Acta orthop. scand. 41, 37–43, 1970

Department of Surgery I, Sahlgrenska sjukhuset, Gothenburg, Sweden.

STUDIES ON THE CIRCULATORY PATHOPHYSIOLOGY OF TRAUMA

II. *Effect of Acute Soft Tissue Injury on the Passage of Macroaggregated Albumin (^{131}I) Particles Through the Hindleg of the Dog*

DAVID H. LEWIS & ROBERT C. LIM, JR.

Received 1.xi.68

In a previous communication (Lewis & Lim 1970) observations were presented on the effect of soft tissue injury on the total flow, nutritional flow, and non-nutritional flow through the hind leg of the dog. It was noted that trauma was associated with a transient increase in total flow, which was for the most part non-nutritional. This was associated with a parallel rise in venous PO_2 draining the injured area, in confirmation of data obtained by Blalock & Bradburn (1930). Evidence was presented suggesting that the increase in shunting seen after trauma was due to an increase in total flow. The shunting could be classified either as "physiological" or "anatomical". The purpose of the present communication is to report on studies on defining the question of anatomical versus physiological shunting in the hind leg of the dog following soft tissue injury.

METHODS AND MATERIALS

Observations were carried out on 10 mongrel dogs of either sex, ranging in weight from 8 to 29 kg. The experimental model and detailed procedure have been described previously and should be consulted for details. The animals were anesthetized intravenously with sodium thiopental (Pentothal®) and repeated small doses were given as needed throughout the experiment. A cuffed endothracheal catheter was inserted and the animal ventilated on room air with a respirator. Through a longitudinal midline incision, the iliac arteries and veins were mobilized to just

Department of Surgery, University of California School of Medicine, San Francisco, U. S. A.

below the inguinal ligament. All collateral branches and the sacral artery were ligated and divided. The inguinal ligaments were divided to give adequate exposure to insure that isolation of the vascular pedicle to each hindleg was complete. The foot was excluded from the hindleg preparation by a tight wire ligature placed around the ankle.

Through the stump of the pudendo-epigastric artery a short, fine-bore (PE 47) polyethylene catheter was introduced. The tip of the catheter was positioned carefully so that it just protruded into the lumen of the iliac artery in the proximal direction. A T-tube of the largest possible diameter was inserted at the midpoint of each iliac vein. Total venous return from the hindleg was collected by diverting the flow out of the sidearm of the T-tube. A slow intravenous infusion of saline was given throughout the experiment via a wide-bore polyethylene catheter in an external jugular vein. This catheter was also used for infusion of the venous blood collected. Arterial blood pressure was monitored continuously via a carotid artery catheter connected to a mercury manometer.

At predetermined intervals the venous return was diverted out the side arm of the T-tube past a scintillation detector. After the level of background radioactivity had been determined and a background sample taken, 5–10 μc of ^{131}I macroaggregated albumin particles (5–50 microns in diameter),* suspended in 1.0 ml saline, was injected rapidly into the iliac arterial catheter. Simultaneously with the injection, a timed collection of venous outflow, was begun. When the detector indicated that the primary curve of isotope activity had passed, the venous return was rediverted back to its normal course. The collected blood was measured and mixed thoroughly. Representative samples were taken, and the remainder of the blood was returned to the animal. Only one leg was studied at a time and at the end of each experiment the legs were removed and weighed.

In four animals a control study was done on the right side first. Study of the left side was done then immediately after trauma. Trauma consisted of 200 blows to the thigh with a hard rubber mallet. In these animals collections were made at 30-min intervals up to 4 hours after trauma, alternating legs, so that the non-traumatized leg was studied at ½, 1½, 2½, etc. hours after trauma and the traumatized leg at 1, 2, 3, etc. hours after trauma.

In three animals only two injections were made, one control (right) and the other (left) when the maximal post-traumatic flow increase had been reached.

In another three animals the effect of the presence of the foot in the circulatory bed was studied. For these one foot was tied off as described above and the other not. Control injections were made bilaterally before traumatizing both thighs (200 blows to each leg). Studies were then carried out on each leg immediately after trauma and at hourly intervals for 4 hours.

The radioactivity of all blood samples was determined in a well-type scintillation counter. The curves obtained during the experiment were used to insure a complete collection of the labeled particles not lodged in the capillary bed of the leg. The percentage of injected particles returning in the venous blood for each injection was calculated as follows: The total amount of radioactivity of the injectate was determined from a standard sample. The total amount collected each time was

* Obtained from AB Atomenergi, Studsvik, Sweden, and manufactured by Hoechst Farbwerk, Frankfurt, Germany.

determined from the net activity collected (activity in collected sample minus activity in blood just before collection) multiplied by the volume of blood collected.

RESULTS

Table 1 shows the percentage of injected particles appearing in the venous return for all of the injections made along with the mean values and standard deviation. The mean values are shown graphically in Figure 1.

Table 1. Percentage of injected particles appearing in the venous return

	Dog	Control	0	½	1	1½	2	2½	3	3½	4
Non-traumatized, foot tied off	1	0.9									
	2	3.5									
	3	2.1									
	4	3.7									
	5	1.9									
	6	3.4		1.6		1.7		2.1		1.7	
	7	1.2		0.8		1.1		0.9		1.3	
	Mean	2.39		1.20		1.40		1.50		1.40	
	S. D.	1.15		–		–		–		–	
Traumatized, foot tied off	1		1.0								
	2		2.3								
	3		4.6								
	4		2.3		1.0						
	5		2.8		1.7		1.3		1.4		0.9
	6		3.3		1.9		1.2		3.8		1.1
	8	3.4	2.4		1.8		1.9		2.5		2.0
	9	7.4	8.2		4.6		6.5		5.6		
	10	6.7	2.6		3.6		2.0		1.8		0.7
	Mean	5.83	3.28		2.43		2.58		3.02		1.18
	S. D.	2.14	2.08		1.37		2.22		1.71		0.57
Traumatized, foot not tied of	7		8.1		2.3		1.4		1.0		
	8	1.1	1.1		1.2		1.2		1.4		
	9	7.5	7.8		17.8		7.3		7.8		
	10	4.2	2.8		1.3		1.9		1.5		0.0
	Mean	4.27	4.95		5.65		2.95		2.93		
	S. D.	3.20	3.54		8.12		2.91		3.26		

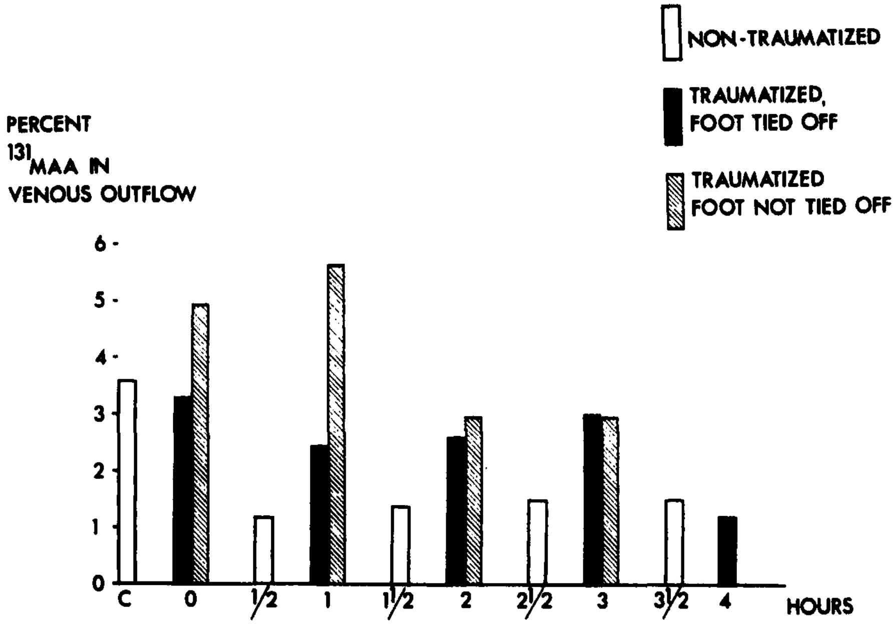

Figure 1. Mean values, 10 dogs. The staples indicate the percentage of injected ¹³¹I-macro-aggregated albumin particles passing through the vascular bed of the hind leg. Note that trauma increased the percentage of particles collected, but only if the foot was present in the circulation.

For the control injections carried out at normal blood flow and blood pressure in a non-traumatized leg the mean recovery rate of these particles whose greatest diameter was 50 microns was on the average 2.4 per cent. The single highest value was 3.7 per cent.

The average value of all those taken immediately after trauma in which the foot was excluded from the circulation was 2.9 per cent. At 1 hour the corresponding value was 1.5 per cent. Note also that in the succeeding hours the values were essentially unchanged.

In one instance, in which the foot was not excluded from the circulatory bed (dog 7), there was a seven-fold increase in the particles appearing in the venous circulation. This was not noted in the next injection.

In the group of animals in which both legs were traumatized and only one had its foot tied off (Dogs 8, 9, 10) there was no difference in the amount of particles passing through the vascular bed.

DISCUSSION

When albumin particles of a size between 5 and 50 microns were injected into the hindleg of the dog, in which the foot had been excluded from the circulation, more than 97 per cent of these particles were trapped in the vasculature. This indicated that the percentage of the open vascular bed was large and that direct arterio-venous communications, greater than 50 microns in diameter, were small.

Following soft tissue trauma the percentage of particles not trapped was the same as before the trauma. Inspection of the data for each individual animal indicates that in four instances there was a greater recovery 1 hour after trauma than in the control, 0.1 per cent, 0.4 per cent, 0.9, and 2.5 per cent. Only the last value, however, would appear to be outside the limit of experimental error.

Direct anatomical observations of the microcirculation of the conjunctiva and mesentery have revealed the opening up of large direct arterio-venous communications following trauma (Gelin 1956). Since no anatomical observations of the circulatory bed were made, no conclusion about whether such vessels open up in the hind leg following trauma can be made. However, whatever the anatomical situation, physiologically they cannot play a significant role, since there is no increase in the fraction of the total flow that passes through them after trauma. When these results are analyzed with those obtained on the uptake of rubidium by the hindleg after trauma, it can be concluded that the increase in non-nutritional flow after trauma is physiological shunting and not anatomical.

There are a number of technical problems connected with the albumin particle method that could preclude the demonstration of anatomical shunts. First, since the particles injected block the vessels in which they are trapped, repeated injections could so seriously compromise the vascular bed that no valid conclusions could be drawn. This was not the case with the use of the small volume and number of particles in the present study. The resistance to flow even after four hourly injections into one leg was essentially unchanged. Furthermore, closure of the capillary bed would if anything tend to open up arterio-venous shunts, in which the particles would then pass into the venous circulation. Second, aggregation of the particles before or after injection could have altered their size so that they became too large to pass any size vessel. This was checked on several occasions by measuring the distribution of particle sizes in a Celloscope®. The studies done on the suspension to be injected revealed no particles larger than that given by the manufacturer (i.e. 50 microns).

In addition to this, an aliquot of the injectate was added to a volume of blood approximately equal to that gathered in a collection. This blood was taken at the end of an experiment (4 hours) at which its aggregating powers should be maximal in this experiment. The largest size particle observed here was 24 microns. Therefore, it would appear that the theoretical possibility of a significant alteration in the particle size cannot explain the result obtained here.

In a previous study it was concluded that trauma interrupts transiently sympathetic vasoconstrictor tone. It is known that such fibers exert control over the arterio-venous shunts in the paws (Celander 1954). It was thought, therefore, that with the foot present, post-traumatically there would be a definitely significant increase in the percentage of particles recovered in the venous outflow. However, this was seen on only one occasion and not on three other occasions, so that no definite conclusions can be reached.

SUMMARY AND CONCLUSIONS

1. Observations have been carried out in 10 dogs on the passage of ^{131}I-macro-aggregated albumin particles through the hindleg of the dog.

2. In the control state the percentage of injected particles of a size 5 to 50 microns that escape trapping in the vasculature was approximately 3 per cent.

3. This was the same after trauma without the foot in the circulation, but was slightly greater with the foot in the circulation.

4. It was concluded that arterio-venous shunting in the skeletal muscle of the hindleg of the dog immediately following trauma plays no significant physiological role and that the post-traumatic increase in non-nutritional flow seen in the previous study was physiological shunting and not anatomical.

ACKNOWLEDGMENTS

The authors wish to express their thanks to Miss Ulla Wetter for her excellent technical assistance and to Dr. Ulf Ljungqvist for his help with the particle size determinations.

The original research reported in this communication was supported by the United States Army through its European Research Office (contract No. DAJA37-

67-C-0460), by the U. S. Public Health Service (Grant HE-28, 487), and by grants from the Swedish Medical Research Council.

REFERENCES

Blalock, A. & Bradburn, H. (1930) Distribution of the blood in shock. The oxygen content of venous blood from different localities in shock produced by hemorrhage, by histamine and by trauma. *Arch. Surg.* **20**, 26.

Celander, O. (1965) The range of control exercised by the sympathico-adrenal system. *Acta physiol. scand.* Suppl. 116.

Gelin, L.-E. (1956) Studies in anemia of injury. *Acta chir. scand.* Suppl. 210.

Lewis, D. H. & Lim, R. C., Jr. (1970) Studies on the circulatory pathophysiology of trauma. I. Effect of acute soft tissue injury on nutritional and non-nutritional shunt flow through the hind leg of the dog. *Acta orthop. scand.* **41**, 17–36.