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SUGGESTED REFERENCE VALUES FOR REGIONAL BLOOD VOLUMES IN CHILDREN AND ADOLESCENTS

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Abstract

Estimates of regional blood volumes (BVs) in humans are needed in dosimetric models of radionuclides and radiopharmaceuticals that decay in the circulation to a significant extent. These values are also needed to refine models of tissue elemental composition in computational human phantoms of both patients and exposed members of the general public. The International Commission on Radiological Protection (ICRP) in its Publication 89 provides reference values for total blood content in the full series of their reference individuals, to include the male and female newborn, 1-year-old, 5-year-old, 10-year-old, 15-year-old, and adult. Furthermore, Publication 89 provides reference values for the percentage distribution of total blood volume in 27 different blood-filled organs and tissues of the reference adult male and adult female. However, no similar distribution values are provided for non-adults. The goal of the present study is to present a volumetric scaling methodology to derive these values for the same organs and tissues at ages younger than the reference adult. Literature data on organ-specific vascular growth in the brain, kidneys, and skeletal tissues are also considered.

Keywords

Pediatric blood volumes; regional blood distribution; reference individuals

1. Introduction

Knowledge of the regional distribution of blood within the organs and tissues of the human body is an important component for both biokinetic and dosimetric models used in the field

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of internal dosimetry for radionuclides. In both diagnostic and therapeutic nuclear medicine, radiopharmaceuticals with short-lived radionuclides are administered, to a large extent, by intravenous injection. Thus, a non-trivial fraction of the radionuclide may decay while the agent is within veins, arteries, and capillary beds prior to organ parenchyma uptake or following metabolic release back to blood. As a consequence, blood within the circulatory system becomes a “source” region for radiation transport and must be considered in addition to radionuclide decays within organ parenchyma following tissue deposition and retention. The same situation is of relevance to occupational and environmental radionuclide exposures following inhalation or ingestion of short-lived radionuclides, where a meaningful fraction of the activity intake translocates to blood from the respiratory and/or alimentary tract organs.

In both the MIRD and ICRP systems of internal dosimetry (Bolch *et al.*, 2009; ICRP, 2016), estimates of organ dose from internal emitters are based in part on radiation transport of photons, electrons, and alpha particles and the tabulation of specific absorbed fractions for all combinations of source and target tissues. Again, blood can be an important source region to consider in computational human phantoms representing either patients or occupationally exposed individuals. In many computational phantoms, geometric models of the circulatory system are limited, at most, to modeling major veins and arteries, with no attempt to spatially represent smaller vessels and capillaries. For example, the majority of computational phantoms published to date model the liver as a single collection of voxels or as a single bounded region defining the liver surface. The interior vasculature of the liver is not explicitly represented. Monte Carlo sampling of sites of radionuclide decay in the liver serve two purposes – (1) they represent decays of radionuclides localized within liver parenchyma, and (2) they represent decays of radionuclides localized within the liver vasculature, where the latter constitutes only a portion of a total body blood source. These computational models of the liver must be modeled using elemental compositions that represent a homogeneous mixture of both liver parenchyma and incorporated blood. As outlined in ICRP Publication 110 for the reference adults, the reference elemental composition of tissues given in either ICRP Publication 89 (ICRP, 2002) or in ICRU Report 46 (ICRU, 1992) comprise the elemental composition of organ parenchyma only. Additional modeling is needed to adjust these elemental compositions to properly account for their organ blood content, which in turn requires knowledge of blood volumes in each body tissue.

ICRP Publication 89, in defining the most recent physiological and anatomic properties of Reference Individuals, provides reference values for total blood content in each of the ICRP reference individuals – newborn, 1-year-old, 5-year-old, 10-year-old, 15-year-old, and adult – both male and female. Further information is also given on the regional distribution of total blood within all blood-filled body tissues, but only for reference adults. The goal of the present study is to extend that model of regional blood distribution to the remaining 10 members of the ICRP family of reference individuals. Accordingly, the scope of this study is limited to modeling adjustments of the ICRP adult blood distribution model. The values given here are thus open to future validation via vascular imaging studies in the pediatric patient population. We also note that reference values from ICRP are to be used for

radiological protection purposes only, and thus they are to be used without consideration of uncertainties or individual variations.

2. Materials and Methods

Reference values for total blood volume within the ICRP age-dependent series of reference individuals are given in Section 7.4 of ICRP Publication 89 (ICRP, 2002) (reproduced here in Table 1, following a conversion to cm³ from liters). They were based on data collected from 18 studies involving healthy subjects who were resting in the recumbent position at the time of measurement (Williams, 1994). Section 7.7.2 of ICRP Publication 89 further provides reference values for both the percent of total blood assigned to different organs and tissues of the reference adult male and adult female (reproduced here in Table 2).¹ These values were based upon an extensive review and analysis of the literature (Williams and Leggett, 1989; Leggett and Williams, 1991, 1995). While Section 7.7.3 of Publication 89 discusses both the physiological and anatomic bases for an age-dependence of the regional distribution of total body blood, no specific reference values are given beyond those for adults.

Our derivation of age-specific fractional blood volumes by anatomic region begins with the initial assumption that the volume ratio of organ blood to organ parenchyma is invariant with age. Accordingly, estimates of absolute and relative age- and gender-dependent organ blood volumes may be derived given their corresponding adult values as:

$$V_{blood}^{organ}(a, s) = V_{blood}^{organ}(adult, s) \left[\frac{V_{parenchyma}^{organ}(a, s)}{V_{parenchyma}^{organ}(adult, s)} \right] \quad 1$$

$$f_{blood}^{organ}(a, s) = \frac{V_{blood}^{organ}(adult, s)}{\sum V_{blood}^{organ}(adult, s)} \quad 2$$

where $V_{blood}^{organ}(a, s)$ and $f_{blood}^{organ}(a, s)$ are the absolute and fractional blood volumes, respectively, in the organ of interest for reference person of age a and gender s , and $V_{parenchyma}^{organ}(a, s)$ is the corresponding value for the organ parenchyma volume. Age-dependent reference organ volumes needed for Eq. 1 may be derived as ratios of their corresponding age-dependent reference organ mass (as given in Table 2.8 of ICRP Publication 89), and an appropriate tissue mass density. In this study, we adopt (when available) the age- and gender-dependent tissue densities tabulated in Appendix A of ICRU Report No. 46 (ICRU, 1992). Values of $V_{blood}^{organ}(adult, s)$ for the adult male and adult female are computed using data from Tables 1 and 2.

¹For improved clarity, the listings for “pulmonary” and “bronchial tissues” in ICRP Publication 89 are listed in Table 2 as “pulmonary gas exchange blood” and “lung nutrient blood”, respectively.

While Eq. 1 presents a physiologically realistic method of extending the data of Table 2 to ages younger than the adult, four tissues require further adjustment as discussed in ICRP Publication 89. First, the percentage of cardiac output to the kidneys may be substantially lower in infants than adults but appears to increase to within a few percent of the values for adults by ages 2–3 years. Second, the brain in children may have higher blood perfusion rates (BPR) than seen in adults. Third, the mineral bone has been shown to have BPRs and total blood content up to 2 to 3 times higher than in adults as based upon animal studies. Fourth, marrow cellularity² changes dramatically across the skeleton as a function of age, and presumably the blood content of active marrow varies accordingly.

These four tissues were thus investigated further to determine if vascular scaling factors (VSFs) could be developed to effectively correct for these regional changes in blood volume per organ parenchyma volume. When direct information on blood volume per organ volume was not available, it was assumed that relative BPRs were direct indicators of these regional changes in vascular growth. It was also decided that a ratio of either BPR or blood volume per organ parenchyma volume would be used to define the VSF. As such, the volume scaling methodology of Eq. 1 was retained, but an additional term – the VSF – would be introduced to further adjust the computed regional blood volume for the kidneys, brain, mineral bone, and active marrow.

Rubin et al. (1949) provides renal plasma flow normalized to the adult body surface area ($\text{cm}^3/\text{min}/1.73 \text{ m}^2$) for 5 ages between 0 and 3 years. Renal plasma flow rates were shown to reach the adult value at about 3 years of age. At the reference ages of the newborn/infant (100 d) and the 1-year-old, the data shown in Figure 1 were used to assign an average renal plasma flow rate. The age-specific values were then divided by the adult value to obtain the VSF.

Data of Chiron et al. (1992) were used to calculate vascular scaling factors for the brain. This study provided the mean global cerebral blood flow (mCBF) in $\text{mL}/\text{min}/100 \text{ g}$ of tissue for 22 ages between 0 and 22 years. Forty-two children between the ages of 2 days and 19 years were imaged using ^{133}Xe single-photon emission computed tomography (SPECT). The adult value was taken as the average obtained over 32 patients between the ages of 19 and 29 years. The authors used an algorithm described by Celsis et al. (1981) to compute the regional cerebral blood flow (rCBF) for 25 regions of interest (ROIs) covering the cortical ribbon, thalamus, and both brain hemispheres as a whole. The mCBF was calculated as the average of all hemisphere ROIs on the upper 4 image slices and whole brain on the bottom image slice. The results of their study can be seen in Figure 2. The adult mCBF was taken to be $51 \text{ mL}/\text{min}/100 \text{ g}$ tissue (22-year-old value). Vascular scaling factors for all reference ages were thus computed as the ratio of the mCBF at the age of interest to the adult value.

Simonet et al. (1988) reported direct measurements of vascular volume per unit volume organ (mL/mL organ) for mineral bone in dogs for a pup, adolescent, and adult canine. In our study, the value reported for the pup was assigned to the reference newborn and 1-year human, while the value reported for the adolescent was assigned to the reference 15-year

²Percentage of marrow volume that is hematopoietically active.

human. Vascular volumes per unit organ volume for the reference 5-year-old and 10-year-old humans were linearly interpolated between the 1-year-old and 15-year-old measurements. The vascular scaling factors were computed as the ratio of the age-dependent vascular volumes to the adult vascular volume in dogs.

Vascular scaling factors for active marrow in children were computed as ratios of age-dependent skeletal-averaged marrow cellularities to the value for the reference adult. Skeletal-averaged marrow cellularities at each reference age were computed as the sum of the product of the bone-specific marrow cellularity and the bone-specific percent distribution of active marrow, with these values taken from Tables 41 and 40 of ICRP Publication 70, respectively (ICRP, 1995). The skeletal-averaged marrow cellularity for the reference adult is 0.58, while that for the newborn, 1-year, 5-year, 10-year, and 15-year reference persons are 1.0, 0.91, 0.76, 0.67, and 0.65, respectively. These changes in bone-specific and skeletal-averaged marrow cellularity are assumed to depend only on subject age and not gender.

Derived values of vascular scaling factors $R_{vas}^{organ}(a, s)$, which may be used to correct for regional changes in vascular growth of this select sub-set of organs at gender s and reference age a , are given in Table 3. Accordingly, we revise Eq. 1 to include this additional term, noting that its value is unity for organs other than kidneys, brain, trabecular bone, cortical bone, and active marrow. Using the revised estimates of blood volumes from Eq. 3 below, Eq. 2 is then used to provide final suggested estimates of relative regional blood distribution in the series of ICRP reference individuals.

$$V_{blood}^{organ}(a, s) = R_{vas}^{organ}(a, s) \times V_{blood}^{organ}(adult, s) \times \left[\frac{V_{parenchyma}^{organ}(a, s)}{V_{parenchyma}^{organ}(adult, s)} \right] \quad 3$$

3. Results

In Table 4, we present our estimates of reference organ volumes $V_{blood}^{organ}(a, s)$ following the same organ and tissue list given in Table 2 for the reference adult. Reference organ masses are taken directly from ICRP Publication 89, Table 2.8, when available. Values of tissue density are taken from Appendix A of ICRU Report 46 (ICRU, 1992), in which age/gender dependent values were adopted when available.

The reference masses for “fat” in Table 4 are taken as those reported for “body fat” in Section 4.3.3. of Publication 89.³ The reference masses of blood in the right and left heart contents as a whole are taken to be the difference between the reference masses for “Heart – with blood” and “Heart – tissue only”, with the latter assigned to “Coronary Tissues”. The blood masses within the heart chambers are then assumed to be equally distributed within

³Adipose tissue is a loose connective tissue containing fat cells specialized for storage of triglycerides. Adipose tissue is often equated with fat, but it also contains non-fatty tissue including elastic and collagenous fibers and cells with different functions including immune cells. Fat represents less than half the mass of adipose tissue in newborns, but the fat fraction increases with age to 80% or more during adulthood.

the left and right heart chambers. In order to derive lung parenchyma masses, we take the differences in masses for “lung – with blood” and “lung – tissue only” as given in Table 2.8 of ICRP Publication 89. A mass density of 1.0 g cm^{-3} is applied, a value taken from Section 5.3.6 of Publication 89 for the specific gravity of blood-free, air-free lung tissue.

The computation of “Other Skeletal Tissues” is outlined at the bottom of Table 4 to include inactive marrow, cartilage, teeth, and miscellaneous skeletal tissues. Publication 89 does not explicitly provide age / gender dependent values of lymphatic node masses, and thus these values were taken from Table 3 of Lee et al. (2013) where these values are given based on Publication 89 data on lymph size, number, and regional distribution. At the bottom of Table 4, we provide our estimates for “All Other Tissues”, whose reference masses are taken to be the difference between “Total Body Tissues” (defined as the total body mass less those of the walled organ contents) and the summation of reference organ masses listed above. Values for “Total Body Tissues” are taken from data in Table 6 of Lee *et al.* (2010) who computed their values for the UF/NCI series of reference hybrid phantoms.

Table 5 presents our estimates of reference blood volumes for the entire series of ICRP reference individuals as computed via Eq. 3 and the data of Table 4. Reference adult values are given using data from Tables 1 and 2, with organ parenchyma volumes carried over from Table 4. Similarly, blood volumes for heart contents, aorta and large arteries, and large veins are taken from their corresponding values in Table 4 and are thus not computed via Eq. 3. For the blood content assigned to lung tissues, Eq. 3 was also not invoked. Instead, this reference blood volume was computed directly from the reference values given in Section 5.3.3 of ICRP Publication 89.⁴

Using both the derived blood volumes from Table 5 from Eq. 3, we present in Table 6 suggested reference values for the regional blood distribution within the tissues and organs of the full ICRP series of reference individuals. As noted in the italicized entries, Eq. 3 was not applied to the right and left heart contents, pulmonary gas exchange and lung nutrient blood pools, or the aorta, large arteries, and large veins. For these blood regions, it was deemed appropriate to fix the age-dependent blood distribution percentages to their reference adult values. For the other tissues, direct application of Eqs. 2 and 3, using the corresponding gender-specific adult values of organ and blood volumes, would yield corresponding gender-specific values of $f_{blood}^{organ}(a, s)$ for the newborn to 10-year-old.

However, these values would be artificially imposed by the methodology of Eq. 3 in which differences in regional blood distribution seen in the adults are transferred to the derived values for children. Resultantly, only gender-averaged values are given in Table 5 in a manner consistent with other reference anatomical values for these members of the ICRP age-dependent series. Values of $f_{blood}^{organ}(a, s)$ from Table 6 are then applied to the reference total blood volumes of Table 1 to give regional and absolute blood volumes by anatomic region in Table 7. Accordingly, conformity with total blood volume reference values is achieved.

⁴Difference between reference lung masses “including pulmonary and bronchial blood” and reference lung masses “excluding blood”.

4. Discussion

At the bottom of Table 5, we compare the summed total of our derived tissue-specific blood volumes to the ICRP reference values of Table 1. Since our methodology is based upon the reference adult fractional distribution of blood of Table 2, an exact agreement is seen for the reference adults. Agreement between reference total blood volumes and the summation of our derived organ-specific values, however, varies across the ICRP reference series. Agreements ranging from 1% to 11% are seen for the male and female newborn, 5-year-old, 10-year-old, and 15-year-old. An overestimate of the assigned reference total blood volume is seen, however, for the reference 1-year male (+42%) and the reference 1-year female (+34%). This disagreement is not fully unexpected as reference values for organ masses and tissue densities come from a variety of sources, which can lead to high variability of values from which ICRP reference values are derived. Additionally, the reference value of 500 cm³ for the total blood volume in the 10-kg 1-year-old child may be an underestimate. Nevertheless, the goal of the present study was not to confirm reference total blood volumes by an organ-by-organ accounting of their blood content, but to derive an extended set of $f_{blood}^{organ}(a, s)$ values for the non-adult members of ICRP reference individuals.

The suggested reference values of $f_{blood}^{organ}(a, s)$ can at times differ substantially from the corresponding reference adult values. In looking at ratios of $f_{blood}^{organ}(a, s)$ to $f_{blood}^{organ}(a, s)(adult, s)$ in the data of Table 6, we see that values for the brain vary from a low of 1.14 (15-year female) to a high of 4.51 (newborn), that values for the kidneys vary from a low of 0.35 (newborn) to a high of 1.09 (10-year-old), that values for active marrow vary from a low of 1.21 (15-year female) to a high of 1.30 (newborn), that values for trabecular bone vary from a low of 3.03 (newborn) to a high of 3.66 (1-year-old and 10-year-old), and that values for cortical bone vary from a low of 1.62 (newborn) to a high of 2.02 (10-year-old). The extremes in this comparison are found for the testes of the 10-year male (ratio of 0.18) and the adrenal glands of the newborn (ratio of 6.91).

The present study provides suggested reference values for the organ-level distribution of total blood within the various ICRP pediatric reference individuals. These values are assigned based upon modeling assumptions regarding (1) proportional changes in assigned adult values based upon volumetric proportions of individual organs in the child relative to their adult values, and (2) specific assumptions regarding age-related changes in organ vascularity within the brain, kidneys, and skeleton. These values should be thus be considered provisional and subject to change given new data on organ vascular volumes in children and adolescents.

5. Conclusions

To date, the ICRP has provided reference values for total blood volume for each member of the ICRP series of reference individuals, but has given guidance for its tissue-specific distribution only for the reference adult male and female. These adult values were integral to the development of tissue models and anatomical characteristics of the ICRP Publication 110 adult reference phantoms (ICRP, 2009). In this work, we propose a volumetric scaling

methodology to derive similar values of fractional blood distribution among the same organs and tissues in the reference newborn, 1-year-old, 5-year-old, 10-year-old, and 15-year-old. The methodology further introduces the concept of vascular scaling factors for the brain, kidneys, active marrow, trabecular bone, and cortical bone to account for presumed age-dependent changes in vascular growth in these tissues. The resulting model may be applied to the construction of tissue models for pediatric phantoms – both reference and non-reference as appropriate. These values are also important for the construction of age-dependent biokinetic models in both radiological protection and nuclear medicine, where explicit treatment of blood as a source of radiation emissions is important to organ dosimetry.

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Figure 1.

Renal plasma flow rates in (A) infants and (B) older children. The solid and dashed lines represent the mean and one standard deviation, respectively, determined from data for adults. These graphs were originally published as Figures 2A and 2B, respectively, in Rubin et al. (1949).

Figure 2.
Mean and regional cerebral blood flow as a function of age. This graph was originally published as Figure 3 in Chiron et al. (1992).

Table 1.Reference values for total blood volume (cm³).

Age	Male	Female
Newborn	270	270
1-year	500	500
5-year	1400	1400
10-year	2400	2400
15-year	4500	3300
Adult	5300	3900

Source: ICRP Publication 89, Section 7.4

Table 2.

Reference values for relative regional blood volumes in the reference adults.

Organ or Tissue	Blood Content (% Total Blood Volume)	
	Adult Male	Adult Female
Fat	5.00	8.50
Brain	1.20	1.20
Stomach & Esophagus Wall	1.00	1.00
Small Intestine Wall	3.80	3.80
Large Intestine Wall	2.20	2.20
Right Heart Contents	4.50	4.50
Left Heart Contents	4.50	4.50
Coronary Tissues	1.00	1.00
Kidneys	2.00	2.00
Liver	10.00	10.00
Lungs		
Pulmonary Gas Exchange Blood	10.50	10.50
Lung Nutrient Blood	2.00	2.00
Skeletal Muscle	14.00	10.50
Pancreas	0.60	0.60
Skeletal Tissues		
Active Marrow	4.00	4.00
Trabecular Bone	1.20	1.20
Cortical Bone	0.80	0.80
Miscellaneous Skeletal Tissues	1.00	1.00
Skin	3.00	3.00
Spleen	1.40	1.40
Thyroid	0.06	0.06
Lymphatic Nodes	0.20	0.20
Testes or Ovaries	0.04	0.02
Adrenal Glands	0.06	0.06
Urinary Bladder Wall	0.02	0.02
All Other Tissues	1.92	1.92
Aorta and Large Arteries	6.00	6.00
Large Veins	18.00	18.00
	100.00	99.98

Source: ICRP Publication 89, Section 7.7.2

Table 3.

Vascular scaling factors for tissues with changing rates of blood vessel growth.

Age	Brain	Kidneys	Trabecular	Cortical	Active
			Bone	Bone	Marrow
Newborn	1.04	0.26	4.70	2.60	1.72
1-year-old	1.16	0.67	4.70	2.60	1.57
5-year-old	1.39	1.00	4.40	2.40	1.31
10-year-old	1.33	1.00	4.00	2.20	1.15
15-year-old	1.13	1.00	3.70	1.90	1.11
Adult	1.00	1.00	1.00	1.00	1.00

Table 4.

Derivation of reference organ volumes as needed in Equation 3.

Organ / Tissue	Male - Newborn			Female - Newborn			Male - 1 Year			Female - 1 Year		
	Mass (g)	Density (g/cm ³)	Vol (cm ³)	Mass (g)	Density (g/cm ³)	Vol (cm ³)	Mass (g)	Density (g/cm ³)	Vol (cm ³)	Mass (g)	Density (g/cm ³)	Vol (cm ³)
Fat [²]	370	0.99	373.74	370	0.99	373.74	2300	0.96	2395.83	2300	0.96	2395.83
Brain	380	1.03	368.93	380	1.03	368.93	950	1.03	922.33	950	1.03	922.33
Stomach & Esophagus Wall	9	1.03	8.74	9	1.03	8.74	25	1.03	24.27	25	1.03	24.27
Small Intestine Wall	30	1.03	29.13	30	1.03	29.13	85	1.03	82.52	85	1.03	82.52
Colon Wall	17	1.03	16.50	17	1.03	16.50	50	1.03	48.54	50	1.03	48.54
Right Heart Contents	13	1.07	12.15	13	1.07	12.15	24	1.06	22.64	24	1.06	22.64
Left Heart Contents	13	1.07	12.15	13	1.07	12.15	24	1.06	22.64	24	1.06	22.64
Coronary Tissues	20	1.04	19.23	20	1.04	19.23	50	1.04	48.08	50	1.04	48.08
Kidneys	25	1.03	24.27	25	1.03	24.27	70	1.04	67.31	70	1.04	67.31
Liver	130	1.04	125.00	130	1.04	125.00	330	1.05	314.29	330	1.05	314.29
Lung Tissues [³]	30	1.00	30.00	30	1.00	30.00	80	1.00	80.00	80	1.00	80.00
Skeletal Muscle	800	1.05	761.90	800	1.05	761.90	1900	1.05	1809.52	1900	1.05	1809.52
Pancreas Skeletal Tissues	6	1.04	5.77	6	1.04	5.77	20	1.04	19.23	20	1.04	19.23
Skeletal Tissues												
Active Marrow	50	1.03	48.54	50	1.03	48.54	150	1.03	145.63	150	1.03	145.63
Trabecular Bone	35	1.72	20.35	35	1.72	20.35	120	1.71	70.18	120	1.71	70.18
Cortical Bone	135	1.72	78.49	135	1.72	78.49	470	1.71	274.85	470	1.71	274.85
Other Skeletal Tissues	151		138.24	151		138.43	430		395.92	430		396.34
Skin	175	1.05	166.67	175	1.05	166.67	350	1.09	321.10	350	1.09	321.10
Spleen	9.5	1.04	9.13	9.5	1.04	9.13	29	1.06	27.36	29	1.06	27.36
Thyroid	1.3	1.05	1.24	1.3	1.05	1.24	1.8	1.05	1.71	1.8	1.05	1.71
Lymphatic Nodes [⁴]	10	1.03	9.71	10	1.03	9.71	29	1.03	28.16	29	1.03	28.16
Testes or Ovaries	0.85	1.04	0.82	0.3	1.05	0.29	1.5	1.04	1.44	0.8	1.05	0.76
Adrenal Glands	6	1.03	5.83	6	1.02	5.88	4	1.03	3.88	4	1.02	3.92
Urinary Bladder Wall	4	1.04	3.85	4	1.04	3.85	9	1.04	8.65	9	1.04	8.65

Organ / Tissue	Male - Newborn			Female - Newborn			Male - 1 Year			Female - 1 Year		
	Mass (g)	Density (g/cm ³)	Vol (cm ³)	Mass (g)	Density (g/cm ³)	Vol (cm ³)	Mass (g)	Density (g/cm ³)	Vol (cm ³)	Mass (g)	Density (g/cm ³)	Vol (cm ³)
All Other Tissues	850	1.03	825.55	851	1.03	826.08	2161	1.03	2097.57	2161	1.03	2098.25
Aorta and Large Arteries	17	1.07	16.20	17	1.07	16.20	32	1.06	30.00	32	1.06	30.00
Large Veins	52	1.07	48.60	52	1.07	48.60	95	1.06	90.00	95	1.06	90.00

Other Skeleton	Male - Newborn			Female - Newborn			Male - 1 Year			Female - 1 Year		
	Mass (g)	Density (g/cm ³)	Vol (cm ³)	Mass (g)	Density (g/cm ³)	Vol (cm ³)	Mass (g)	Density (g/cm ³)	Vol (cm ³)	Mass (g)	Density (g/cm ³)	Vol (cm ³)
Inactive Marrow	0	0.98	0.00	0	0.98	0.00	20	0.98	20.41	20	0.98	20.41
Cartilage	130	1.10	118.18	130	1.10	118.18	360	1.10	327.27	360	1.10	327.27
Teeth	0.7	1.10	0.64	0.7	1.10	0.64	5	1.10	4.55	5	1.10	4.55
Miscellaneous Tissues	20	1.03	19.42	20	1.02	19.61	45	1.03	43.69	45	1.02	44.12
Totals	150.70		138.24	150.70		138.43	430.00		395.92	430.00		396.34

All Other Tissues												
Total Body Tissues [²]	3340			3340			9790			9790		
Total Organ Masses (above)	2490			2489			7630			7629		
Totals	850	1.03	825.55	851	1.03	826.08	2161	1.03	2097.57	2161	1.03	2098.25

Organ / Tissue	Male - 5 Year			Female - 5 Year			Male - 10 Year			Female - 10 Year		
	Mass (g)	Density (g/cm ³)	Vol (cm ³)	Mass (g)	Density (g/cm ³)	Vol (cm ³)	Mass (g)	Density (g/cm ³)	Vol (cm ³)	Mass (g)	Density (g/cm ³)	Vol (cm ³)
Fat [²]	3600	0.96	3750.00	3600	0.96	3750.00	6000	0.96	6250.00	6000	0.96	6250.00
Brain	1310	1.04	1259.62	1180	1.04	1134.62	1400	1.04	1346.15	1220	1.04	1173.08
Stomach & Esophagus Wall	60	1.03	58.25	60	1.03	58.25	103	1.03	100.00	103	1.03	100.00
Small Intestine Wall	220	1.03	213.59	220	1.03	213.59	370	1.03	359.22	370	1.03	359.22
Colon Wall	120	1.03	116.50	120	1.03	116.50	210	1.03	203.88	210	1.03	203.88
Right Heart Contents	68	1.06	63.68	68	1.06	63.68	115	1.06	108.49	115	1.06	108.49

Organ / Tissue	Male - Newborn			Female - Newborn			Male - 1 Year			Female - 1 Year		
	Mass (g)	Density (g/cm ³)	Vol (cm ³)	Mass (g)	Density (g/cm ³)	Vol (cm ³)	Mass (g)	Density (g/cm ³)	Vol (cm ³)	Mass (g)	Density (g/cm ³)	Vol (cm ³)
Left Heart Contents	68	1.06	63.68	68	1.06	63.68	115	1.06	108.49	115	1.06	108.49
Coronary Tissues	85	1.04	81.73	85	1.04	81.73	140	1.04	134.62	140	1.04	134.62
Kidneys	110	1.04	105.77	110	1.04	105.77	180	1.04	173.08	180	1.04	173.08
Liver	570	1.05	542.86	570	1.05	542.86	830	1.05	790.48	830	1.05	790.48
Lung Tissues [³]	125	1.00	125.00	125	1.00	125.00	210	1.00	210.00	210	1.00	210.00
Skeletal Muscle	5600	1.05	5333.33	5600	1.05	5333.33	11000	1.05	10476.19	11000	1.05	10476.19
Pancreas	35	1.04	33.65	35	1.04	33.65	60	1.04	57.69	60	1.04	57.69
Skeletal Tissues												
Active Marrow	340	1.03	330.10	340	1.03	330.10	630	1.03	611.65	630	1.03	611.65
Trabecular Bone	250	1.75	142.86	250	1.75	142.86	460	1.79	256.98	460	1.79	256.98
Cortical Bone	1010	1.75	577.14	1010	1.75	577.14	1840	1.79	1027.93	1840	1.79	1027.93
Other Skeletal Tissues	830		771.21	830		771.73	1570		1488.57	1570		1489.42
Skin	570	1.09	522.94	570	1.09	522.94	820	1.09	752.29	820	1.09	752.29
Spleen	50	1.06	47.17	50	1.06	47.17	80	1.06	75.47	80	1.06	75.47
Thyroid	3.4	1.05	3.24	3.4	1.05	3.24	7.9	1.05	7.52	7.9	1.05	7.52
Lymphatic Nodes [⁴]	55	1.03	53.40	55	1.03	53.40	92	1.03	89.32	92	1.03	89.32
Testes or Ovaries	1.7	1.04	1.63	2	1.05	1.90	2	1.04	1.92	3.5	1.05	3.33
Adrenal Glands	5	1.03	4.85	5	1.02	4.90	7	1.03	6.80	7	1.02	6.86
Urinary Bladder Wall	16	1.04	15.38	16	1.04	15.38	25	1.04	24.04	25	1.04	24.04
All Other Tissues	2388	1.03	2318.19	2517	1.03	2444.12	4978	1.03	4832.56	5156	1.03	5005.86
Aorta and Large Arteries	89	1.06	84.00	89	1.06	84.00	153	1.06	144.00	153	1.06	144.00
Large Veins	267	1.06	252.00	267	1.06	252.00	458	1.06	432.00	458	1.06	432.00

Other Skeleton	Male - 5 Year			Female - 5 Year			Male - 10 Year			Female - 10 Year		
	Mass (g)	Density (g/cm ³)	Vol (cm ³)	Mass (g)	Density (g/cm ³)	Vol (cm ³)	Mass (g)	Density (g/cm ³)	Vol (cm ³)	Mass (g)	Density (g/cm ³)	Vol (cm ³)
Inactive Marrow	160	0.98	163.27	160	0.98	163.27	630	0.98	642.86	630	0.98	642.86
Cartilage	600	1.10	545.45	600	1.10	545.45	820	1.10	745.45	820	1.10	745.45

Organ / Tissue	Male - Newborn			Female - Newborn			Male - 1 Year			Female - 1 Year		
	Mass (g)	Density (g/cm ³)	Vol (cm ³)	Mass (g)	Density (g/cm ³)	Vol (cm ³)	Mass (g)	Density (g/cm ³)	Vol (cm ³)	Mass (g)	Density (g/cm ³)	Vol (cm ³)
Teeth	15	1.65	9.09	15	1.65	9.09	30	2.33	12.88	30	2.33	12.88
Miscellaneous Tissues	55	1.03	53.40	55	1.02	53.92	90	1.03	87.38	90	1.02	88.24
Totals	830.00		771.21	830.00		771.73	1570.00		1488.57	1570.00		1489.42
All Other Tissues							0					
Total Body Tissues [²]	17845			17845			31855			31855		
Total Organ Masses (above)	15457			15328			26877			26699		
Totals	2388	1.03	2318.19	2517	1.03	2444.12	4978	1.03	4832.56	5156	1.03	5005.86

Organ / Tissue	Male - 15 Year			Female - 15 Year			Male - Adult			Female - Adult		
	Mass (g)	Density (g/cm ³)	Vol (cm ³)	Mass (g)	Density (g/cm ³)	Vol (cm ³)	Mass (g)	Density (g/cm ³)	Vol (cm ³)	Mass (g)	Density (g/cm ³)	Vol (cm ³)
Fat [²]	9000	0.96	9375.00	14000	0.96	14583.33	14600	0.95	15368.42	18000	0.95	18947.37
Brain	1420	1.04	1365.38	1300	1.04	1250.00	1450	1.04	1394.23	1300	1.04	1250.00
Stomach & Esophagus Wall	150	1.03	145.63	150	1.03	145.63	190	1.03	184.47	175	1.03	169.90
Small Intestine Wall	520	1.03	504.85	520	1.03	504.85	650	1.03	631.07	600	1.03	582.52
Colon Wall	300	1.03	291.26	300	1.03	291.26	370	1.03	359.22	360	1.03	349.51
Right Heart Contents	215	1.06	202.83	160	1.06	150.94	255	1.06	240.57	185	1.06	174.53
Left Heart Contents	215	1.06	202.83	160	1.06	150.94	255	1.06	240.57	185	1.06	174.53
Coronary Tissues	230	1.04	221.15	220	1.04	211.54	330	1.05	314.29	250	1.05	238.10
Kidneys	250	1.05	238.10	240	1.05	228.57	310	1.05	295.24	275	1.05	261.90
Liver	1300	1.06	1226.42	1300	1.06	1226.42	1800	1.06	1698.11	1400	1.06	1320.75
Lung Tissues [²]	330	1.00	330.00	290	1.00	290.00	500	1.00	500.00	420	1.00	420.00
Skeletal Muscle	24000	1.05	22857.14	17000	1.05	16190.48	29000	1.05	27619.05	17500	1.05	16666.67
Pancreas	110	1.04	105.77	100	1.04	96.15	140	1.04	134.62	120	1.04	115.38
Skeletal Tissues												
Active Marrow	1080	1.03	1048.54	1000	1.03	970.87	1170	1.03	1135.92	900	1.03	873.79

Organ / Tissue	Male - Newborn			Female - Newborn			Male - 1 Year			Female - 1 Year		
	Mass (g)	Density (g/cm ³)	Vol (cm ³)	Mass (g)	Density (g/cm ³)	Vol (cm ³)	Mass (g)	Density (g/cm ³)	Vol (cm ³)	Mass (g)	Density (g/cm ³)	Vol (cm ³)
Trabecular Bone	810	1.83	442.62	740	1.83	404.37	1100	1.92	572.92	800	1.92	416.67
Cortical Bone	3240	1.83	1770.49	2960	1.83	1617.49	4400	1.92	2291.67	3200	1.92	1666.67
Other Skeletal Tissues	2820		2712.05	2480		2398.35	3830		3741.45	2900		2825.11
Skin	2000	1.09	1834.86	1700	1.09	1559.63	3300	1.09	3027.52	2300	1.09	2110.09
Spleen	130	1.06	122.64	130	1.06	122.64	150	1.06	141.51	130	1.06	122.64
Thyroid	12	1.05	11.43	12	1.05	11.43	20	1.05	19.05	17	1.05	16.19
Lymphatic Nodes [⁴]	161	1.03	156.31	152	1.03	147.57	210	1.03	203.88	173	1.03	167.96
Testes or Ovaries	16	1.04	15.38	6	1.05	5.71	35	1.04	33.65	11	1.05	10.48
Adrenal Glands	10	1.03	9.71	9	1.02	8.82	14	1.03	13.59	13	1.02	12.75
Urinary Bladder Wall	40	1.04	38.46	35	1.04	33.65	50	1.04	48.08	40	1.04	38.46
All Other Tissues	6486	1.03	6297.28	6696	1.03	6501.44	6803	1.03	6604.54	6554	1.03	6362.95
Aorta and Large Arteries	286	1.06	270.00	210	1.06	198.00	337	1.06	318.00	248	1.06	234.00
Large Veins	859	1.06	810.00	630	1.06	594.00	1011	1.06	954.00	744	1.06	702.00

Organ / Tissue	Male - 15 Year			Female - 15 Year			Male - Adult			Female - Adult		
	Mass (g)	Density (g/cm ³)	Vol (cm ³)	Mass (g)	Density (g/cm ³)	Vol (cm ³)	Mass (g)	Density (g/cm ³)	Vol (cm ³)	Mass (g)	Density (g/cm ³)	Vol (cm ³)
Inactive Marrow	1480	0.98	1510.20	1380	0.98	1408.16	2480	0.98	2530.61	1800	0.98	1836.73
Cartilage	1140	1.10	1036.36	920	1.10	836.36	1100	1.10	1000.00	900	1.10	818.18
Teeth	45	3.00	15.00	35	3.00	11.67	50	3.00	16.67	40	3.00	13.33
Miscellaneous Tissues	155	1.03	150.49	145	1.02	142.16	200	1.03	194.17	160	1.02	156.86
Totals	2820.00		2712.05	2480.00		2398.35	3830.00		3741.45	2900.00		2825.11

All Other Tissues												
Total Body Tissues [²]	55990			52500			72280			58800		
Total Organ Masses (above)	49504			45804			65477			52246		
Totals	6486	1.03	6297.28	6696	1.03	6501.44	6803	1.03	6604.54	6554	1.03	6362.95

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- [1] Age-specific and organ-specific tissue densities were taken (when available) from ICRU Report 46 - Appendix A
- [2] Reference masses for fat are taken to be those of body fat from Section 4.3.3.3. of ICRP 89
- [3] The tissue density of lung parenchyma (lung mass exclusive of air and blood) is taken to be 1.0 as given in ICRP 89 - section 5.3.6
- [4] Age-dependent masses of the lymphatic nodes taken from Table 3 of Lee et al. (2013) (ICRP values)
- [5] Age-dependent masses of the Total Body Tissues taken from Table 6 of 2010 PMB article by Lee et al. (2010)

Table 5.

Derivation of reference blood volumes as computed using Equation 3.

Organ or Tissue	Male - Adult			Female - Adult			Male - Newborn			Female - Newborn		
	V _{blood} (%)	V _{blood} (cm ³)	V _{organ} (cm ³)	V _{blood} (%)	V _{blood} (cm ³)	V _{organ} (cm ³)	R _{growth}	V _{organ} (cm ³)	V _{blood} (cm ³)	R _{growth}	V _{organ} (cm ³)	V _{blood} (cm ³)
Fat	5.00	265.00	15368.42	8.50	331.50	18947.37	1.00	373.74	6.44	1.00	373.74	6.54
Brain	1.20	63.60	1394.23	1.20	46.80	1250.00	1.04	368.93	17.50	1.04	368.93	14.37
Stomach & Esophagus Wall	1.00	53.00	184.47	1.00	39.00	169.90	1.00	8.74	2.51	1.00	8.74	2.01
Small Intestine Wall	3.80	201.40	631.07	3.80	148.20	582.52	1.00	29.13	9.30	1.00	29.13	7.41
Colon Wall	2.20	116.60	359.22	2.20	85.80	349.51	1.00	16.50	5.36	1.00	16.50	4.05
Right Heart Contents	4.50	238.50		4.50	175.50				12.15			12.15
Left Heart Contents	4.50	238.50		4.50	175.50				12.15			12.15
Coronary Tissues	1.00	53.00	314.29	1.00	39.00	238.10	1.00	19.23	3.24	1.00	19.23	3.15
Kidneys	2.00	106.00	295.24	2.00	78.00	261.90	0.26	24.27	2.27	0.26	24.27	1.88
Liver	10.00	530.00	1698.11	10.00	390.00	1320.75	1.00	125.00	39.01	1.00	125.00	36.91
Lung Tissues [¹]	12.50	662.50	500.00	12.50	487.50	420.00			28.04			28.04
Skeletal Muscle	14.00	742.00	27619.05	10.50	409.50	16666.67	1.00	761.90	20.47	1.00	761.90	18.72
Pancreas	0.60	31.80	134.62	0.60	23.40	115.38	1.00	5.77	1.36	1.00	5.77	1.17
Skeletal Tissues												
Active Marrow	4.00	212.00	1135.92	4.00	156.00	873.79	1.72	48.54	15.58	1.72	48.54	14.91
Trabecular Bone	1.20	63.60	572.92	1.20	46.80	416.67	4.70	20.35	10.62	4.70	20.35	10.74
Cortical Bone	0.80	42.40	2291.67	0.80	31.20	1666.67	2.60	78.49	3.78	2.60	78.49	3.82
Other Skeletal Tissues	1.00	53.00	3741.45	1.00	39.00	2825.11	1.00	138.24	1.96	1.00	138.43	1.91
Skin	3.00	159.00	3027.52	3.00	117.00	2110.09	1.00	166.67	8.75	1.00	166.67	9.24
Spleen	1.40	74.20	141.51	1.40	54.60	122.64	1.00	9.13	4.79	1.00	9.13	4.07
Thyroid	0.06	3.18	19.05	0.06	2.34	16.19	1.00	1.24	0.21	1.00	1.24	0.18
Lymphatic Nodes	0.20	10.60	203.88	0.20	7.80	167.96	1.00	9.71	0.50	1.00	9.71	0.45
Testes or Ovaries	0.04	2.12	33.65	0.02	0.78	10.48	1.00	0.82	0.05	1.00	0.29	0.02
Adrenal Glands	0.06	3.18	13.59	0.06	2.34	12.75	1.00	5.83	1.36	1.00	5.88	1.08
Urinary Bladder Wall	0.02	1.06	48.08	0.02	0.78	38.46	1.00	3.85	0.08	1.00	3.85	0.08
All Other Tissues	1.92	101.76	6604.54	1.92	74.88	6362.95	1.00	825.55	12.72	1.00	826.08	9.72

Organ or Tissue	Male - Adult			Female - Adult			Male - Newborn			Female - Newborn		
	V_{blood} (%)	V_{blood} (cm ³)	V_{organ} (cm ³)	V_{blood} (%)	V_{blood} (cm ³)	V_{organ} (cm ³)	R_{growth}	V_{organ} (cm ³)	V_{blood} (cm ³)	R_{growth}	V_{organ} (cm ³)	V_{blood} (cm ³)
Aorta and Large Arteries	6.00	318.00		6.00	234.00				16.20			16.20
Large Veins	18.00	954.00		18.00	702.00				48.60			48.60
<i>Derived Total Blood Volume</i>		5300			3899				285			270
<i>ICRP Reference TBV</i>		5300			3900				270			270
<i>Ratio</i>		1.00			1.00				1.06			1.00
Organ or Tissue	Male - 1 Year			Female - 1 Year			Male - 5 Year			Female - 5 Year		
	V_{blood} (%)	V_{blood} (cm ³)	V_{organ} (cm ³)	V_{blood} (%)	V_{blood} (cm ³)	V_{organ} (cm ³)	R_{growth}	V_{organ} (cm ³)	V_{blood} (cm ³)	R_{growth}	V_{organ} (cm ³)	V_{blood} (cm ³)
Fat	1.00	2395.83	41.31	1.00	2395.83	41.92	1.00	3750.00	64.66	1.00	3750.00	65.61
Brain	1.16	922.33	48.81	1.16	922.33	40.06	1.39	1259.62	79.87	1.39	1134.62	59.05
Stomach & Esophagus Wall	1.00	24.27	6.97	1.00	24.27	5.57	1.00	58.25	16.74	1.00	58.25	13.37
Small Intestine Wall	1.00	82.52	26.34	1.00	82.52	21.00	1.00	213.59	68.17	1.00	213.59	54.34
Colon Wall	1.00	48.54	15.76	1.00	48.54	11.92	1.00	116.50	37.82	1.00	116.50	28.60
Right Heart Contents			22.64			22.64			63.68			63.68
Left Heart Contents			22.64			22.64			63.68			63.68
Coronary Tissues	1.00	48.08	8.11	1.00	48.08	7.88	1.00	81.73	13.78	1.00	81.73	13.39
Kidneys	0.67	67.31	16.19	0.67	67.31	13.43	1.00	105.77	37.97	1.00	105.77	31.50
Liver	1.00	314.29	98.09	1.00	314.29	92.80	1.00	542.86	169.43	1.00	542.86	160.30
Lung Tissues [¹]			66.04			66.04			165.09			165.09
Skeletal Muscle	1.00	1809.52	48.61	1.00	1809.52	44.46	1.00	5333.33	143.28	1.00	5333.33	131.04
Pancreas	1.00	19.23	4.54	1.00	19.23	3.90	1.00	33.65	7.95	1.00	33.65	6.83
Skeletal Tissues												
Active Marrow	1.57	145.63	42.67	1.57	145.63	40.82	1.31	330.10	80.70	1.31	330.10	77.20
Trabecular Bone	4.70	70.18	36.61	4.70	70.18	37.05	4.40	142.86	69.78	4.40	142.86	70.60
Cortical Bone	2.60	274.85	13.22	2.60	274.85	13.38	2.40	577.14	25.63	2.40	577.14	25.93
Other Skeletal Tissues	1.00	395.92	5.61	1.00	396.34	5.47	1.00	771.21	10.92	1.00	771.73	10.65

Organ or Tissue	Male - Adult			Female - Adult			Male - Newborn			Female - Newborn		
	V_{blood}	V_{blood}	V_{organ}	V_{blood}	V_{blood}	V_{organ}	R_{growth}	V_{organ}	V_{blood}	R_{growth}	V_{organ}	V_{blood}
	(%)	(cm ³)	(cm ³)	(%)	(cm ³)	(cm ³)		(cm ³)	(cm ³)		(cm ³)	(cm ³)
Skin	1.00	321.10	16.86	1.00	321.10	17.80	1.00	522.94	27.46	1.00	522.94	29.00
Spleen	1.00	27.36	14.35	1.00	27.36	12.18	1.00	47.17	24.73	1.00	47.17	21.00
Thyroid	1.00	1.71	0.29	1.00	1.71	0.25	1.00	3.24	0.54	1.00	3.24	0.47
Lymphatic Nodes	1.00	28.16	1.46	1.00	28.16	1.31	1.00	53.40	2.78	1.00	53.40	2.48
Testes or Ovaries	1.00	1.44	0.09	1.00	0.76	0.06	1.00	1.63	0.10	1.00	1.90	0.14
Adrenal Glands	1.00	3.88	0.91	1.00	3.92	0.72	1.00	4.85	1.14	1.00	4.90	0.90
Urinary Bladder Wall	1.00	8.65	0.19	1.00	8.65	0.18	1.00	15.38	0.34	1.00	15.38	0.31
All Other Tissues	1.00	2097.57	32.32	1.00	2098.25	24.69	1.00	2318.19	35.72	1.00	2444.12	28.76
Aorta and Large Arteries			30.00			30.00			84.00			84.00
Large Veins			90.00			90.00			252.00			252.00
<i>Derived Total Blood Volume</i>			711			668			1548			1460
<i>ICRP Reference TBV</i>			500			500			1400			1400
<i>Ratio</i>			1.42			1.34			1.11			1.04

Organ or Tissue	Male - 10 Year			Female - 10 Year			Male - 15 Year			Female - 15 Year		
	V_{blood}	V_{blood}	V_{organ}	V_{blood}	V_{blood}	V_{organ}	R_{growth}	V_{organ}	V_{blood}	R_{growth}	V_{organ}	V_{blood}
	(%)	(cm ³)	(cm ³)	(%)	(cm ³)	(cm ³)		(cm ³)	(cm ³)		(cm ³)	(cm ³)
Fat	1.00	6250.00	107.77	1.00	6250.00	109.35	1.00	9375.00	161.65	1.00	14583.33	255.15
Brain	1.33	1346.15	81.67	1.33	1173.08	58.41	1.13	1365.38	70.38	1.13	1250.00	52.88
Stomach & Esophagus Wall	1.00	100.00	28.73	1.00	100.00	22.95	1.00	145.63	41.84	1.00	145.63	33.43
Small Intestine Wall	1.00	359.22	114.64	1.00	359.22	91.39	1.00	504.85	161.12	1.00	504.85	128.44
Colon Wall	1.00	203.88	66.18	1.00	203.88	50.05	1.00	291.26	94.54	1.00	291.26	71.50
Right Heart Contents			108.49			108.49			202.83			150.94
Left Heart Contents			108.49			108.49			202.83			150.94
Coronary Tissues	1.00	134.62	22.70	1.00	134.62	22.05	1.00	221.15	37.29	1.00	211.54	34.65
Kidneys	1.00	173.08	62.14	1.00	173.08	51.55	1.00	238.10	85.48	1.00	228.57	68.07
Liver	1.00	790.48	246.72	1.00	790.48	233.42	1.00	1226.42	382.78	1.00	1226.42	362.14
Lung Tissues [ℓ]			273.58			273.58			537.74			433.96

Organ or Tissue	Male - Adult			Female - Adult			Male - Newborn			Female - Newborn		
	V _{blood} (%)	V _{blood} (cm ³)	V _{organ} (cm ³)	V _{blood} (%)	V _{blood} (cm ³)	V _{organ} (cm ³)	R _{growth}	V _{organ} (cm ³)	V _{blood} (cm ³)	R _{growth}	V _{organ} (cm ³)	V _{blood} (cm ³)
Skeletal Muscle	1.00	10476.19	281.45	1.00	10476.19	257.40	1.00	22857.14	614.07	1.00	16190.48	397.80
Pancreas	1.00	57.69	13.63	1.00	57.69	11.70	1.00	105.77	24.99	1.00	96.15	19.50
Skeletal Tissues												
Active Marrow	1.15	611.65	131.28	1.15	611.65	125.58	1.11	1048.54	217.22	1.11	970.87	192.40
Trabecular Bone	4.00	256.98	114.11	4.00	256.98	115.46	3.70	442.62	181.80	3.70	404.37	168.05
Cortical Bone	2.20	1027.93	41.84	2.20	1027.93	42.33	1.90	1770.49	62.24	1.90	1617.49	57.53
Other Skeletal Tissues	1.00	1488.57	21.09	1.00	1489.42	20.56	1.00	2712.05	38.42	1.00	2398.35	33.11
Skin	1.00	752.29	39.51	1.00	752.29	41.71	1.00	1834.86	96.36	1.00	1559.63	86.48
Spleen	1.00	75.47	39.57	1.00	75.47	33.60	1.00	122.64	64.31	1.00	122.64	54.60
Thyroid	1.00	7.52	1.26	1.00	7.52	1.09	1.00	11.43	1.91	1.00	11.43	1.65
Lymphatic Nodes	1.00	89.32	4.64	1.00	89.32	4.15	1.00	156.31	8.13	1.00	147.57	6.85
Testes or Ovaries	1.00	1.92	0.12	1.00	3.33	0.25	1.00	15.38	0.97	1.00	5.71	0.43
Adrenal Glands	1.00	6.80	1.59	1.00	6.86	1.26	1.00	9.71	2.27	1.00	8.82	1.62
Urinary Bladder Wall	1.00	24.04	0.53	1.00	24.04	0.49	1.00	38.46	0.85	1.00	33.65	0.68
All Other Tissues	1.00	4832.56	74.46	1.00	5005.86	58.91	1.00	6297.28	97.03	1.00	6501.44	76.51
Aorta and Large Arteries			144.00			144.00			270.00			198.00
Large Veins			432.00			432.00			810.00			594.00
<i>Derived Total Blood Volume</i>			2562			2420			4469			3631
<i>ICRP Reference TBV</i>			2400			2400			4500			3300
<i>Ratio</i>			1.07			1.01			0.99			1.10

[1] Blood volumes for pediatric pulmonary & bronchial tissues are taken directly from mass differences of reference values given in Section 5.3.3 of ICRP Publication 89

Table 6.

Suggested reference values for regional blood distribution (% total blood volume) for the ICRP reference persons.

Organ or Tissue	Newborn	1-Year	5-Year	10-Year	15-Year		Adult	
	Male / Female	Male / Female	Male / Female	Male / Female	Male	Female	Male	Female
Fat	2.2	5.0	4.1	4.2	3.6	6.6	5.0	8.5
Brain	5.4	5.3	4.3	2.7	1.6	1.4	1.2	1.2
Stomach & Esophagus Wall	0.8	0.7	0.9	1.0	0.9	0.9	1.0	1.0
Small Intestine Wall	2.8	2.8	3.8	3.9	3.6	3.3	3.8	3.8
Colon Wall	1.6	1.6	2.1	2.2	2.1	1.8	2.2	2.2
<i>Right Heart Contents</i>	<i>4.5</i>	<i>4.5</i>	<i>4.5</i>	<i>4.5</i>	<i>4.5</i>	<i>4.5</i>	<i>4.5</i>	<i>4.5</i>
<i>Left Heart Contents</i>	<i>4.5</i>	<i>4.5</i>	<i>4.5</i>	<i>4.5</i>	<i>4.5</i>	<i>4.5</i>	<i>4.5</i>	<i>4.5</i>
Coronary Tissues	1.1	0.9	0.8	0.9	0.8	0.9	1.0	1.0
Kidneys	0.7	1.8	2.2	2.2	1.9	1.8	2.0	2.0
Liver	12.9	11.4	10.3	9.2	8.5	9.4	10.0	10.0
<i>Lungs</i>								
<i>Pulmonary Gas Exchange Blood</i>	<i>10.5</i>	<i>10.5</i>	<i>10.5</i>	<i>10.5</i>	<i>10.5</i>	<i>10.5</i>	<i>10.5</i>	<i>10.5</i>
<i>Pulmonary Nutrient Blood</i>	<i>2.0</i>	<i>2.0</i>	<i>2.0</i>	<i>2.0</i>	<i>2.0</i>	<i>2.0</i>	<i>2.0</i>	<i>2.0</i>
Skeletal Muscle	6.8	5.5	8.5	10.3	13.7	10.3	14.0	10.5
Pancreas	0.4	0.5	0.5	0.5	0.6	0.5	0.6	0.6
Skeletal Tissues								
Active Marrow	5.2	5.0	4.9	4.9	4.8	5.0	4.0	4.0
Trabecular Bone	3.6	4.4	4.4	4.4	4.0	4.4	1.2	1.2
Cortical Bone	1.3	1.6	1.6	1.6	1.4	1.5	0.8	0.8
Other Skeletal Tissues	0.7	0.7	0.7	0.8	0.9	0.9	1.0	1.0
Skin	3.0	2.0	1.8	1.6	2.2	2.2	3.0	3.0
Spleen	1.5	1.6	1.4	1.4	1.4	1.4	1.4	1.4
Thyroid	0.07	0.03	0.03	0.04	0.04	0.04	0.06	0.06
Lymphatic Nodes	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Testes or Ovaries	0.01	0.01	0.01	0.01	0.02	0.01	0.04	0.02
Adrenal Glands	0.4	0.1	0.1	0.1	0.1	0.04	0.06	0.06
Urinary Bladder Wall	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
All Other Tissues	3.8	3.3	1.9	2.4	2.2	1.9	1.9	1.9
<i>Aorta and Large Arteries</i>	<i>6.0</i>	<i>6.0</i>	<i>6.0</i>	<i>6.0</i>	<i>6.0</i>	<i>6.0</i>	<i>6.0</i>	<i>6.0</i>
<i>Large Veins</i>	<i>18.0</i>	<i>18.0</i>	<i>18.0</i>	<i>18.0</i>	<i>18.0</i>	<i>18.0</i>	<i>18.0</i>	<i>18.0</i>
	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 7.Suggested reference values for regional blood volume (cm³) for ICRP reference persons.

Organ or Tissue	Newborn	1-Year	5-Year	10-Year	15-Year		Adult	
	Male / Female	Male / Female	Male / Female	Male / Female	Male	Female	Male	Female
Fat	6.0	24.8	56.9	99.8	162.1	218.2	265.0	332.5
Brain	14.6	26.4	60.4	64.1	70.6	45.2	63.6	46.8
Stomach & Esophagus Wall	2.1	3.7	13.1	23.7	42.0	28.6	53.0	39.0
Small Intestine Wall	7.7	14.0	53.3	94.4	161.6	109.8	201.4	148.2
Colon Wall	4.3	8.2	28.9	53.2	94.8	61.1	116.6	85.8
Right Heart Contents	12.2	22.5	63.0	108.0	202.5	148.5	238.5	175.5
Left Heart Contents	12.2	22.5	63.0	108.0	202.5	148.5	238.5	175.5
Coronary Tissues	2.9	4.8	11.9	20.6	37.4	29.6	53.0	39.0
Kidneys	1.9	8.8	30.2	52.1	85.7	58.2	106.0	78.0
Liver	34.9	56.8	143.8	220.6	383.9	309.6	530.0	390.0
Lungs								
Pulmonary Gas Exchange Blood	28.4	52.5	147.0	252.0	472.5	346.5	556.5	409.5
Blood								
Pulmonary Nutrient Blood	5.4	10.0	28.0	48.0	90.0	66.0	106.0	78.0
Skeletal Muscle	18.0	27.7	119.6	247.4	615.8	340.1	742.0	409.5
Pancreas	1.2	2.5	6.4	11.6	25.1	16.7	31.8	23.4
Skeletal Tissues								
Active Marrow	14.0	24.9	68.9	118.0	217.8	164.5	212.0	156.0
Trabecular Bone	9.8	21.9	61.3	105.6	182.3	143.7	63.6	46.8
Cortical Bone	3.5	7.9	22.5	38.7	62.4	49.2	42.4	31.2
Other Skeletal Tissues	1.8	3.3	9.4	19.1	38.5	28.3	53.0	39.0
Skin	8.3	10.3	24.7	37.4	96.6	73.9	159.0	117.0
Spleen	4.1	7.9	19.9	33.6	64.5	46.7	74.2	54.6
Thyroid	0.2	0.2	0.4	1.1	1.9	1.4	3.2	2.3
Lymphatic Nodes	0.4	0.8	2.3	4.0	8.1	5.9	10.6	7.8
Testes or Ovaries	0.03	0.04	0.1	0.2	1.0	0.4	2.1	0.8
Adrenal Glands	1.1	0.5	0.9	1.3	2.3	1.4	3.2	2.3
Urinary Bladder Wall	0.1	0.1	0.3	0.5	0.9	0.6	1.1	0.8
All Other Tissues	10.3	16.9	28.1	61.1	97.3	65.4	101.8	74.9
Aorta and Large Arteries	16.2	30.0	84.0	144.0	270.0	198.0	318.0	234.0
Large Veins	48.6	90.0	252.0	432.0	810.0	594.0	954.0	702.0
<i>Totals</i>	270	500	1400	2400	4500	3300	5300	3900