UNDERWATER BLAST INJURIES OF THE ABDOMEN*

BY

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In modern sea warfare abdominal injuries caused by underwater blast are common, and increasing numbers of cases are now being reported. As the mechanism underlying the injuries is still uncertain, and the mortality in cases with intestinal perforations coming to operation in the series reported by Pinnock and Wood (1943), Goligher, King, and Simmons (1943), Gill and Hay (1943), and Cameron, Short, and Wakeley (1943) has varied from 100% to 50%, it is important to study all cases available. I should like, therefore, to give my experiences of the condition, and the opinions which I have formed about it, based on the personal treatment of 18 patients, nine of whom were subjected to operation, and the interrogation and examination of 22 others who were under my care after operation elsewhere, two of whom required late operations for intraperitoneal abscesses—one subphrenic and one in the right iliac fossa.

The wave of positive pressure may be caused by depth charges, already primed, which go off when a sinking vessel submerges to the required depth; or by bomb, mine, or torpedo blast directed at other ships in the vicinity; or by depth charges dropped by neighbouring ships at an offending submarine. The blast in water differs from that in air, physically in that there is no after-wave of negative pressure, and clinically in that the abdomen is more affected than the thoracic cavity. Probably the fact that the chest is usually partly out of the water and protected by a life-jacket of the "Mae West" type accounts for the latter difference. It is interesting to hear described the actual sensations experienced by the victims. All feel the shock of the explosion on the abdomen. Many describe it as "like a severe kick," others as "a vice-like tightening around the abdomen," others as "if the abdominal contents were being forced up through the body into the head," and others as "if a giant hand were squeezing me from the waist downwards." Many have the sensation of their legs being shot away, and several have actual temporary paraplegia. None of my patients has described pain in the testes noted by other writers. The abdominal pain usually abates, and most patients manage to swim. Frequently no abdominal pain is noticed until they are picked up by another vessel, when they find that they cannot straighten themselves or walk because of it. One of my patients actually had a shower and a meal before he felt any abdominal pain. It is not uncommon after rescue for an urgent desire to defaecate to occur and a blood-containing stool to be passed. Only one of my patients complained of any difficulty in micturition. Vomiting is a very common symptom, and is often erroneously attributed to the swallowing of oil-contaminated sea-water. Three of my patients complained of chest pain, but none had haemoptysis. In no case was there any injury to the parietes.

Clinical Condition

These cases have been subjected to a generalized severe disruptive abdominal blow, which affects all the abdominal contents, including blood vessels and nerves. Many die at once, or in a very short time, from shock and haemorrhage. The clinical picture in those that survive to be picked up varies according to the time interval after the injury at which they are seen and the extent of the internal injuries. Although they can be very ill without perforations having occurred, in general the more severe the injuries, particularly if intestinal perforations are present, the more severe the abdominal pain and vomiting and the more severe the shock. When seen in the later stages the shock has disappeared and the condition is one of spreading peritonitis. The first essential of diagnosis, no matter at what stage the patient is seen, is to decide if intestinal per-

foration has occurred or not. Many have written on the excellence of the general condition in some of these cases although perforations have been present, and they have been misled into postponing operation so late that death has followed.

While all aspects of the case, both general and local, must be taken into account in coming to a decision, I believe that it is the local signs to which the greatest attention must be paid. Abdominal tenderness, rigidity, and the absence of peristaltic sounds, and diminution in liver dullness, must all be taken into account. The most important are tenderness and rigidity. In the early cases the latter is of the typical board-like variety. In the later cases—and the cases are usually late owing to the distances they have to be transported to hospital—the rigidity is more muscle resistance associated with some abdominal distension. Skill in abdominal diagnosis is bred of long experience, and each must learn to assess the relative value of clinical findings and come to a definite decision. In these cases it is essential for the safety of the patient to decide early whether an intestinal perforation is present or not. It may be simulated by intraperitoneal haemorrhage and by injury to the lungs. One sign can no more make a diagnosis than one swallow can make a summer. There is one sign, however, on which I personally place the greatest reliance. Abdominal examination is carried out extremely gently with the flat hand. The abdomen is generally examined for rigidity both in inspiration and in expiration. If the rigidity is caused by peritonitis due to perforation it does not relax during expiration. I have never known this sign to fail. Some of these cases have blast injury to the lungs, which may have accentuated the abdominal pain and rigidity. The actual local signs of this injury are extremely slight, and consist of an increased respiratory rate, diminution of the percussion note, diminished air entry, and rales in the affected part of the lungs. When no perforation has occurred the abdominal pain disappears in a day or two without any further symptoms. However, sometimes intestinal haemorrhages arise, and are manifested by haematemesis or melaena. Cases have also been reported in which perforations of the intestine have occurred after seven days—no doubt due to infection of an intestinal haematoma, with late perforation.

Pathological Lesions

Haemorrhages.—A common finding in these cases is subperitoneal haemorrhages. In my experience these are of three types—viz.: (1) Scattered pin-point haemorrhages beneath the peritoneum covering the bowel, usually parts of the terminal ileum, and pelvic colon. (2) Peculiar linear subperitoneal haemorrhages arranged in transverse rings around parts of the terminal ileum. (3) More massive subperitoneal haemorrhages of irregular shape on various parts of the bowel, but particularly over the ascending colon and in the subperitoneal tissues lateral to it. I have also seen small petechial haemorrhages in the mesentery of the terminal ileum.

Perforations.—Perforations have been found in my cases in a loop of the terminal ileum 6 in. to 12 in. long, and about 2 ft. to 3 ft. from the ileo-caecal valve—in the apex of the loop of the pelvic colon—and in the ascending colon just below the hepatic flexure. In size the perforations have varied from a pin-point to 3 cm. in diameter. They may occur on the antemesenteric border of the bowel or on one of the lateral walls. Some have been situated just at the attachment of the mesentery to the bowel. In some cases the perforation has been an oblique slit in the bowel wall near the mesenteric attachment, and has been found only on careful examination. Frequently only one perforation is present, but one of my patients had three perforations in the ileum and two in the pelvic colon.

Personal Cases: Post-mortem Findings.—In addition to findings noted at operation, at necropsy submucous haemorrhages have also been found, particularly in the lower ileum. In one case there were two curious herniations of the mucosa of the colon through the circular muscle just below the splenic flexure and in the pelvic colon. In both sites there was marked haemorrhage in the wall of the bowel. Some interstitial haemorrhage into the free anterior margin of the liver was found in one case. In one fatal case almost the whole of the right lung was the site of massive interstitial haemorrhage, and to the naked eye looked very much like liver. Micro-

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scopical examination of the intestine has shown submucous haemorrhages with rupture of the muscular coat in parts. Examination of the affected part of the lung has shown the typical appearances of blast-lung.

Additional Pathological Findings Reported by Others.—Perforations of the duodenum, caecum, and transverse colon have occurred. Sometimes tears of the mucosa of parts of the bowel have been observed. Some writers have noted haemorrhages below the tunica albuginea of the testes in fatal cases. Similar lesions have also been produced experimentally in animals.

Mechanism of the Lesion

It is interesting to note that it is only gas-containing abdominal viscera which are markedly affected, and it has been suggested that it is the liberation of kinetic energy by the pressure wave at surfaces where two different media join which is the cause of the injury. There is some experimental evidence to suggest that the wearing of an absorbent protective over the abdomen will lessen the injury. From my cases the effective distance from the explosion appears to be anything up to 200 yards. Patients facing the explosion are usually more severely injured than those with their backs to it. Although the best safeguard against injury is distance, the safest position appears to be floating on the back. I have never seen a person who was floating on his back at the time of explosion who has sustained any severe intra-abdominal injury. Two patients whom I have treated were in the water together; one was floating on his back, but the other was unable to do so because of some difficulty with his life-jacket. The former was uninjured, and the latter sustained a perforation of the ileum.

Treatment

Treatment is carried out on orthodox lines. Rest, warmth, and morphine are essential. If much shock is present intravenous infusions may be used, but they are better avoided because of the possibility of associated lung damage. If they are essential, blood or plasma is the safest. Where marked chest lesions are present oxygen should be administered by the B.L.B. mask. When perforation is not thought to be present the case is carefully observed until recovery is complete. It is most important, because of the danger of late perforation, to keep the patient under observation for at least ten days. If a perforation is diagnosed operation must be undertaken as soon as the patient is fit for surgery. In late cases, although the shock has been recovered from, I always use a continuous intravenous drip of saline and glucose given at a slow rate, so that fluid by mouth can be very limited after operation, and a solution of sulphapyridine can be conveniently given by it. The anaesthetic is of importance. Owing to associated chest lesions ether is contraindicated. Spinal analgesia, skilfully used, is suitable for these cases if shock has been overcome. I have also found intravenous pentothal, combined with local block to give relaxation, very useful in these cases. The abdomen is opened by a right paramedian or midline incision. The intestine is carefully examined for perforations, and those found are carefully sutured and oversewn. All blood and intestinal contents, and inflammatory exudates, are sucked out of the peritoneal cavity. In the absence of sulphadiazine, or other more suitable sulphonamide preparation, I have usually gently swabbed the peritoneal cavity with a weak solution—about 1%—of sodium sulphapyridine. The wound is closed, with drainage of the peritoneal cavity. When the colon is involved I have performed suture in the ordinary way with success. On one occasion when there was a large irregular sloughy perforation in the ascending colon I performed exteriorization. Though it was successful I have the feeling that it was unnecessary and that it would probably have been safe to perform simple suture. In late cases such as I have treated it is essential, after operation, to have continued gastric aspiration through an inlying Ryle's tube and fluid intravenously by drip. This method, the greatest advance in surgical treatment in the last thirty years, is a great life-saver. It is amazing how long patients can go with this artificial existence, with large quantities of fluid being withdrawn from the bowel daily, and make an excellent recovery. Combined with the intravenous glucose-saline, I always give 4 to 5 g. of soluble sulphapyridine daily for 4 to 5 days.

Personal Cases

Eighteen cases have been treated, of which 5 were admitted to hospital 20 hours after the injury and the remainder 16 hours after. Two estimated that they were respectively 500 to 700 yards away from the explosion, and one that he was 200 yards away; two were 100 yards distant, and the remainder from 5 to 50 yards. Neither of the first two had any symptoms, and one who was 100 yards away but floating on his back escaped injury entirely. The other 15 all had symptoms of varying degrees of severity. The one who was 200 yards away had melaena only for a few days. Five patients had some abdominal pain and vomiting on admission, but recovered with conservative treatment. One of these collapsed suddenly on the night of admission, and was thought to have had an internal haemorrhage. He recovered with conservative treatment, and passed a melaenic stool two days later and had melaena for a few days. No later complications occurred among these cases, and all made a complete recovery. Nine cases were submitted to operation. Eight of these were thought pre-operatively to have perforations. The other was believed to have a perforation with local peritonitis, or a large sub-peritoneal haematoma. It was thought safer to operate. At operation perforations were found in all eight cases. Four had solitary ileal perforations only, one had three ileal perforations, one had two ileal perforations and a perforation of the pelvic colon, one had two ileal perforations and two in the pelvic colon, and one had a perforation of the ascending colon just below the hepatic flexure. Suture was performed, in all cases with drainage of the peritoneal cavity, except in those with a single ileal perforation, when the wound alone was drained. In the case of rupture of the ascending colon the bowel was exteriorized; as the transverse colon was full of hard faeces it was thought that there might be abnormal tension on the sutured bowel. In the ninth case a large sub-peritoneal ecchymosis was found covering most of the ascending colon and the peritoneum lateral to it. Appendicectomy was performed and the wound closed.

Anaesthetic.—Spinal analgesia with heavy percaine was used on three occasions and light percaine on one occasion. Pentothal, local nerve-block, nitrous oxide and oxygen, in combination, were used on each of the other five cases.

Results.—Two deaths occurred. One of these cases had two perforations of the ileum and a large 2-cm. perforation of the pelvic colon with diffuse peritonitis. At necropsy a severe degree of blast-lung was found. The other death occurred, just as operation was about to be started, in a short-necked emphysematous patient. A spinal analgesic had unfortunately been administered by the Etherington-Wilson technique. It was undoubtedly the cause of death. At necropsy he was found to have a large perforation in the ileum and a minor degree of blast-lung. In my series there is thus a mortality of 22% among operative cases.

Post-operative Complications.—Apart from peritonitis, from which all the patients were suffering, three were much troubled by a widespread purulent bronchitis, but made satisfactory recoveries. The patients with the perforation of the ascending colon developed acute small-bowel intestinal obstruction two months after operation. At the second operation a fibrous band beneath which a loop of the jejunum was tightly constricted was divided. To make subsequent closure of the colostomy safer a transverse ileo-colostomy was performed at the same time. No other complications have occurred in my cases. Two cases previously treated elsewhere for perforations of the bowel were operated upon successfully by me: one two months later for an intraperitoneal abscess in the right iliac fossa, and the other three months later for a right posterior subphrenic abscess.

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