abdominal contents after his first examination. It is, however, his duty, except in cases where it is clear that no abdominal injury exists, to observe the course of events over the next few hours and where necessary amend an original provisional opinion in favour of laparotomy. It requires a vast experience or a degree of foolhardiness to pronounce in the negative upon the doubtfully injured abdomen and retire with finality from the scene.

The prognosis of intra-abdominal injury rests upon many circumstances, but, excluding the standards of resuscitation, anaesthesia, and surgery, finally depends upon two factors—multiplicity of injury, and time interval between accident and operation. In the case of injury to a hollow viscus many authors have shown that mortality is increased by each hour in delay in treatment, and Tschistosserdoff (1957) found that where operation was delayed beyond 24 hours "every patient perished." Clearly also where gross haemorrhage has occurred its early arrest is of paramount importance.

While the first of these factors is outside surgical control, correct priority in treatment of the injuries is essential; the second dictates that where operation is required it should be done with the minimum of delay. What, however, of the case where reasonable doubt exists or where immediate operation and anaesthesia for an associated injury deny the abdominal surgeon the opportunity of an unhindered period of observation?

Abdominal exploration should never become a substitute for careful physical examination, but where suspicion exists laparotomy is advisable. Probably in no other field is the adage "Better to look and see than wait and see" so apt, and in most cases justification will be found for this course of action. Modern laparotomy is attended by infinitesimal mortality. Its morbidity is also slight, and any incurred by an occasional needless laparotomy must surely be more than offset by the serious mistake of failed diagnosis, and, as Gordon-Taylor (1957) has stated, the grave consequences of leaving unoperated an abdominal casualty requiring surgery.

Evaluation of Physical Signs

As the early clinical picture of intra-abdominal injury is produced by peritoneal irritation by gastro-intestinal fluid, blood, bile, or urine or by systemic evidence of bleeding, or both, it would seem that diagnosis should rarely be difficult. In cases of hollow viscus injury where generalized peritoneal contamination has occurred no great difficulty should be experienced in making a

diagnosis. Pain, rigidity, and tenderness are such that no reasonable doubt can exist that perforation of a hollow viscus has occurred. In others the picture is dominated by the unmistakable signs of shock from blood loss, and even without arresting signs in the abdomen the diagnosis of intra-abdominal haemorrhage is clear.

In many cases, however, a definite diagnosis of intra-abdominal injury is less easily made. Where localized leakage has occurred—for example, into the lesser sac or with retroperitoneal rupture of the second part of duodenum—tenderness and guarding may well be very localized and not striking. Normal bowel sounds may also be audible. Confusion may also easily arise with the picture of retroperitoneal haemorrhage where the patient may complain of severe abdominal pain and marked abdominal tenderness, and guarding with very faint or absent bowel sounds may be found on examination.

In few cases can one demonstrate all or even a few of the classical signs of closed intra-abdominal injury. It is proposed to comment upon a personal experience of some of these.

Pulse Rate and Blood-pressure

A normal or slow pulse rate and normal blood-pressure readings in surgery are notorious in their misleading quality. Ample confirmation of this has been available in this series. Of particular danger in this respect is the slow pulse which may accompany liver rupture, described by Grey Turner and Rogers (1943). Case 3 is a typical example of this: a boy of 9 years who after extensive liver rupture with 2 pints (1,140 ml.) of blood in the peritoneal cavity had a pulse rate below 70 within the first two hours in hospital. While a rising pulse rate may be of diagnostic aid, a single or even several low recordings mean nothing and must not lull the inexperienced into a false sense of security.

Bowel Sounds

The value of auscultation of the abdomen as a diagnostic aid in abdominal injury was first stressed by Rob (1957). Often repeated auscultation and assessment of the patient's general condition are, however, essential in the interpretation of bowel-sound findings. Their continued absence, confirmed several times, is highly suggestive of intraperitoneal disorder, and in the opinion of Gordon-Taylor (1957) is an indication for laparotomy. Bowel sounds are, however, frequently absent during periods of hypotension (this has been personally confirmed in patients with severe gastro-duodenal haemorrhage as well as major orthopaedic injuries) and also in many cases of retroperitoneal haemorrhage. Two cases of the latter with severe abdominal pain, convincing diffuse tenderness, and resistance throughout the abdomen and with bowel sounds absent have been subjected to laparotomy. No intraperitoneal lesion was present in either case. Even if their absence constitutes an indication for laparotomy the converse is certainly not true. Peristalsis is probably absent only when the activity of all the intestine is paralysed by general soiling. Where only local peritoneal soiling has taken place, as occurred in Case 15, bowel sounds may well persist. Little comfort can be gained from their presence except where all other signs also suggest that the abdominal contents are undamaged. Their presence is certainly no guarantee against visceral perforation and not a positive indication for conservative management.

In intraperitoneal haemorrhage bowel sounds may be absent or present throughout, present initially only to disappear, or absent initially later to reappear. In most cases in this series of patients with haemoperitoneum, bowel sounds have been absent throughout, but in three cases they have remained normal. In one case of combined liver and spleen rupture with 4 pints (2.3 litres) of blood in the peritoneal cavity (Case 2) bowel sounds were initially absent but reappeared. Interestingly they were first heard to reappear on auscultation of the lung bases. It would seem that while their continued absence in a case of suspected intraperitoneal bleeding may be supportive evidence of haemorrhage, their presence in no way precludes the possibility of severe intraperitoneal bleeding.

At the most, absence or presence of bowel sounds in suspected abdominal trauma can provide additional evidence; their presence or absence *per se* would appear to be of no diagnostic value.

Radiographic Signs

While radiography may be theoretically helpful in demonstrating free intraperitoneal air in injury involving a hollow viscus, orthopaedic injury commonly precludes the taking of upright films, and lateral films are commonly unsatisfactory. No free air was demonstrated in the three cases in this series of viscus perforation in which this investigation was carried out. In the diagnosis of solid viscus rupture it has been repeatedly stated that radiography may be helpful in that rib fracture may be demonstrated. It would seem, however, to be of no value; although rib fracture may be shown (of eight cases of solid viscus rupture only two cases in fact had a rib injury) this finding can neither support nor oppose a diagnosis of solid viscus rupture. Radiography is, however, of the greatest assistance in the diagnosis of traumatic diaphragmatic hernia (Figs. 2, 3, 4, and 5).

Flank Dullness and Classical Signs Associated with Splenic Rupture

Pain in the left shoulder (Kehr's sign) is stated to be the most constant sign of ruptured spleen, and, in the opinion of Tagart (1956), if absent the diagnosis should be suspect. Only one of the three cases of ruptured spleen in this series demonstrated this sign and in neither of the cases in which the test was negative was it possible to produce the sign with abdominal pressure. A "right-sided Kehr's" sign was, however, present in one case of ruptured spleen, and Kehr's sign was decidedly positive in a case of ruptured right kidney in which no associated intraperitoneal lesion was present. The phrenic point test of Saegesser was negative in all three cases of ruptured spleen and would seem to be of little diagnostic aid.

While flank dullness on one or both sides has been present in most of the cases of haemoperitoneum I have failed to demonstrate Ballance's test—fixed dullness in the left flank with shifting dullness in the right flank—in all the cases of splenic rupture. One case of intraperitoneal bleeding in which the sign was convincingly positive was found at laparotomy to have widespread free blood and clot in the peritoneum from a rupture of the liver; the spleen was intact and normal. The sign has proved valueless.

Although flank dullness has been of assistance in determining the presence of blood in the peritoneal

cavity the test has not been helpful in deciding the site of solid viscus injury. Associated bony injuries have also on occasion made the demonstration of shifting dullness impracticable.

Abdominal Tenderness and Resistance

Tenderness over the area of liver or spleen with some degree of abdominal resistance was constantly present in rupture of these viscera and would seem the most useful abdominal sign of their injury.

FIG. 2.—Traumatic rupture of left diaphragm—a large gastric air bubble within the chest.

FIG. 3.—Traumatic rupture of left diaphragm: collapse of left lung with air and fluid within left side of chest.

Apart from these findings, with increasing experience, more can usually be learned from a single look at the patient's face—its pallor and his demeanour—than by prolonged search for physical signs. Certainly in few cases can one demonstrate many of the signs of intra-abdominal injury, and it seems that little is to be gained from prolonged efforts to elicit them. More important, their absence must not distract the emergency surgeon from the comprehensive picture.

Pathological and Operative Findings

It is proposed now to describe the pathological and operative findings and elaborate on certain instructive and interesting cases.

Liver

Closed injury to the liver occurred in six cases. In only one case was an associated injury—rupture of the

FIG. 4.—Traumatic rupture of left diaphragm. Barium meal with patient in Trendelenburg position showing stomach within left side of chest.

FIG. 5.—Traumatic rupture of left diaphragm. Barium meal (lateral view) showing grossly distended stomach within left side of chest.

spleen—present within the abdomen. In five cases the right lobe of the liver was involved and in one the left lobe. Gross intraperitoneal haemorrhage occurred in four cases; in two, only moderate bleeding had taken place, but one of these cases was associated with profuse bile leakage from the liver into the general peritoneal cavity.

Spleen

Splenic rupture occurred in three cases, one in association with a tear of the liver. An associated left renal lesion was present in two cases, but in neither was surgical treatment to the kidney also required.

Gastro-intestinal Tract

Stomach

One case of closed rupture of the stomach occurred in association with open rupture of a testicle. At laparotomy a linear tear 2.5 cm. in length was present on the posterior surface of the stomach in the pyloric antrum. The tear lay across the long axis of the stomach; gastric mucosa pouted through the perforation, temporarily sealing the rupture, which was recognized at operation by the fortunate observation of moving air bubbles through the gastro-hepatic omentum. The stomach was not the seat of disease.

Small Bowel

Closed rupture of small bowel occurred in four cases.

Case 7.—A 50-year-old miner received a severe crush injury to the back, head, abdomen, arms, and legs by a fall of coal. He was admitted to hospital unconscious with a head injury, fractures of femoral shaft and ulna, and signs of abdominal hollow and solid viscus injury. Laparotomy findings were a gross haemoperitoneum from a 25-cm. transverse tear of mesentery of jejunum close to its mesenteric border, multiple linear ruptures of mid-small bowel, and extraperitoneal rupture of the bladder.

The multiplicity of injury and the unusual involvement of the free middle segment of small bowel are of considerable interest.

Case 17.—A 51-year-old farm worker stumbled while carrying wooden fence posts and struck his abdomen on the ground. He was wearing a spring truss for a left inguinal hernia of long standing. He immediately complained of severe lower abdominal pain, and at laparotomy three hours later was found to have a linear perforation of distal ileum on its antimesenteric border.

This case is a further example of the strange relationship described by Aird (1937, 1957) of inguinal hernia and closed injury of bowel. The hernia in this case was, however, unusual in being left-sided.

Colon

Case 5.—A male pedestrian aged 49 was knocked over by a car and sustained concussion and fracture of a tibial shaft. Wound toilet and reduction of the fracture were carried out. Twenty-four hours after the injury, having recovered from concussion, alcoholic stupor, and anaesthesia, he first complained of abdominal pain, and was found to be surprisingly ill, pyrexial, and rigid and tender over the right side of the abdomen. At laparotomy soon thereafter the entire right side of the colon from caecum to the middle of the transverse colon was gangrenous, with thrombosis of the right colonic arterial arcades.

With no previous history the conclusion drawn that the thrombosis was traumatic and gangrene the result of this seems reasonable.

Case 20.—A farm worker aged 65 fell from a loft and complained immediately of generalized abdominal pain. He

was admitted to hospital three days later, gravely ill, with signs of generalized peritonitis. At operation he was found to have generalized peritonitis with perforation of small bowel, a tear of small-bowel mesentery, and gangrene of the middle third of the transverse colon.

While delayed small-bowel rupture and gangrene of small bowel have been recognized to occur after abdominal trauma, to my knowledge no case of gangrene of large bowel due to trauma has previously been reported.

Genito-urinary Tract

Kidney

Case 8.—A girl of 15 was admitted to hospital, having been involved as a passenger in a car crash. She complained of severe pain over the right iliac crest and in the lower abdomen. Tenderness was present over the iliac crest on the right side, but there were no abdominal signs of viscous injury. The pulse rate was 100 but her general condition was good. A period of observation was decided upon, but during the two hours following her admission her pulse rate rose to 136 and other signs of shock appeared. She also developed left shoulder-tip pain and had gross haematuria. Marked tenderness was then present in the right loin; the abdomen remained normal on examination. On exploration the right kidney was found to be grossly ruptured and bleeding profusely. Nephrectomy was carried out. A small entry was also made into the peritoneum but no abnormality was present therein. The case is of interest in several respects. Until haematuria presented no suspicion had been cast upon the urinary tract; the contralateral shoulder-tip pain remains unexplained. Ruptured kidney is also a most uncommon injury in females.

Case 16.—A man of 23 was admitted to hospital after a motor-cycle accident with very severe backache and abdominal pain. He was severely shocked, with signs of probable liver rupture, and also had gross haematuria. Fracture dislocation of the fifth lumbar vertebra was present. Laparotomy was carried out, the liver sutured, and his haematuria treated expectantly. During a stormy convalescence acute renal tubular necrosis ensued. Hypertension, persisting for four weeks, was also present.

The transient hypertension is of interest. Braasch and Strom (1943) reported one case in which hypertension—apparently post-traumatic—occurred in a case of renal injury treated expectantly, and McCague (1950) recorded a similar case where hypertension was improved by late nephrectomy.

Bladder

Rupture of the bladder occurred in five cases; in four of these an associated fracture of the pelvis was present. In three cases the rupture had occurred intraperitoneally—an uncommon occurrence in closed bladder injury in civilian life.

Haemoperitoneum of Undisclosed Origin

Case 4.—A boy of 2 years, passenger in the front of a car, was thrown by deceleration against the dashboard. When his admission to hospital was requested the general practitioner was of the opinion that it was unlikely that the child would survive the short journey. On admission he was exsanguinated and unconscious from anoxia. No external injury was present and no abnormal physical signs were found on examination of the abdomen. It was clear, however, that only abdominal haemorrhage could explain the clinical picture; he was infused with dextran and received 350 ml. of blood. At laparotomy a haemoperitoneum of 500 ml. (approximately one-half of his circulating blood volume) was found, but bleeding had ceased and no source of blood loss could be discovered.

Diaphragm

One case of traumatic diaphragmatic hernia was encountered.

Case 14.—A miner aged 25 received a crush injury to the right upper abdomen at work. He complained of severe pain in the left hypochondrium, quickly became dyspnoeic, and was stated to have been slightly cyanosed. A few hours later, when admitted to hospital, respiration and colour had returned to normal. Tenderness was present in the left hypochondrium. Bowel sounds were present in the abdomen and none were audible in the chest. X-ray examination of the chest showed what appeared to be a raised left diaphragm with a large gastric air bubble below it (Fig. 2). Eventration of the diaphragm was initially suspected. A repeat x-ray film of chest next day showed the left lung collapsed, and, although the radiological picture was indistinguishable from hydropneumothorax or haemopneumothorax (Fig. 3), a barium meal showed quite clearly a traumatic diaphragmatic hernia with the stomach in the left side of the chest (Figs. 4 and 5).

Treatment and Complications

Liver

Although a conservative management of liver rupture has been advocated and may well be satisfactory in many cases where bleeding is not catastrophic and this is the only injury, the difficulty of excluding splenic or other visceral injury commonly necessitates laparotomy. Operation has in fact been carried out in all but one case of liver injury in this series. Except in one case where profuse bile leakage had occurred, a large quantity of blood was found in the peritoneal cavity, and blood loss was still continuing. In no case, however, has the serious flooding type of bleeding reported to occur on reducing intra-abdominal pressure by opening the peritoneum been encountered. Many methods of liver suture have been advised, some with the use of special needles. In this series no attempt has been made to deal with individual bleeding vessels. Satisfactory haemostasis has been secured by repairing the tear with a minimum of sutures of thick chromic catgut, taking deep bites of liver using a large round-bodied needle with strips of absorbable gelatin sponge sandwiched between the cut edges and the suture knots tied over similar strips of sponge on the liver surface. Drainage of the area is, however, required, as continued bile leakage is often substantial for a few days. In one case, despite drainage, a right posterior subphrenic abscess occurred; this same patient developed severe haematemesis and melaena on the tenth and eleventh days after injury, the bleeding being presumed to be due to haemobilia from secondary haemorrhage into bile ducts.

Spleen

Splenectomy was carried out in the three cases of splenic rupture. No attempt was made to ligate splenic artery and vein separately. No difficulty of access has been found through a right paramedian incision, and operation and convalescence have been without incident or complication in all three cases.

Gastro-intestinal Tract

Stomach.—The rupture of the stomach was treated by simple suture and drainage of the lesser sac.

Small Bowel.—In three of the four cases of small-bowel rupture suture of the perforation was carried out, while double resection of the bowel was necessary in the other case. Wound sepsis followed one repair

and strangulation of small bowel in another. Incisional hernia also later developed in the patient whose wound discharged pus.

Colon.—Primary right hemicolectomy with end-to-end anastomosis was performed in the case of gangrene of the right colon. Only exteriorization of the gangrenous colonic segment was possible, on account of the patient's extremely poor condition, in the case where localized colonic gangrene had occurred in association with small-bowel injury.

Diaphragm

Thoracotomy was carried out in the case of traumatic diaphragmatic hernia, the stomach replaced in the abdomen, and the diaphragm defect, which lay close to the hiatus, repaired with floss nylon sutures. Massive collapse of lung followed this procedure. The subsequent course after decortication was satisfactory and post-operative barium-meal study showed no abnormality.

Urinary Tract

Kidney.—Uneventful nephrectomy was carried out in one patient while two cases were treated expectantly. In one of the latter cases temporary hypertension occurred.

Bladder.—Closure of the bladder tear with drainage by cystostomy or urethral catheter was carried out in all cases of bladder rupture. In three cases no complication followed. In one patient fatal pulmonary embolism occurred, while urethral stricture and a bladder calculus developed as late complications in another.

Haemoperitoneum of Undisclosed Origin

The abdomen was emptied of blood and after a fruitless search for the source of blood loss the abdomen was closed without drainage. During the post-operative period there was no evidence that further bleeding had occurred; convalescence was uneventful apart from a post-operative chest infection, and the patient's development since has been normal.

Three cases during the period under review have undergone needless laparotomy. In two cases an extensive retroperitoneal haemorrhage was found in association with injury to the lumbar spine and fracture dislocation of the sacro-iliac joint respectively, while in the remaining case only haemorrhage around the ligamentum teres was present, there being no free blood in the peritoneal cavity.

With increasing experience the number of cases in which needless laparotomy is performed may diminish, but where clinical doubt exists there need be no occasion for regret in connexion with these cases. Neither mortality nor morbidity has resulted in this series, while failure to operate where operation is necessary is known to have dire consequences.

Deaths

Four deaths have occurred in this series of cases—two immediate, after operation, and two delayed. One patient died from pulmonary embolism after a convalescence from surgical treatment of bladder rupture and fractured femur initially complicated by paralytic ileus. The second delayed death was due to tubular necrosis in a case of liver rupture and closed testicular injury treated conservatively. Of the deaths classified as immediate one was due to peritonitis in a

patient admitted to hospital three days after abdominal injury with generalized peritonitis present. He survived operation but died next day. The other early death occurred in a patient with multiple injuries including extensive multiple tears of small-bowel mesentery, simple fractures of the upper third of femur and tibia, compound fracture of the patella of the other leg, and "middle third" fracture of the maxilla. Virtual exchange transfusion was carried out, but, despite this treatment of shock and the satisfactory control of fractures and arrest of abdominal bleeding, he failed to maintain his initial post-operative improvement and died suddenly 12 hours after operation.

Discussion on Treatment

With clear evidence of visceral injury laparotomy is essential; where reasonable doubt of visceral injury is present it is advisable. The timing of abdominal operation, however, requires a nicety of judgment and commonly the closest of co-operation between general and orthopaedic surgeons. While early fixation of major fractures is of course desirable, the early arrest of intra-peritoneal bleeding or treatment of a perforated hollow viscus will almost always demand priority. In cases with intra-abdominal bleeding massive transfusion may be required before and during operation, which should, however, be delayed only until such time as the patient is fit for the operating-theatre. Where splenic rupture can be confidently diagnosed a left paramedian incision would seem most suitable, but the right paramedian wound is the best all-purpose incision and provides satisfactory access to all areas of the abdomen. Traumatic abdominal surgery requires composure and speed but is in itself not unduly difficult. Even with the abdominal cavity open, however, mistakes are all too easy to make. Where the expected lesion is not evident the lesser sac must be explored and the retroperitoneal duodenum examined. Even where injury to one viscus is apparent the whole abdominal cavity requires examination as multiplicity of injury is not uncommon. Even multiplicity of injury to bowel, mesentery, and solid viscus does not absolve the surgeon from excluding injury, both intraperitoneally and extraperitoneally, to the bladder.

Summary

Twenty-three cases of proved intra-abdominal injury admitted to a general surgical unit have been treated, with four deaths. Road accidents were the cause in eleven cases (48%).

The importance of the role of the general surgeon in an accident unit is stressed.

The problems of diagnosis are discussed and the physical signs evaluated.

The pathological and operative findings are detailed and certain instructive and interesting cases presented.

The treatment of the injuries in the series is described and the complications and deaths are detailed.

A general policy of treatment is presented.

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TRIAMTERENE, A NEW DIURETIC DRUG

I. STUDIES IN NORMAL MEN AND IN ADRENALECTOMIZED RATS

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Triamterene (2,4,7-triamino-6-phenylpteridine) represents a new type of diuretic drug. It has been shown to have a diuretic effect in normal subjects (Hild and Krueck, 1961; Laragh *et al.*, 1961; Crosley *et al.*, 1962), producing increased excretion of sodium and water but a decrease in potassium excretion. This effect was at first attributed mainly to aldosterone antagonism (Crosley *et al.*, 1961; Wiebelhaus *et al.*, 1961). Hild and Krueck (1961) suggested that, in addition to aldosterone antagonism, triamterene probably had an independent direct effect on the kidneys.

We have studied the effect of triamterene in normal subjects and in adrenalectomized rats. Our results suggest that the natriuresis and potassium retention are due to direct action on renal tubular cells.

Studies in Normal Men

The observations were made on eight healthy men aged 26-44 years. During the studies the subjects carried out their normal hospital and laboratory duties and a normal diet was taken. When a high salt intake was required 12 g. of sodium chloride daily was added to the normal diet.

The following substances were taken by mouth during the experiments: triamterene (as capsules), hydroflumethiazide and fludrocortisone acetate (both as tablets). The dosage regime is indicated below.

Urine was collected at two-hourly intervals for ten hours during the period 8 a.m. to 6 p.m., after giving the drug at 8 a.m. At least two days were allowed to elapse before a further dose was given. Similar collections were also made on other days when no drugs were given.

Studies in Adrenalectomized Rats

Male albino rats weighing initially 250-300 g. were used. Adrenalectomy was performed under ether anaesthesia, and the rats were kept in a controlled-temperature room (25° C.). They were given a constant diet of commercial rat cake and were allowed to drink 1% sodium chloride solution freely. All experiments were performed at least two weeks after adrenalectomy.

The rats were studied in groups of three in each metabolism cage, and the urine collection from each group was pooled. At the beginning of each experiment the bladder was emptied by gentle suprapubic pressure. An intragastric tube was passed and the required dose of triamterene or spironolactone suspended in 4 ml. of water was introduced into the stomach. Control groups of rats received 4 ml. of water by the same route. Urine collections were made from each group of rats for five hours and then the bladders were emptied again.

Chemical Procedures

The concentrations of sodium and potassium in all urine samples were determined by flame photometer. Chloride was estimated by potentiometric titration with silver nitrate (Sanderson, 1952) and bicarbonate by a microdiffusion method (Conway, 1950). Titratable acidity and pH of urine were measured by a Marconi pH meter.

Measurement of triamterene in urine samples was carried out by fluorimetry, using the Hilger H 730 fluorescent attachment in conjunction with Hilger H 700 Uvispek spectrophotometer. The highest concentration of triamterene that could be measured by the fluorimeter was 0.1 µg./ml. A stock solution of 400 µg./ml. of triamterene was prepared in 98% formic acid. From this, two series of seven dilutions of triamterene ranging from 0.1 µg./ml. to 0.005 µg./ml. were made, the first series by diluting with water and the second series by diluting with water containing 1:2,000 parts normal urine. The concentration of triamterene was plotted against the percentage transmission scale reading of the spectrophotometer, and two parallel straight lines were obtained, the dilutions containing urine giving consistently slightly higher readings. In preparation of urine samples for fluorimetry, 0.1 ml. of urine was made up to 200 ml. with 0.02% formic acid. A blank was prepared from urine passed by the same subject just before triamterene had been given. As a reference standard, triamterene solution 0.1 µg./ml. was used. The spectrophotometer scale was set to 100% transmission with the reference standard, and the blank and the unknown solutions were measured. After subtracting the reading of the blank, which was always less than 3%, the concentration of triamterene in the urine was determined from the calibration curve. To check the reproducibility of the method, the same urine sample was estimated twelve times and the coefficient of variation was 1%.

Results in Normal Men

Response to Increasing Doses of Triamterene

The effect of triamterene in doses of 50-300 mg. was studied in four subjects while on an ordinary diet. All the doses used increased sodium excretion and produced considerable decrease in potassium excretion. The effect of the oral dose was apparent in the first two hours and the maximal effect occurred after four to six hours. In