LONDON SATURDAY OCTOBER 21 1944

PLASMA VOLUME IN TRAUMATIC SHOCK

BY

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The estimation of plasma volume in patients with traumatic shock has been beset with difficulties. Most methods have depended upon the estimation of Evans's blue in plasma after the injection of a known quantity of the dye into the blood stream. In fasting subjects quite reliable results can be obtained by direct determination of the dye in plasma, but the turbidity of the plasma of non-fasting subjects, and especially of patients with traumatic shock, renders this method very unreliable. The technique described by Crooke and Morris (1942) has overcome this difficulty, but it has been found that a small amount of haemolysis which cannot always be avoided in shocked patients has led to considerable errors in the estimation. A method of correction for this has now been devised (Morris, 1944), but a further serious cause of error has been traced to the effect of morphine or hyoscine given to patients before the injection of Evans's blue (Bowler, Crooke, and Morris, 1944). These substances may cause anomalous dye concentration curves, thus making the determination of plasma volume impossible. Normal curves are obtained, however, when the dye is injected a sufficient time before the morphine or hyoscine to allow it to become uniformly mixed in the circulation. In the light of these observations a number of determinations of plasma volume in shocked patients can now be regarded as valid, although many of the earlier cases have had to be discarded.

The haemoglobin (pyridine-haemochromogen method, Rimington, 1942) and haematocrit were measured repeatedly in some of the cases and were found to run parallel. The determination of haemoglobin is more accurate than that of the haematocrit, and the latter has been omitted in more recent cases. Total blood volume cannot, therefore, be determined, but it gives little more information than plasma volume when the haemoglobin value is also known. Only the values of plasma volume and of haemoglobin will, for this reason, be recorded in this paper.

A few typical cases are described briefly. Some of the patients were admitted to the London Hospital, while others were seen in outlying hospitals.

Clinical Material

Case 1.—A man aged about 50 was run over by a heavy lorry at 10.30 p.m. He was admitted at 11.10 p.m., conscious but restless, and protesting against interference. His skin was cold, clammy, and cyanosed, and his blood pressure was 98/72 mm. Hg. He was found to have a badly crushed pelvis. The gluteal muscles were partly torn off and the left testicle was hanging out of the torn scrotum. The extent of internal injuries could not be ascertained, but the rectum appeared to be intact. There was also a cut over the right eye and blood in the left ear. He vomited beer-smelling fluid material. At 11.45 p.m. a determination of plasma volume was started, and a value of 1.75 l., or about 2.1% of body weight (about 13 st.), was obtained. His haemoglobin was 14.1 g./100 c.cm. At 11.55 p.m. he was given morphine gr. 1/4, and at 12 a.m. a

transfusion of plasma was begun. At 12.10 a.m. his blood pressure was found to be 58/38 mm. Hg and pulse rate 80. At 12.30 a.m. he was given morphine gr. 1/4, but he got steadily worse. At 1.10 a.m. his blood pressure had fallen to 43/30 mm. Hg and his haemoglobin to 11.9 g./100 c.cm. after a transfusion of about one bottle of plasma. He died at 2.15 a.m. He was found at necropsy to have extensive crushing injuries across the left groin and hip, with a 14-in.-long split from the groin through the perineum to the buttock. The left ilium was fractured, but no injury of internal organs was found.

Case 2.—A woman aged 36 was kicked in the abdomen by a horse at 3 p.m. She was admitted to hospital at 5.30 p.m. complaining of severe abdominal pain. Unfortunately we did not see this patient alive, but she was said to be very shocked on admission. The pulse was very weak—the rate about 130. The blood pressure was about 60/30 mm. Hg. The abdominal wall was lax, especially in the left hypochondrium, where she was tender on palpation. No free fluid was detected in the abdomen and no other injury found. She was given morphine gr. 1/6 and atropine gr. 1/100 on admission, followed by morphine gr. 1/4 at 6.55 p.m. At 9.15 p.m. her blood pressure had risen to 100/50 mm. Hg, her pulse had fallen to 110, and her general condition was stated to have improved slightly. At 9.30 p.m. she was catheterized and almost pure blood was withdrawn. At 10.7 p.m. a determination of plasma volume was started; this gave a figure of 1.9 l., or about 3.3% of body weight (about 9 st.). The haemoglobin was 10 g./100 c.cm. At this time the blood pressure had fallen again to 80/30 mm. Hg, and the pulse to 90. She was given morphine gr. 1/4 at 10.40 p.m. She was said to have improved slightly during the night, but at 7.5 a.m. she died suddenly. A coroner's post-mortem examination was performed, and she was found to have a complete rupture of the left kidney with a large retroperitoneal haematoma of from one to two pints. There was a small rupture of the spleen, with fractures of the 8th, 9th, and 10th ribs near their costo-vertebral joints.

Case 3.—A woman aged 22 was admitted to hospital at 4.22 a.m. complaining of profuse vaginal bleeding, which began about midnight, but her history was unreliable. She was conscious but collapsed and very pale, with a pulse rate of 132 and a blood pressure of 95/45 mm. Hg. She had extensive vaginal lacerations, apparently inflicted manually, but there was only slight bleeding when admitted. She was not pregnant. At 4.55 a.m. her condition was unchanged and a determination of plasma volume was begun which gave a value of 2.74 l., or about 4.5% of body weight (9½ st.). The haemoglobin was 10 g./100 c.cm. The lacerations were subsequently sutured and she made an uninterrupted recovery.

Case 4.—A woman aged 55 was beaten on the head and arms by a man with an iron bar at 10.30 a.m. The police reported finding a great deal of blood about. On admission at 12.10 p.m. she was conscious but apathetic and very pale and cold. The pulse was 80, regular and of small volume. The blood pressure was 70/50 mm. Hg. She had multiple lacerations of the scalp, with little bleeding at this time, a fracture of the shaft of the lower third of the left ulna, and some cuts on the hands. A determination of plasma volume was started at 12.38 p.m., and a figure of 1.92 l. was obtained, or about 3.8% of body weight (about 8 st.). The haemoglobin was 13.8 g./100 c.cm. The blood pressure and pulse were unchanged. At 1.25 p.m. she was becoming restless, and was given omnopon gr. 1/3 and scopolamine gr. 1/150. At 1.55 p.m. a transfusion was started, and she was given two bottles of blood. Her condition then improved steadily, and her wounds were dressed and the fracture set at 8 p.m. Ultimately she was discharged well.

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Case 5.—At 11.15 a.m. a man aged 54 fell 30 ft. from a building he was demolishing. He was semiconscious on admission to hospital at 12 p.m. and resisted attempts to examine him. His extremities were cold. His pulse rate was 156 and blood pressure 115/90 mm. Hg. There was a deep laceration of the right cheek, and cerebrospinal fluid was escaping from the left nostril. The pupils were equal, but the right reacted to light better than the left. Slight left facial weakness and slight spastic weakness of the left arm were present. The left plantar response was equivocal, but the right was flexor. There was swelling of the right wrist and the left ankle. Subsequent x-ray examination showed a fracture of the left malar bone running back into the anterior cranial fossa, involving the floor of the left orbit. There was also a fracture of the right radial styloid process and the left internal malleolus. The plasma volume, determined at 2.6 p.m., was 2.2 l., or 3.9% of body weight (about 8 st. 12 lb.). The haemoglobin was 13.4 g./100 c.cm. The blood pressure at this time had fallen to 115/80 mm. Hg and the pulse to 130. He was given morphine gr. 1/4 at 2.15 p.m. He gradually recovered consciousness during the next three days, but was found to have complete aphasia. He continued to improve, however, and the plasma volume was estimated again two weeks after admission. It was found to have risen to 3.1 l., or 5.5% of body weight. The haemoglobin had fallen to 9.5 g./100 c.cm.

Case 6.—A boy aged 14 fell in front of a bus and sustained a head injury at 5.10 p.m. He was admitted to hospital unconscious at 5.30 p.m. His skin was grey-coloured but warm and not sweating. His blood pressure was 156/110 mm. Hg and pulse rate 100. His pupils were deviated to the left, but otherwise there were no abnormal signs in the central nervous system. There was no evidence that he had lost any blood. At 6.30 p.m. he had recovered consciousness sufficiently to take sips of tea. The pupils were still deviated to the left. The blood pressure was 130/85 mm. Hg and pulse rate 96. A determination of plasma volume was started at 6.36 p.m., and was found to be 3.45 l., or 6.2% of body weight (8 st. 11 lb.). His haemoglobin was 11.6 g./100 c.cm. He continued to improve steadily, the deviation of the pupils disappeared, and he was finally discharged well.

Discussion

A reduction of plasma volume is accepted as being characteristic of traumatic shock, the amount of the fall being proportional to the severity of the shock. In general this has been confirmed in the present series of cases, but the reduction is greatest when examined early, as shown by the first two patients, both of whom died of their injuries. In Case 1 the plasma volume had fallen from the normal level of between 4.5 and 5.5% of body weight to about 2.1% in 1½ hours. This patient died 3½ hours after a severe crushing injury of the pelvis. In Case 2 the plasma volume was about 3.3% of body weight 7½ hours after the patient sustained a ruptured kidney and spleen. She died 16 hours after the injury. In less severe cases the reduction of plasma volume may be slight, especially if not examined until some hours after the injury. This is demonstrated by Case 3, in which the plasma volume was about 4.5% of body weight some five hours after traumatic vaginal haemorrhage, from which the patient made an uninterrupted recovery.

Head injuries may also be accompanied by a reduction of plasma volume, but only when haemorrhage has occurred. In Case 4 the plasma volume was about 3.8% of body weight some two hours after the patient received severe lacerating wounds of the scalp, cuts on the hands, and a fractured ulna. It was not known if she had temporarily lost consciousness. She made an uninterrupted recovery. In Case 5 the plasma volume was about 3.9% of body weight some three hours after the patient sustained a fractured skull with cerebral contusion, deep lacerations of the face, and minor injuries of the wrist and ankle. In both these patients there had been obvious haemorrhage associated with the head injuries. In contrast to them, no haemorrhage occurred in Case 6, a patient who received severe cerebral concussion which was associated with a transient hypertension. The plasma volume was about 6.2% of body weight about 1½ hours after the accident.

Haemoglobin concentration falls following traumatic shock, but the fall is minimal immediately after the injury, and may not become marked until several hours later. In Case 1, the most severe example, it was normal—14.1 g./100 c.cm. at the time of estimation of the plasma volume 1½ hours after the accident. In Case 4 it was 13.8 g./100 c.cm. and in Case 5 13.4 g./100 c.cm. at the time of estimation of the plasma volume about two hours and three hours respectively

after the patients were injured. In both Case 3 and Case 2 it was 10 g./100 c.cm. some 5 hours and 7½ hours respectively after the injury. This series shows a progressive fall in haemoglobin concentration as the time since the injury increases. The fall must be due to dilution of the blood with extravascular fluids, so that the determination of plasma volume at a later time may give a figure which is appreciably higher than would have been found one or two hours after the injury. Thus in Case 5 the haemoglobin was 13.4 g./100 c.cm. and the plasma volume 3.9% of body weight some three hours after the accident. Subsequently the haemoglobin fell to 9.5 g./100 c.cm. when a second determination of plasma volume showed that this had risen to normal—5.5%.

The reduction of plasma volume in all the cases which we have examined could be explained by haemorrhage alone, but many workers have claimed that shock is a toxic condition associated with haemoconcentration (see Moon, 1944). Haemoconcentration as judged by increased concentration of haemoglobin or a haematocrit value above normal has not been observed in any of the cases in our series except when associated with burns or with the crush syndrome (Bywaters, Crooke, and Morris, 1943). Haemoconcentration in these cases is due to loss of serum into the damaged tissues without a corresponding loss of corpuscles. The conception that haemoconcentration occurs in traumatic shock in man is probably due to the cyanosed, viscid character of the blood in severe cases. We have found, however, that in contrast to this increased viscosity of whole blood the viscosity of plasma is below normal. In one instance a man aged 70 sustained multiple injuries. He had a fractured spine, pelvis, ribs, humerus, tibia, and fibula, and a ruptured aorta and pericardium. A little blood was obtained for examination at the time when a transfusion was started some 45 minutes after the accident. It welled slowly from a vein in the leg when this was cut down upon. It was very cyanosed and viscid. The plasma viscosity was 1.62 at 20°C., which is significantly less than the normal—2.0 at 20°C.

Dr. E. R. Holliday kindly examined this plasma, and reported as follows: The plasma was examined in the Tiselius electrophoresis apparatus at pH 7.5 in 0.05 ionic diethyl barbiturate buffer at a dilution of 1 part of plasma to 3 parts of buffer. The migration diagram obtained by the Philpot modification of the "Schlieren" method was not entirely satisfactory. The ascending and descending diagrams showed considerable differences. The main abnormality of both diagrams is a deficiency in α component.

The increased viscosity of the blood with a decreased clotting time and a normal haemoglobin suggests a state of incipient clotting. The fibrinogen content of the plasma was, however, found to be normal by electrophoresis. The increased viscosity of the whole blood may therefore be due to an abnormal state of dispersion of the α component, since it is known that both α and β components readily form gels under certain abnormal conditions. This gel would be removed in the centrifugal separation of cells and plasma, and such plasma would have a decreased viscosity, a deficiency in α component, and a normal fibrinogen content. A further study of this problem is, however, necessary.

Summary

Difficulties in the estimation of plasma volume in shocked patients and the methods employed in overcoming them are described.

The plasma volume may be reduced to about 2% of body weight in the most severe cases.

The haemoglobin concentration is generally reduced, except in some cases of burn shock and crush syndrome.

The reduction in haemoglobin concentration does not run parallel to the reduction in plasma volume. It is least pronounced immediately after the injury, but subsequently progresses as water is restored to the circulation from surrounding tissues. It is most pronounced after the plasma volume has been restored to normal.

The theory that haemoconcentration occurs in shock is discussed.

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