Absolute and Relative Residual Organ Blood Volumes and Organ Hematocrits in Growing Beagles[1] (36442)

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Recent investigations of relative volume changes in the body fluid compartments with growth revealed that in the period between birth and 1 year of age the red cell, plasma, and blood volumes as well as the extracellular and total body water of beagles expressed in milliliters per kilogram of body weight were highest during the first week after birth (1–3). At 6 months of age the dogs reached maturity for all of these parameters. The distribution of tagged red cells and radioiodinated protein in the large and minute vessels of mature animals has been reported for several species including the dog (4–8); however, whether or how the distribution is influenced by the growth process has not been investigated. Therefore, in this paper data are presented on the red cell and plasma volumes contained in the small vessels of some of the major organs of developing beagles from 5 hr to 7 months of age.

Materials and Methods. The beagles, ranging in age from 0 day (from 4 to 15 hr after birth) to 7 months of age, were anesthetized with a combination of morphine sulfate subcutaneously and sodium pentobarbital intravenously. The dose of each drug was adjusted to the age and size of the dog (2). Other experimental procedures were the same for all animals. The right atrium was cannulated with polyethylene tubing of appropriate size via the right external jugular vein for injections and for withdrawal of blood. Red cell and plasma volumes were determined by standard dilution methods using ^{51}Cr-tagged red cells (autologous, mother's, littermate's) and ^{131}I-tagged human serum albumin, respectively, as described previously (1). After mixing was complete in the circulation (30 min for red cells; 10 min for albumin) a blood sample was drawn, and then the animals were sacrificed by bleeding them either from the carotid artery, or in the case of very young pups (0–8 days) from the atrial catheter, until the bleeding stopped. The bleeding volumes for the different age groups are shown in Table I. The organs were excised, blotted to remove excess blood, weighed, recorded, and digested in concentrated HNO_3 (^{51}Cr) or 40% KOH (^{131}I) as reported elsewhere (6). The heart, lungs, kidneys, spleen, and stomach were digested as whole organs, while in large dogs aliquots of liver and intestines were used. Skin samples from the thoracic and abdominal regions and muscle samples from the left foreleg and right hindleg of each dog were excised and digested. The blood sample taken just prior to bleeding was used to calculate the circulating red cell and plasma volumes and the cell and plasma volumes in the small vessels of the tissues. In order to compare the ^{51}Cr and ^{131}I spaces of the various tissues of

TABLE I. Bleeding Volumes.

Age (days)	Body wt (kg)	Bleeding vol (ml/kg)	Bleeding vol % BV
0 (4–15 hr)	0.241 ± 0.005	26.8	28.1
1 (24–48 hr)	0.273 ± 0.009	50.4	48.4
7–8 (av 7.3)	0.464 ± 0.036	41.7	44.7
41–56 (av 46)	2.31 ± 0.185	50.4	60.0
3–7 months (90–225 days)	6.91 ± 0.481	52.4	59.0

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the growing beagle, the data were expressed in milliliters of cells, plasma, and blood per 100 g of wet tissue weight, and the total organ blood volumes as a percentage of the measured blood volumes. To calculate total organ volumes, the skin and skeletal muscle were taken to comprise 16.11 and 42.84%, respectively, of the total body weight (9). These values were probably somewhat in error for very young pups since it has been reported that the integument comprises a higher and skeletal muscle a lower percentage of body weight in the newborn beagle up to approximately 7 weeks of age (10). Average recovery for the individual isotopes was 81% for ^{131}I and 74% for ^{51}Cr, with no special attempt to recover the total amount injected, as we did not analyze the brain, skeleton, and some other small organs.

Results. The data are expressed in milliliters of cells and plasma per 100 g of wet tissue weight as shown in Table II. The total blood volume of organs as a percentage of the total circulating blood volume (relative organ blood volume) is shown in Table III.

Red cell volume. Red cell volume per unit weight of wet tissue for all organs was higher in the 4- to 15-hr-old (0-day) pups than that of the 1-day-olds (24–48 hr). The reduction was statistically significant for the heart, stomach, GI tract, and skin. The combined red cell volume of the nine tissues represented 28% of the total circulating red cell volume in 0-day-old and 16% in 1-day-old pups. Red cell volume (ml/100 g) of the heart, stomach, and muscle did not change significantly from the first day on. The tissues of the lungs, kidneys, liver, and spleen of the 3- to 7-month-old beagles contained more red cells per unit weight than those of the 0-day-old pups. The greatest variation in red cell content was found in the spleen and lungs. This was true for all age groups studied. After the first day the combined tissue cell volume was approximately a constant percentage of the total measured red cell volume, from 17 to 20% in the different age groups. In all groups of dogs the muscle, liver, and skin comprised approximately two-thirds of the body weight and contained approximately two-thirds of the combined red cell volume of the nine organs analyzed.

Plasma volume. The plasma volume (ml/100 g) of the 1-day-old pups was significantly greater than that of any other age group. Organ plasma volumes were more variable depending on the age and the particular organ. Between 0 and 1 days the plasma volume (ml/100 g) of the heart decreased significantly while that of the kidney increased significantly, with no further changes in either organ through the period of study. The plasma volume of the lungs, spleen, and stomach did not change significantly with growth. Plasma volume of the liver was reduced from 1 day through 46 days, and then it increased in the 3- to 7-month-old beagles. The plasma volume of the intestines decreased progressively with growth, but the differences were significant only between 1 day and 1 week and 1 week and 7–8 weeks of age. Skin plasma volume (ml/kg) decreased between 1 day and 1 week of age while muscle plasma volume did not change until the eighth week when there was a significant reduction. Relative organ plasma volume was 42% of the total circulating plasma volume in the 0- and 1-day-old beagles, and 20% at 5–7 months of age. The liver, muscle, and skin were the three organs containing the largest amounts of plasma.

Blood volume. In general, the tissues with the highest blood volume (ml/100 g) were the spleen, liver, lungs, heart, and kidneys. In spite of variation in the cell and plasma volumes of the various organs, milliliters of blood per 100 g wet tissue remained relatively constant from birth through the seventh month. Exceptions were the intestines, muscle, and skin insofar as the blood volume of these tissues decreased by one-half to two-thirds from 0 day to 3 to 7 months of age. With the exception of the stomach, the relative blood volume of each organ decreased from birth to 7 months of age. The blood contained in the nine organs of the newborn pup represented 36% of the total measured blood volume, while it was only 21% in the 3- to 7-month-old group, but in both groups the liver, muscle, and skin contained 70% of the total organ blood volume.

TABLE II. Residual Organ Red Cell and Plasma Volumes (ml/100 g wet tissue wt) of Growing Beagles.

	0 Day (4–15 hr)[a] (6)[c]		1 Day (24–48 hr)[a] (4)		7.3 Days (7–8)[a] (6)		46 Days (41–56)[a] (8)		148 Days (90–225)[a,b] (11)	
Vol:	Red cell	Plasma	Red cell	Plasma	Red cell	Plasma	Red cell	Plasma	Red cell	Plasma
Total body	4.08 ± 0.10[d]	5.47 ± 0.21	3.76 ± 0.42	6.65 ± 0.52	3.25 ± 0.17	6.08 ± 0.18	2.30 ± 0.17	6.09 ± 0.08	3.72 ± 0.22	5.15 ± 0.15
Heart	3.04 ± 0.21	7.27 ± 0.45	1.81 ± 0.25	5.86 ± 0.06	1.66 ± 0.22	5.83 ± 0.25	1.56 ± 0.42	5.77 ± 0.61	1.98 ± 0.02	4.87 ± 0.37
p[e]			< 0.01	< 0.05	NS	NS	NS	NS	NS	NS
Lung	3.04 ± 0.27	6.65 ± 0.69	2.75 ± 1.03	6.29 ± 0.78	3.53 ± 0.61	6.99 ± 0.34	2.69 ± 0.40	8.63 ± 0.96	4.38 ± 0.62	7.93 ± 0.37
p			NS	NS	NS	NS	NS	NS	< 0.05	NS
Kidney	1.65 ± 0.25	8.10 ± 0.62	1.12 ± 0.25	9.86 ± 0.33	1.11 ± 0.09	8.73 ± 0.42	1.22 ± 0.28	12.12 ± 1.87	1.95 ± 0.19	10.41 ± 0.60
p			NS	< 0.05	NS	NS	NS	NS	< 0.05	NS
Spleen	11.48 ± 3.06	9.09 ± 0.73	8.89 ± 2.67	10.3 ± 2.07	8.25 ± 1.06	7.30 ± 0.63	14.27 ± 4.52	6.52 ± 0.55	26.22 ± 4.53	6.37 ± 0.27
p			NS	NS	NS	NS	NS	NS	NS	NS
Liver	3.54 ± 0.67	8.96 ± 0.81	2.89 ± 0.79	10.69 ± 0.42	3.54 ± 0.50	8.59 ± 0.23	2.78 ± 0.59	5.91 ± 0.66	7.01 ± 0.68	8.26 ± 0.75
p			NS	NS	NS	< 0.01	NS	< 0.01	< 0.001	< 0.05
Stomach	1.06 ± 0.15	3.01 ± 0.32	0.41 ± 0.04	2.31 ± 0.84	0.31 ± 0.05	2.05 ± 0.42	0.23 ± 0.07	2.22 ± 0.20	0.53 ± 0.13	1.78 ± 0.33
p			< 0.01	NS	NS	NS	NS	NS	NS	NS
Intestines	1.60 ± 0.05	4.39 ± 0.44	0.80 ± 0.31	5.94 ± 1.09	0.65 ± 0.06	3.25 ± 0.13	0.24 ± 0.05	2.29 ± 0.24	0.65 ± 0.15	1.91 ± 0.13
p			< 0.02	NS	NS	< 0.02	< 0.001	< 0.01	< 0.05	NS
Muscle	0.85 ± 0.14	1.45 ± 0.16	0.47 ± 0.09	2.19 ± 0.44	0.39 ± 0.10	1.46 ± 0.12	0.36 ± 0.12	1.45 ± 0.07	0.41 ± 0.05	0.76 ± 0.04
p			NS	NS	NS	NS	NS	NS	NS	< 0.001
Skin	1.72 ± 0.20	2.50 ± 0.35	0.34 ± 0.12	2.82 ± 0.34	0.44 ± 0.06	1.24 ± 0.11	0.22 ± 0.07	1.04 ± 0.07	0.36 ± 0.06	1.06 ± 0.17
p			< 0.001	NS	NS	< 0.001	= 0.05	NS	NS	NS

[a] Mean ages and ranges.

[b] No significant difference was found in any of the cell volumes and plasma volumes of the 3-, 5-, and 7-month-old dogs; therefore, the data were combined into one group.

[c] Number of determinations per age group.

[d] Mean ± SE.

[e] p values are for differences between two consecutive age groups, e.g., cell volume day 0 vs cell volume day 1.

TABLE III. Residual Organ Blood Volumes and Hematocrits of Growing Beagles.

	0 Day (4–15 hr)[a]			1 Day (24–48 hr)			7.3 Days (7–8)			46 Days (41–56)			148 Days (90–225)		
	Blood vol[b]		Hematocrit[c]	Blood vol		Hematocrit	Blood vol		Hematocrit	Blood vol		Hematocrit	Blood vol		Hematocrit
	ml/100 g	%	%	ml/100 g	%	%	ml/100 g	%	%	ml/100 g	%	%	ml/100 g	%	%
Total body	9.95	100	42.7	10.40	100	35.9	9.33	100	34.8	8.39	100	27.4	8.87	100	41.9
Heart	10.31	1.00	29.5	7.67	0.70	23.6	7.49	0.62	22.2	7.33	0.54	21.3	6.85	0.56	28.9
Lung	9.69	2.34	31.4	9.04	2.07	30.4	10.52	1.66	33.5	11.32	1.38	23.8	12.31	1.84	35.6
Kidney	9.75	1.82	16.9	10.98	1.85	10.2	9.84	1.66	11.3	13.34	1.56	9.1	12.36	0.88	15.8
Spleen	20.57	1.13	55.8	19.19	0.80	46.3	15.55	1.29	53.0	20.79	1.00	68.6	32.59	0.79	80.4
Liver	12.50	8.13	28.3	13.58	6.49	21.3	12.13	5.58	29.2	8.69	4.38	32.0	15.27	5.36	45.9
Stomach	4.07	0.28	26.0	2.72	0.27	15.1	2.36	0.34	13.0	2.45	0.64	9.4	2.31	0.48	22.9
Intestines	5.99	3.78	26.7	6.74	3.78	11.9	3.90	2.19	16.7	2.53	2.14	9.5	2.56	1.81	25.4
Muscle	2.30	10.65	36.9	2.66	11.19	17.7	1.85	8.08	21.1	1.81	8.87	19.9	1.17	5.90	35.0
Skin	4.22	7.26	40.7	3.16	4.84	10.8	1.68	3.02	26.2	1.26	2.38	17.5	1.42	2.96	25.3
Total organs	8.82[d]	36.40		8.41[d]	32.0		7.26[d]	24.4		7.72[d]	22.9		9.65[d]	20.6	

[a] Mean ages and ranges.

[b] Organ blood vol (ml) ÷ total body blood vol = organ blood vol (%).

[c] Red cell vol (ml/100 g) ÷ red cell + plasma vol (ml/100 g) = hematocrit.

[d] Average blood vol (ml/100 g) for the 9 organs.

Hematocrits. The hematocrits were calculated for each organ by dividing the red cell volume (ml/100 g) by the combined red cell and plasma volume (blood volume, ml/100 g) of that organ. In all age groups the hematocrit of the spleen was higher than the corresponding body and venous hematocrits. In addition, the liver had a higher concentration of red cells than the total body and the large vessel blood in the 46-day and 3- to 7-month-old groups. The lowest hematocrits recorded were those for the 46-day-old pups.

Discussion. Residual red cell and blood volumes (ml/100 g wet tissue) in the small vessels of each of the nine organs analyzed were highest in the newborn pup (0 to 1 day old). The combined residual blood volume of the nine organs expressed as a percentage of the animals' total circulating blood volume was reduced progressively with age, from 36% in the 0-day-old to 20% in the 3- to 7-month-old pups. Among some of the factors determining the amount of blood remaining in the tissues after an acute, lethal hemorrhage would be the amount of blood removed prior to excision of the tissues. However, this does not necessarily follow from these data since the bleeding volume of the 0-day-old pups was 28% of the blood volume and the remaining blood in the organs represented 36%, while in the 1-day-old pups the bleeding volume was 48% with 32% remaining in the organs, and in the 1-week-old pups with a 45% bleeding volume, the organs contained 24% of the total blood volume. Perhaps a reasonable explanation for the relatively larger amount of blood in the small vessels of the very young pups is that reflex control of the circulation is not yet fully developed at birth. Recently it was reported that the autonomic control of the heart of the newborn dog was poorly developed and at 3 months of age it was only 50% of that of an adult dog (11). This is also true for newborn humans, who, in contrast to adults, do not maintain their blood pressure well during hemorrhage or anoxia (12). However, the rabbit seems to be an exception to these findings since the circulatory mechanisms of a newborn rabbit to maintain arterial pressure were found to be as efficient as those of an adult rabbit (13).

The data on 3- to 7-month-old dogs compare well with data on adult mongrel dogs by the same method (6). In the living animal the small vessels of the muscle, skin, and liver of the dog, as well as of other species, contain a large percentage of the total blood volume (4-7).

Organ or small vessel hematocrits, with the exception of the spleen and in the 46-day and 3- to 7-month-old pups the liver, were lower than the jugular or large vessel hematocrits, as has been found for adult mongrel dogs (5–6). Total body hematocrit was also less than the venous hematocrit; however, with growth, the ratio tended to approach unity. This might be a reflection on the ability of the older pups to constrict their spleen as a result of the bleeding, thereby increasing the small vessel hematocrit (14).

Summary. Residual red cell, plasma, and blood volumes were measured in the small vessels of nine major organs of the developing beagle, ranging in age from 4 hr to 7 months. The animals were sacrificed by bleeding. The tissues analyzed were the heart, lung, kidney, spleen, liver, stomach, intestines, muscle, and skin. The data showed that these organs contain a significantly larger volume of the total blood volume in the newborn than in the 3- to 7-month-old dogs. In all age groups the muscle, skin, and liver contained the largest amount of blood, approximately 70% of the total organ blood volume. With the exception of the spleen, and in some cases the liver, the organ hematocrits for a particular age group were lower than the corresponding total body and the large vessel hematocrits.

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