Weight Gain and Cardiopulmonary Bypass

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Abstract

Seventy-two consecutive patients undergoing coronary revascularization were divided initially into three groups consisting of those with perfusion time less than or equal to 90 minutes (Group I), those with perfusion time between 90 and 150 minutes (Group II), and those with perfusion time 150 minutes or longer (Group III). The patients having the longest perfusion displayed, as anticipated, the highest weight gain of 4.4 ± 0.6 Kg following cardiopulmonary bypass in contrast to 2.6 ± 0.3 Kg in Group II and 2.1 ± 0.3 Kg in Group I ($p < 0.05$). This corresponds to a linear progression with increasing weight gain proportional to increasing perfusion time (0.02–0.03 Kg/min of bypass).

These same 72 patients were then divided into two groups: Group A having weight gain less than 2.0 Kg and Group B with weight gain of 2.0 or more Kg. Group B showed a significant reduction of 39% in the serum protein level and 28% in serum albumin as compared to the control level. This is significantly different from the 28% reduction in total serum protein and 17% reduction in serum albumin as was noted in Group A, having the shorter bypass interval ($p < 0.05$). Thus, while the duration of perfusion is primarily responsible for fluid accumulation and weight gain, the low serum protein may serve to accentuate edema formation. Hemodilution and nonpulsatile flow are factors promoting tissue edema during cardiopulmonary bypass.

Introduction

It was observed that some patients undergoing cardiopulmonary bypass had a large weight gain (>4.5 Kgs) measured in the immediate postoperative period. We considered a weight gain of this magnitude to be undesirable since it was most often manifested as tissue edema and have attempted to identify the etiology.

Methods

All patients undergoing cardiopulmonary bypass at the Baystate Medical Center undergo an exhaustive preoperative examination. The results of this examination are then entered into a computer for future reference. It is from this list that some of the parameters have been taken for this study: preoperative weight, history of diuretic therapy, hypertension, and chronic congestive heart failure. Exact records are also kept by the anesthesiologist, perfusionist, and intensive care staff as to fluids given, urine output, blood loss, postoperative weight, and blood chemistries. These parameters are also computerized and were used in the study. For purposes of this study, 72 consecutive patients undergoing coronary revascularization were analyzed.

Cardiopulmonary bypass was instituted using a Sarns* roller pump and the BOS 10** bubble oxygenator. The circuitry was primed with 1500 cc Plasmalyte 148*** and 250 cc of 12.5 grams of human

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TABLE 1
The Preoperative Profile of the Three Groups

Group	Perfusion Time (min)	Congestive Heart Failure	Dia-betes	Diuretic Therapy	Hyper-tension
I	<90	10%	20%	30%	30%
II	90–150	11%	14%	19%	29%
III	>150	12%	15%	25%	50%

* indicates significant difference $p < 0.05$

serum albumin. No blood was used to prime the circuitry of these patients. Total prime volume for this circuit was 1750 cc. The pump index is maintained between 1.6 and 2.4 liters/minute/meter square body surface area. Moderate hypothermia of 25° rectal temperature is generally achieved. Additional red cell volume is given should the hematocrit fall below 20% during hypothermia or 25% during the rewarming phase. All fluids administered were correlated with the urine output, duration of perfusion, and the postoperative weight. Comparisons were carried out with respect to both perfusion and weight gain. All analyses were reported as the mean plus/minus the standard error of the mean, and the Student's t-test was used for determining the significance of differences between sample means. The correlation coefficient (r) was determined by a linear regression and the least squares method.

Results

The 72 patients had a mean perfusion time of 132.8 ± 12.8 minutes with a range of 37–334 minutes and a mean weight gain of 3.0 ± 0.2 Kg with a range of 0–9 Kg. The 72 patients were then divided into three groups, depending upon the length of perfusion. The 10 patients in Group I were those with pump times less than, or equal to, 90 minutes ($\bar{m}$ 76.0 ± 5.5 min), Group II (42 patients) pump times between 90 and 150 minutes ($\bar{m}$ 123.4 ± 2.2 min), and Group III (20 patients) pump times 150 minutes or greater ($\bar{m}$ 181.1 ± 9.2 min).

TABLE 2
Fluid Administered During Perfusion

Group	Plasmalyte 148	Total Colloid	Total Given	Fluid Absorbed/ Min. Bypass
I	3885 ± 287*	265 ± 16*	4150 ± 303*	58.2 ± 7.2
II	5855 ± 271*	470 ± 53*	6335 ± 324*	51.6 ± 2.3
III	7196 ± 664*	847 ± 114*	8043 ± 879*	47.8 ± 3.9

* indicates significant difference $p < 0.05$

TABLE 3
Urine Output During Perfusion

Group	Urine Output(cc)	Urine/Min. Bypass
I	679 ± 192*	8.9 ± 2.0
II	1295 ± 130*	10.6 ± 0.1
III	1940 ± 318*	10.7 ± 1.2

* indicates significant difference $p < 0.05$

The initial comparison between the three groups concerns pre-existing conditions such as diabetes, hypertension, chronic congestive heart failure, diuretic therapy and preoperative weights (Table 1). The comparison between groups does not reveal any significant differences in their preoperative histories.

Further studies (Table 2) analyzed the types and amounts of fluid added to the pump and the patient during the perfusion. As would be expected, there is a direct relationship between the length of perfusion and the total amount of fluids administered. The correlation coefficient is 0.992, indicating an almost linear relationship ($p < 0.01$). Therefore, the longer the pump time, the more fluid necessary to maintain an adequate volume within the extracorporeal circuit. It should be noted, however, that the absorption of fluid per minute of bypass, averaged over the entire duration of bypass, decreased progressively with prolongation of perfusion. While the difference between groups does not reach significance when calculated as an average of the entire duration of perfusion, it may be assumed that with lengthening the duration of perfusion the amount of fluid absorbed per minute of bypass progressively decreases.

The amount of urine excreted during perfusion is compared between groups in Table 3. Again, it can be seen that there appears to be a direct relationship with the duration of perfusion. The correlation coefficient is 0.992, which indicates a linear relationship ($p < 0.01$) between the amount of urine produced and the length of perfusion. In this instance there is an increase in urine excreted per minute of bypass with lengthening perfusion, but the difference between groups is not significant.

The fluid gradient per minute is calculated by adding all input solutions, subtracting the urine excreted, and

TABLE 4
Fluid Gradient During Perfusion

Group	Total In(cc)	Urine Output(cc)	Gradient/ minute (cc/min)
I	8154 ± 913*	679 ± 192*	49.5 ± 7.8
II	10079 ± 333*	1295 ± 130*	41.6 ± 1.9
III	11863 ± 758*	1940 ± 318*	37.2 ± 3.1

* $p < 0.05$

dividing by the perfusion time in minutes (fluid in—fluid out/minutes of bypass = fluid gradient) and is described in Table 4. As can be seen from the table, while both the fluid added and urine excreted increase significantly with each increased interval of perfusion, the gradient/minute of bypass decreases with each progressively increased length of perfusion. The gradient/minute was averaged over the entire length of perfusion, and the difference between groups was, therefore, not significant but, because of the clearly apparent trend, it may be assumed that less fluid is retained per minute of bypass with lengthening perfusion.

The fluid gradient for the entire operating room experience is shown in Table 5. This includes all solutions in, such as blood, lactated Ringer's and dextrose, and all solutions out, such as blood loss, urine output and waste during induction of anesthesia, surgical incision, etc. There is, again, a trend to greater fluid absorption with longer bypass times, but the actual numbers are not significantly different between the three groups.

TABLE 5

Group	Total O.R. Fluid Gradient (cc's)
I	4239 ± 622
II	4704 ± 350
III	5314 ± 568

TABLE 6
Weight Gain vs. Perfusion Time

Group	Weight Gain (Kgs)	(Kgs/min)
I	2.1 ± 0.3*	.027 ± .003
II	2.6 ± 0.3*	.022 ± .003
III	4.4 ± 0.6*	.025 ± .003

* $p < 0.05$

TABLE 7
Postoperative Fluid Balance

Group	Postoperative Blood Lost (cc)	Postoperative Blood Given (units)
I	108 ± 22*	3.1 ± 0.8*
II	154 ± 34	3.4 ± 0.3
III	359 ± 130*	6.4 ± 1.0*

* $p < 0.05$

In Table 6, weight gain is correlated with perfusion time. This shows a progressive increase in weight gain with each increased duration of perfusion, but a significant difference is apparent only between Groups I and III and II and III. When the increased weight gain is indexed against the perfusion time, the differences in weight gain/minute of perfusion are not significant.

In the immediate postoperative period (until 7 a.m. the following morning), there was a significant increase in the amount of blood loss via chest drainage between the three groups (Table 7). Group III lost 359 ± 130 cc, Group II 154 ± 34 cc, and Group I 108 ± 22 cc. The difference between Groups III and I or II was significant. Accordingly, there was a greater amount of blood given to Group III (6.4 ± 1.0 units) than to either Group I (3.1 ± .8) or II (3.4 ± 0.3).

The same 72 patients were then divided into two groups. Group A were those 45 patients with a weight gain of less than 2.0 Kg ($\overline{m}$ 1.1 ± 0.2 Kg) and Group B, 29 patients with a weight gain of 2.0 or more Kg ($\overline{m}$ 4.4 ± 0.5 Kg). An analysis was made of the patients' total serum protein and serum albumin concentration pre- and immediately postoperatively. The results are given in Table 8. In the Group B patients (weight gain >2.0 Kg), there was a reduction of 39% in total serum protein and of 28% for serum albumin when comparing the control or pre-bypass level to the immediate postoperative level. This decrease is significantly different from the reduction in serum protein and albumin noted in Group A (weight gain <2.0 Kg) where the decrease

TABLE 8
Serum Colloid Concentration Correlated With Weight Gain

Group	% Change Total Protein	% Change Albumin	Weight Gain (Kgs)
A	28.0 ± 1.8*	16.6 ± 1.6*	1.1 ± 0.2*
B	38.9 ± 2.7*	27.8 ± 3.2*	4.5 ± 0.5*

* $p < 0.05$

was only 28% for total serum protein and 17% for serum albumin.

Discussion

From this study it is clear that weight gain is a function of the perfusion time. All of the parameters involved, including the amount of fluid given, the amount of urine excreted, and the weight gain, show a linear relation to the duration of perfusion. When weight gain is indexed per minute of perfusion, weight gain remains relatively constant at 0.02–0.03 Kg/min (Table 6). There is a definite trend toward a decrease in the amount of fluid retained per minute of bypass as the perfusion time becomes longer, but the difference between groups is not significant ($p > 0.05$) (Table 4).

Weight gain routinely occurs during cardiopulmonary bypass.[1] Two aspects of bypass have been defined which contribute to fluid accumulation: hemodilution,[2,3,4,5] leading to a significant decrease in the concentration of serum proteins,[3] and nonpulsatile perfusion.[6] Due to a relative reduction in serum proteins, hemodilution significantly reduces the plasma oncotic pressure.[7] This is supported by the present study which demonstrates a clear relationship between weight gain and the reduction of serum proteins (Table 8).[5,8]

The second feature of cardiopulmonary bypass which promotes tissue fluid accumulation is nonpulsatile perfusion.[6] Protein clearance from the interstitium is via the lymphatic system,[9] and it is this system's function that is impaired due to the nonpulsatile flow of cardiopulmonary bypass.[6] The lack of a contractile movement of the blood vessel wall, which is a result of an absence of pulsation and alteration of the pulse pressure, results in a decrease in lymphatic drainage. In addition, skeletal muscle contractility promotes lymphatic drainage, and such skeletal muscle function is obviously lacking during operation. Thus, protein clearance from the valved vascular lymphatic system[10] is impaired during cardiopulmonary bypass resulting in an increase in interstitial proteins which cannot return to the bloodstream via their normal channels.[11] This increase naturally causes an increase in interstitial colloid osmotic pressure.[1]

In addition to an increase in edema formation,[12] another deleterious effect of prolonged perfusion can be seen from Table 7. The group having the longest perfusion, Group III, showed a significant increase in postoperative blood loss when compared to Group I. It is conceivable that the greater blood loss following prolonged perfusion represents heparin rebound with heparin being carried into the third space along with edema fluid. Also, the increased blood loss may be a result of damage to clotting factors due to the increased perfusion time[13], but such factors were not evaluated in this study.

Conclusion

The two mechanisms, hemodilution and nonpulsatile perfusion, serve to increase the interstitial colloid osmotic pressure relative to plasma oncotic pressure. This increase will promote the translocation of water from the vascular space to the interstitial space. As the interstitial fluid accumulates with the development of edema, it will ultimately produce a decrease in tissue oncotic pressure, resulting in an equilibrium between the intra- and extravascular space. This is reflected by weight gain and could possibly be reduced by two steps. First, one can keep the perfusion time to an absolute minimum and secondly, by increasing the amount of colloid given as a maintenance fluid, it is possible to reduce the relative difference between the interstitial colloid osmotic pressure and the plasma oncotic pressure. Two protocols exist which can help to reduce this difference. Normal serum albumin ($12\frac{1}{2}$ grams) is added with every 1000 cc's of crystalloid diluent unless the hematocrit of 20% is reached. Should the hematocrit reach 20% or fall below this level whole blood is added as the maintenance volume. Whole blood is preferred to packed cells in this situation because the plasma has not been removed and, therefore, not only is the hematocrit being raised but also the plasma oncotic pressure.

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