

## AN EVALUATION OF POSITIVE PRESSURE TRANSFUSIONS \*

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OPERATIVE procedures of formidable magnitude are no longer unusual experiences in surgical practice. Accordingly, the proper and efficient conduct of replacement of whole blood has become a matter of great interest and importance to the surgeon and anesthesiologist. Rapid transfusion during anesthesia and operation by methods which employ positive pressure has been of considerable clinical value in overcoming the circulatory depression which results from hemorrhage. The purpose of this paper is to evaluate intravenous and intra-arterial transfusions administered under pressure and to enumerate their advantages and dangers.

Since 1939 when Seeley suggested to Kohlstaedt and Page that the clinical use of intra-arterial transfusion had practical merit, there has been increased interest in the use of positive pressure transfusions. The latter authors found that a loss of blood equivalent to 3.3 to 3.9 per cent of the body weight was uniformly fatal in dogs. Replacement of one-half of the removed blood intra-arterially resulted in survival of 75 per cent of the dogs. Only 30 per cent recovered when the same quantity of blood was replaced intravenously (1). In 1946, Page suggested that intra-arterial transfusion perfuses the coronary arteries with blood and minimizes the myocardial ischemia of shock. The heart then becomes more capable of pumping blood to all parts of the body. The blood pressure rises rapidly and latent bleeding becomes perceptible immediately. A depleted blood volume may also be replaced in this manner (2). Glasser and Page, in 1948, studying experimental shock, found that intra-arterial blood transfusion was a good means of resuscitation (3). Robertson, Trincher and Dennis observed a decrease in blood flow in the extremities despite a minimal depression of arterial blood pressure soon after hemorrhage. Later the arterial pressure fell in association with a sharp reduction in blood flow, cardiac output, renal and coronary flow. Intra-arterial transfusion produced an immediate and sustained response with a rapid rise in blood pressure and blood volume. The same result was achieved intravenously but took four times as long (4).

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Jones, Davis, Hubay and Holden, reviewing the physiology of shock, remarked that the sino-aortic pressoreceptors compensate for hypotension by initiating vasoconstriction reflexly. When intra-aortic pressure rises during intra-arterial transfusion, vasoconstriction is reduced. This, coupled with the steady stream of perfusion fluid delivered into the arterial tree, restored normal vascular tone with a consequent perfusion of the capillary network and the flow of stagnant blood into the active circulation again (5). Pierce, Robbins and Brunschwig (6) showed that remarkably large quantities of blood could be rapidly injected intravenously into patients in shock, with little harm. Experimentally in dogs in hemorrhagic shock, extremely large amounts of water could be pumped in without ill effect. Dogs that were not bled did not tolerate rapid overloading with blood as well as dogs that had been bled. It was concluded that rapid overloading of the heart during rapid transfusion in shock does not occur until normal blood volume is approached.

In some patients who suffer from hemorrhage, rapid intravenous transfusion may overload the heart. Significant rises in venous pressure may indicate that the heart is incapable of handling the venous return and that the rate of transfusion must be slowed or congestive failure will result. The following case illustrates this complication.

*Case 1.*—A 58 year old arteriosclerotic diabetic white man, who had previously had two myocardial infarctions, was admitted in shock from a bleeding peptic ulcer. Whole blood therapy was immediately and vigorously instituted with pressure technic. Although there was no evidence of new myocardial damage, the venous pressure rose during transfusion and pulmonary congestion developed in the presence of full digitalization. When the rate of transfusion was slowed the signs of failure were reduced, but the arterial blood pressure fell to shock levels again. Surgical intervention, with arterial transfusion if necessary, was decided upon, but the latter was not needed. Subtotal gastrectomy was performed and recovery was uneventful.

*Comment.*—This patient already had a damaged myocardium and the additional strain of transfusion under pressure was sufficient to precipitate congestive failure.

#### BLOOD VOLUME STUDIES

It has been increasingly clear that red blood cell counts, hemoglobin, hematocrit and plasma protein determinations do not necessarily reflect the absolute quantity of the circulating blood volume (7, 8, 9). Volumetric determinations conducted on surgical patients have revealed blood volume deficiencies of significance (10). If these deficiencies are not corrected before operation, susceptibility to shock is increased when the insults of operation, hemorrhage and anesthesia are superimposed. A relatively simple and useful method of measuring the blood volume is the technic of Gregersen (11). Patients in whom there is evidence of

bleeding or of malignant disease of the gastrointestinal or genitourinary tracts are most likely to suffer from a reduced blood volume. When proper replacement therapy has been carried out before operation, the subsequent operative and postoperative courses have been smoother. It has been useful to replace deficits with 500 cc. of blood every second day to allow proper distribution of all the blood elements until the deficiency has been made up. Blood volume determinations after operation have guided adequate replacement during the period of wound healing.

#### METHODS OF RAPID TRANSFUSION

The primary purpose of blood transfusion is the restoration of previously depleted blood volume. This may be accomplished by gravity methods or by the imposition of positive pressure on the transfusion reservoir. Pressure transfusions may be administered intravenously or intra-arterially. Many pumping apparatuses have been devised (5, 6, 13, 14, 18, 19). If basic physiologic concepts are kept in mind, the actual physical structure of the pump is not important, provided it is capable of delivering a large volume of blood in a short period of time under controllable pressure. An efficient pump must be capable of delivering 500 cc. of blood in less than three minutes.

Gravity methods of transfusion are the safest since the organism can adjust more easily during the course of administration. When optimal volumetric status has been attained preoperatively, gravity replacement is usually sufficient to combat satisfactorily operative blood loss. When blood loss is excessive, rapid intravenous transfusion under pressure may be required. When large amounts of blood are deposited on the venous side, the heart must deliver it into the arterial circulation. This imposes a burden on cardiac function. When intravenous pumping has been undertaken, the peripheral venous pressure must be followed constantly, since the heart may be overloaded and congestive heart failure result.

Arterial transfusion is superior to venous transfusion in only one respect. It artificially supports the blood pressure while blood volume is being replaced. The centripetal injection of blood toward the heart exerts back pressure that is equally distributed to all parts of the vascular closed system. As shock deepens and hypotension becomes severe there is a reduction of coronary flow, and the heart itself, along with the liver, brain and kidneys, becomes anoxic. Intra-arterial transfusion forces oxygenated blood, ejected from the heart, back into the coronary arteries under relatively normal diastolic pressure, thus breaking the anoxic cycle of deep shock. Some authors who have studied the subject of arterial transfusion have advocated pumping gradients of 25 mm. and 50 mm. of mercury above the exhibited systolic pressure (4, 12). Jones, Davis, Hubay and Holden have used gradients

of normal mean blood pressure (5). Porter, Sanders and Lockwood observed in animals that blood pressures of more than 20 mm. of mercury higher than normal could not be obtained even by employing very high intra-arterial pressures (13). Seely has demonstrated graphically the effect of pumping pressure and needle size, and concluded that a 15 gauge needle is the optimal caliber (14). The principle of bringing the arterial pressure rapidly to normal appears the most reasonable; therefore, pumping pressure has been "titrated" against arterial pressure, delivering sufficient pressure to maintain normotension, after raising the blood pressure as rapidly as possible with high initial pumping pressure up to 400 mm. of mercury. The remainder of the blood volume deficit may then be replaced more slowly. Blood replacement by intra-arterial means may mask an increasingly severe volumetric deficit as the processes of vasoconstriction go on. When constriction is maximum and loss continues, the organism depends increasingly on artificial support of the circulation and it becomes difficult to discontinue use of the pump. If shock is already irreversible, according to the criteria of Frank, Seligman and Fine (15), intra-arterial transfusion will not favorably affect the result except to prolong the time of inevitable death.

#### INDICATIONS FOR ARTERIAL TRANSFUSION

The indications for intra-arterial transfusion are definite and were enumerated by Porter (16): (1) sudden massive hemorrhage and imminent exsanguination; (2) moribund circulatory status following hidden or prolonged bleeding; (3) inadequacy of intravenous positive pressure transfusion after a fair trial, and (4) physiologic antidote during the surgical correction of coarctation of the aorta and pulmonic stenosis.

These indications are in essential agreement with those stated by Seely (14) and Dornette (17). The majority of cases fall into the second and third categories, as is illustrated by the following case reports.

*Case 2.*—A 14 year old white boy injured his side in an accident. During the following five days pain and shock developed and a mass was found in the right upper abdominal quadrant. He was admitted to another hospital where a subcapsular hematoma of the right lobe of the liver was drained. Three weeks later he suffered a massive hematemesis and passed several voluminous tarry stools. Administration of 2000 cc. of blood brought him out of shock, but he subsequently became jaundiced. During the next month he suffered five massive hemorrhages from the wound; he had four bouts of large tarry stools and received 32 pints of blood. In the seventy-two hours before admission to the hospital, he continuously vomited blood, passed tarry stools and bled from the wound. On admission he was given 2500 cc. of blood rapidly under pressure, but his condition deteriorated. When operation was decided upon, the needle was shifted to his artery and the pressure was raised to normal. Celiotomy re-

vealed that the right lobe of the liver was completely necrotic. This was evacuated. The right hepatic artery was observed to be bleeding into the right hepatic duct. These vessels were ligated and his blood volume rapidly re-expanded. He received 4500 cc. of blood intra-arterially. The postoperative course was stormy, but the patient survived and is well today.

*Comment.*—Intra-arterial transfusion was used because of prolonged bleeding and an unsatisfactory response to intravenous transfusion.

*Case 3.*—A 65 year old white woman was admitted because of a huge retroperitoneal mass which filled the right upper quadrant and epigastrium and surrounded the right kidney, duodenum, ascending colon and great vessels. Attempts to mobilize the mass resulted in the rupture of many vessels, including the inferior vena cava, and the colon and duodenum. Intravenous transfusion under positive pressure obviously was inadequate and only by intra-arterial transfusion could the blood pressure be maintained. Bleeding was finally controlled and the blood volume rapidly re-expanded. The patient was given 9500 cc. of blood intra-arterially. Despite repeated stellate ganglion blocks, gangrene of the fingers developed. At postmortem examination six days later, death was found to be due to thrombosis of the inferior vena cava, with pulmonary emboli and pneumonia.

*Comment.*—This is a case of exsanguination, and is an indication for intra-arterial transfusion.

Peripheral arteries may be sacrificed needlessly at times when rapid transfusion intravenously would suffice. The ability to cannulate the artery rapidly, however, comes only with practice. In cases of shock from concealed bleeding, intra-arterial transfusion is valuable because it allows rapid return to normal tension and quickly demonstrates the bleeding vessel.

The fourth group of cases which includes coarctation of the aorta and pulmonic stenosis comprises physiologic replacement. After resection of the coarctation and release of the clamps, the new and wide pathway for blood may precipitate hypotension. This, however, is not on a basis of depleted volume and usually requires only a short period of support of the circulation until the patient compensates for the new channel. Volumetric deficit is usually not a factor in pulmonic stenosis and only momentary support is necessary. This group requires prophylactic arterial cannulation.

It is seldom necessary to ligate the cannulated artery. Compression for ten minutes usually stops the flow of blood.

#### DANGERS OF POSITIVE PRESSURE TRANSFUSIONS

The dangers of transfusions under positive pressure are few but serious and are: (1) air embolus; (2) gangrene of an extremity; (3) congestive heart failure; (4) increased bleeding tendency and (5) tetany.

Air embolus is the ever present threat to the use of positive pressure transfusion. Constant vigilance of the individual giving the transfusion, who must be a separate and distinct member of the operating team with no other duties, is the price of safety. Gangrene of an extremity, arteriospasm and ischemic tissue changes may be minimized by the local use of procaine and regional sympathetic blocks. High pumping pressures and cold blood will throw arteries into spasm. Ruptures of small arterial radicals may be recognized as black streaks, patches and blisters. Damage to the vasa vasorum results in arterial thrombosis. In general, the larger the artery the less difficulty with spasm. The aorta has been used occasionally, but the radial and femoral arteries are more readily available. It is always safe to do one or two sympathetic blocks postoperatively on an extremity in which an artery has been cannulated.

Congestive heart failure is usually limited to a complication of too rapid intravenous pumping. Its incidence may be minimized with the aid of determinations of peripheral venous pressure during pressure transfusions. When the venous pressure exhibits a significant rise, the rate of transfusion should be slowed. If this does not bring about a fall in venous pressure, a single full digitalization dose with lanatoside C and "bloodless phlebotomy" with tourniquets can be used efficiently.

Increased bleeding tendency and tetany result presumably from large amounts of citrate in bank blood which bind the ionized calcium of the blood. Injection of 0.1 gm. of calcium gluconate usually controls this phenomenon satisfactorily.

#### SUMMARY

The technic of rapid transfusion under pressure is a valuable adjuvant to the treatment of hemorrhagic shock. After the blood volume has been restored to normal before operation, transfusion should be administered by gravity as the method of choice. If this proves ineffective to combat hemorrhage, intravenous positive pressure is indicated, controlled by determinations of venous pressure. When intra-arterial technic is employed, the pumping gradients should be sufficient so that normotension is regained rapidly. The indications and dangers of pressure transfusions have been enumerated and discussed. The intra-arterial route is reserved for these special cases which cannot be managed by the aforementioned methods. Use of pressure transfusions indiscriminately and when not indicated is to be discouraged.

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