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UNACZYNIENIE POWIERZCHNI ODDECHOWYCH
U NIEKTÓRYCH *SALIENTIA*

THE VASCULARISATION OF THE RESPIRATORY
SURFACES OF SOME *SALIENTIA*

by

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With Plates I and II

Wymiana gazowa u płazów jest stosunkowo nieźle poznana od strony fizjologicznej, szczególnie jeśli chodzi o płazy bezogonowe. Jednak struktura anatomiczna narządów biorących udział w oddychaniu i ich unaczynienie badane były tylko powierzchownie. Brak jest danych ilościowych co do unaczynienia skóry, jamy gębowej i płuc, oraz badań porównawczych między różnymi gatunkami Salientia. W pracy niniejszej zbadano anatomiczną budowę narządów, biorących udział w wymianie gazowej, oraz ich unaczynienie u następujących płazów bezogonowych: Bombina bombina (L.), Pelobates fuscus (L a u r.), Bufo bufo (L.), Hyla arborea (L.), Rana temporaria L., Rana terrestris A n d r z. i Rana esculenta L. Do pracy użyto 22 okazy nastrykane od truncus arteriosus błękitem berlińskim. Skóra badanych okazów wykazuje w szczegółach swej budowy dość znaczne różnice. Dotyczą one grubości nabłonka i skóry właściwej, ich stosunku do siebie oraz ilości gruczołów w skórze. Gatunki bardziej lądowe mają nabłonek grubszy niż gatunki więcej związane z wodą. Najcieńszy nabłonek posiada Bombina bombina (L.) (22,8µ), najgrubszy Pelobates fuscus (L a u r.) (53,6µ). Ilość gruczołów przypadająca na 1 mm² skóry waha się u poszczególnych gatunków w dość znacznych granicach: od 97 u Hyla arborea (L.) do 8 u Bufo bufo (L.) Zarówno gruczoły śluzowe jak i jadowe unaczynione są przez biegnące w ich pobliżu kapilary podnabłonkowe. Wyjątkiem są gruczoły jadowe ropuchy, posiadające zawsze własną siatkę kapilar. Jest to być może spowodowane większą aktywnością tych gruczołów albo ich dość znacznymi rozmiarami.

Badane gatunki wykazują znaczne różnice w gęstości sieci kapilar podnabłonkowych skóry. Tak np. u Bombina bombina (L.) przypada zaledwie 68 oczek kapilar na 1 mm² skóry, u Rana esculenta L., która posiada najsilniej unaczynioną skórę aż 220 oczek na 1 mm² (średnie z badanych oka-

zów). Należy podkreślić, że formy o mniejszych rozmiarach ciała mają siatkę kapilar skórnych znacznie rzadszą niż formy większe. Wskutek tego długość kapilar podnabłonkowych skóry, przypadająca na 1 g wagi ciała, waha się u badanych gatunków z wyjątkiem Hyla arborea (L.) w dość ciasnych granicach (od 5,44 m u Bufo bufo (L.) do 7,85 m u Bombina bombina (L.). Dość duże różnice w gęstości siatek kapilar skóry można tłumaczyć w sposób następujący: u form drobniejszych stosunek powierzchni skóry do objętości ciała jest korzystniejszy niż u form wielkich, przez co te ostatnie muszą mieć znacznie silniej rozwiniętą sieć kapilar skóry, by osiągnąć taką intensywność oddychania skórnego co formy drobne. U poszczególnych gatunków istnieją zapewne wahania w intensywności tego oddychania wskutek występujących znacznych różnic w grubości nabłonka i kutikuli, utrudniającej przenikanie tlenu do kapilar podnabłonkowych.

Ewentualne różnice w intensywności oddychania jamą gębową mogą być wywołane nie tylko różną grubością nabłonka błony śluzowej, jaką wykazują badane gatunki, lecz także natężeniem ruchów przewietrzających jamę gębową i płuca. Kapilary błony śluzowej podniebienia posiadają (z wyjątkiem kumaka) silnie wykształcone palczaste wyrostki. Zwiększają one znacznie powierzchnię wymiany gazowej kapilar, a utrudniając przepływ krwi, powodują jej lepsze utlenienie. Długość kapilar podniebienia przypadająca na 1 g wagi ciała waha się od 0,128 m u Rana terrestris A n d r z. do 0,350 m u Pelobates fuscus (L a u r.).

Badane gatunki wykazują znaczne różnice w gęstości siatki kapilar płucnych, jak również w samej strukturze wnętrza płuc, wskutek czego istnieją duże wahania w długości kapilar płucnych przypadających na 1 g wagi ciała, a to od 6,60 m u kumaka do 34,36 m u rzekotki.

Wyrażając na podstawie długości kapilar skóry, jamy gębowej i płuc przypadającej na 1 g wagi ciała procentowy udział tych powierzchni w oddychaniu, można stwierdzić u badanych gatunków znaczne różnice. Tak u kumaka kapilary skóry stanowią 53,7%, kapilary płuc tylko 45,2%. U grzebiuszki kapilary skóry stanowią 48,3%, kapilary płuc 49,3%. W rodzaju Rana kapilary skóry wynoszą od 32,4% u Rana terrestris A n d r z. do 36,6% u Rana temporaria L., kapilary płuc od 66,9% u Rana terrestris A n d r z. do 62,5% u Rana temporaria L. Jeszcze mniejszy procent niż w rodzaju Rana stanowią kapilary skóry u ropuchy (27,6%) i rzekotki (24,2%). Kapilary płuc stanowią natomiast u ropuchy 71,5%, a u rzekotki aż 74,7% wszystkich kapilar unaczyniających powierzchnie oddechowe. Znikoma część ogólnej ilości kapilar oddechowych przypada na jamę gębową, bo tylko od 0,7% (Rana terrestris A n d r z.) do 1,1% (Hyla arborea (L.). Wyjątkiem jest Pelobates fuscus (L a u r.) u którego kapilary podniebienia stanowią 2,4%, co jest spowodowane znacznymi rozmiarami jamy gębowej w stosunku do rozmiarów całego ciała.

CONTENTS

THE PROBLEM

The gaseous exchange of amphibians is specific, and cardinally different from the mechanisms found in other groups of Vertebrates. It is correlated with their amphibious mode of life. The respiration takes place through the skin of the body, mucous membrane of the mouth, lungs, and eventually gills.

The respiration through the surface of the body is possible due to the comparatively thin and steady wet skin, which has a superficially situated and well developed net of capillaries. Therefore the skin has a character of a respiratory surface. The importance of cutaneous respiration is exceptionally marked among certain *Urodela,* which are completely deprived of lung and gills (*Plethodontidae*). The blood supply to the skin in *Salientia* shows an exact correspondence with the ability to the cutaneous respiration. A great part of their skin receives the blood from *arteria cutanea magna,* that as a branch of *ductus pulmo-cutaneus* transports a weakly oxidised blood. This probably favors the use of the skin as a respiratory organ.

The investigations of B o h r (1900), K r o g h (1904), D o l k and P o s t m a (1927), L a s k o w s k i (1929), and others, show that the cutaneous respiration in the animals belonging to the genus *Rana* is very considerable, and is not subjected to greater changes throughout the year, meanwhile the respiration with lungs varies very much. The quantity of oxygen taken by the lungs in autumn and winter is considerably less that simultaneously taken by the skin. This amount increases rapidly in spring, exceeding the cutaneous respiration, and having attained its maximum in April it decreases gradually during the summer.

It was also stated, that the major part of carbon dioxide is given out through the skin (D o l k and P o s t m a 1927). An important role in the gaseous exchange has the skin in tadpoles. The caudal fin is particularly vascularised and may be considered as a larval respiratory organ (M e d v e d e v 1937).

The respiration by means of the mouth-cavity is due to the considerable vascularisation of the mucous membrane. It depends on the ventilla-

tion of the mouth. Among lungless salamanders the ventillatory move-
ment are considerably faster than in forms possesing lungs. In tadpoles
and in adult *Urodela* there is a respiration through the mouth-cavity
during the stay in water.

As follows from the works of previously mentioned authors and also
from investigations of J o r d a n (1927, 1929) and B a s t e r t (1929), the
amphibian lungs are reserve organs, having a more important role in
the moment of increased need of oxygen by the organism.

We see from the above mentioned facts, that the respiration of *Am-
phibia* is relatively well known from the physiological point of view, par-
ticularly regarding the genus *Rana*. On the other hand the anatomical
structure of respiratory organs and especially their vascularisation was
only superficially investigated. (M a u r e r 1897, B e t h g e 1898, L e y d i g
1898, F i c a l b i 1899, N o b l e 1925). There is, as far as I know, a com-
plete lack of quantitative data about the vascularisation of the skin,
mouth-cavity and lungs, as also of comparative studies of different spe-
cies of *Salientia*. All deductions about the gas exchange were namely ba-
sed on experiments with the animals belonging to the genus *Rana*. Accor-
ding to the modern views on the systematics of *Salientia* the suborder
Diplasiocoela, to which the genus *Rana* belongs is however a branch well
remoted from the other groups (T e r e n t i e w 1950).

MATERIAL AND METHODS

The investigated animals belonged to the following species: *Bombina
bombina (L.), Pelobates fuscus* (L a u r.), *Bufo bufo (L.), Hyla arborea (L.),
Rana temporaria* L., *Rana terrestris* A n d r z., and *Rana esculenta* L. They
were collected in the vicinity of Toruń, except *Hyla arborea* (L.) which
occurs in this region rarely. The specimens of this species were taken in
Ostrowiec Świętokrzyski in the summer months of 1950 and 1951. For
investigation purposes 22 specimens were used, 17 of which were exami-
ned in detail. All the animals had the blood vessels injected with
Prussian-blue through the *truncus arteriosus,* and after the dissection of
lungs, were fixed in a mixture of formalin and alcohol (2 parts of 96%
alcohol + 1 part of 40% formalin), or in 10% formalin.

Further investigations consisted in the providing of preparations that
would make possible to count the capillaries of respiratory surfaces. The
preparations from following regions were made:

1. The skin of the body. 2. The mucous membrane of the mouth.
3. The lungs.

1. From the left half of the body of every injected specimen, the follo-
wing, always the same parts of the skin were cut out: dorsal and ventral
sides of the fore-limb, dorsal and ventral sides of the thigh, dorsal and

ventral sides of the shank, flank of the trunk, anterior and posterior parts of the belly, ventral side of the head, and finally anterior and posterior parts of the back (Fig. 1).

The fragments of the skin were cut rather wide, but the largest of them i.e. from the belly and from the back did not exceed 15 mm of width, owing to the difficulty in cutting large pieces of skin with the microtome. From the fragments, after the dehydration in dioxane and embedding in paraffine, cross sections were made. They were stained with hematoxylin and eosin and closed in Canada balsam. These sections were used for microscopic description of skin structure, and for counting the cross sections of skin capillaries. Only the vessels laying directly under epithelium were counted, neglecting those of the corium and of the subcutaneous connective tissue. From the results the average values were calculated, that squared gived the approximative vascularisation of the area of 1 mm^2 in the skin investigated.
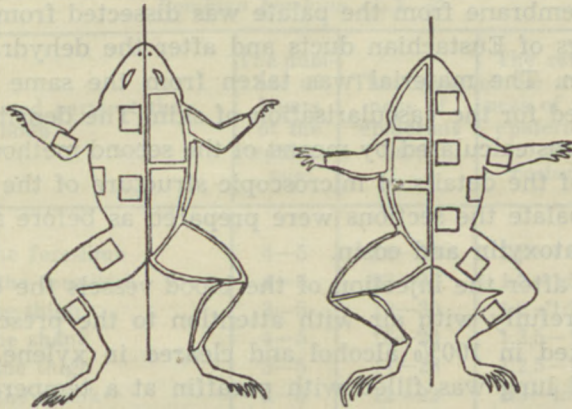

Fig. 1. Scheme showing the fragments of skin investigated.

From the same specimen from which the microscopic sections were prepared, the skin of the right side was taken off, divided into the earlier mentioned parts, and after dehydration in dioxane closed in Canada balsam. The fragments obtained in this manner were larger than those used in the preparations of the sections, therefore the microscopic investigation of the density of the vessels-net with the second method embraced considerably greater part of the skin surface (about 90%). The density of vessels-net was measured as follows: the eyepiece of the microscope was lifted until the diameter of the field was 1 mm. In the ocular a thin, stretched hair was mounted. All meshes lying on the hair were counted. Subsequently the eyepiece was turned about 90° and the counting was repeated. In this way on every mm^2 of cleared skin two measurement were made. From these measurements the average for the given part of

the body was calculated, that squared was giving the average density of the net of capillaries on 1 mm² on the investigated fragment of the skin.

So two methods of counting the skin-blood-vessels were used. The first of them i.e. from the sections should be regarded as a control one, giving usually too high results. This results from the fact that the vessels forming the net have very often a sinusoidal course, therefore in a section the same vessel may be cut twice or even more times, and counted accordingly. Since such events are the more often, the more vessels are in a net, deviations between the one method and the other are proportional to the degree of vascularisation of the skin of a given animal (as it will be apparent from the calculations). Also the quantity of skin of a given specimen, investigated by means of this method consists of not more than 15 percent of the total quantity of skin and this fact also influences the small accuracy of measurements. So the second method in comparison with the first one is much more accurate.

2. For the calculation of the density of the vascularisation of the mouth, the mucous membrane from the palate was dissected from *choanae* back to the openings of Eustachian ducts and after the dehydration closed in Canada balsam. The material was taken from the same specimen that was investigated for the vascularisation of skin. The density of capillary-net in 1 mm² was calculated by means of the second method only. For the investigation of the details of microscopic structure of the mucous membrane of the palate the sections were prepared as before and stained by means of hematoxylin and eosin.

3. Directly after the injection of the blood vessels the dissected lungs were filled carefully with air with attention to the preservation of natural sizes, fixed in 100% alcohol and cleared in xylene. Subsequently the interior of lung was filled with paraffin at a temperature of 60 °C and the whole preparation was embedded in paraffin. One of the lungs of every specimen of a given species was cut by means of microtom parallel to its long axis, the second perpendicular. The sections prepared in this way allowed to examine more exactly the differences in structure of the interior of lungs of the investigated species. The density of vessels-net in 1 mm² of lungs-surface of a given species was calculated from the preparations made as follows: the lungs dissected from the injected specimen were cut into two halves; each of which (in order to avoid folding) was incised on the edges, spread on a slide and after the fixing in 100% alcohol closed in Canada balsam. For the investigation of the vascularisation density the second method of calculation was used.

THE SKIN

The skin of the body of the investigated species shows considerable differences in their structure-details. They refer to the number of cell-layers in the cuticle, the thickness, relation of epidermis to the corium

and to the variations in the amount of glands and vascularisation. The layer of subcutaneous connective tissue (*tela subcutanea*) doesn't show any considerable differences.

A. The Structure of the Skin

I will begin the description of the structure of the skin from *Bombina bombina* (L.) as this form stays systematically lowest of all the species under consideration. We can see from the given data (Table 1) that the number of layers of epidermis, its thickness and relation to the corium shows considerable fluctuations even in the same part of the body. These fluctuations, as we will see from the enclosed tables, are greater among species having the skin covered with warts and less among those which have it smooth. The location and quantity of skin-glands in a given part of

TABLE 1.

Bombina bombina (L.) ♂

The investigated parts ot the body	The number of layers of the epidermis	The thickness of epidermis in μ	The ratio of the thickness of the epidermis to the corium	The number of glands in 1 mm² of the skin
Dorsal side of the fore-limb	4—5	12—33	1:2—1:4	48
Ventral side of the fore-limb	4—6	23—35	1:2—1:5	29
Dorsal side of the thigh	3—5	18—30	1:2—1:7	44
Dorsal side of the shank	4—5	16—26	1:2,5—1:5	48
Ventral side of the thigh	3—5	14—28	1:2,5—1:8	34
Ventral side of the shank	3—6	12—22	1:3—1:5	33
The flank of the body	3—5	16—30	1:3—1:10	55
Anterior part of the belly	3—6	16—35	1:3—1:7	50
Posterior part of the belly	4—6	19—33	1:2—1:6	53
Ventral side of the head	3—5	12—33	1:2—1:8	46
Anterior part of the back	3—6	12—28	1:3—1:8	54
Posterior part of the back	3—5	12—30	1:5—1:10	50
The average value	3,3—5,5	15,1—30,5	1:2,8—1:7,1	47

the body shows considerable variability too. At the tables, however, only the average values are given. The mucous and poison glands are counted together. The rather warty skin of *Bombina bombina* (L.) has relatively thin epidermis. The average thickness of skin for the whole body is 22,8μ. It is formed by usually 4—5 layers of cells and the relation of epidermis to the corium (cutis) varies between 1 : 2,8 to 1 : 7,1 with an average 1 : 4,9. On the average we have 47 glands in 1 mm².

The next species in systematic order is *Pelobates fuscus* (L a u r.) (Table 2). This species posesses more than twice as thick epidermis as the former (on the average 53,6 µ). It is composed of 5—7 layers of cells. The ratio of epidermis to the corium is considerably less than in *Bombina bombina* L. and varies in the limits 1 : 1,3 — 1 : 4 with an average 1 : 2,6. The number of glands is also less and amounts on the average 33 glands per 1 mm² of the skin.

The common toad *Bufo bufo* (L.) is richly covered with warts. The variations of the thickness of epidermis and its relation to the corium are on account of the warty structure of the skin very considerable. (Table 3). While the summits of the warts have mostly an epidermis of considerable thickness (above 70 µ) and its relation to the corium is 1 : 13 (sometimes even higher), in the parts between the warts the thickness of epidermis is 18—27 µ and its ratio to the corium is the highest of the species under investigation i. e. 1 : 8,2. In comparison with the other species *Bufo bufo* (L.) has on the epidermis-surface a very well formed cuticula of the thickness of 8—15 µ, which on the summits of some warts especially on the ventral side of the body reaches even 54 µ. *Bufo bufo* (L.) posesses the lowest quantity of glands of all the investigated species i. e. on an average 8 on 1 mm² of the skin. The only exception are the so called „parotid glands" which form a great accumulation of mucous and poison glands. The poison glands of the toad have a very considerable size in compari-

TABLE 2.

Pelobates fuscus (L a u r.) ♀

The investigated parts of the body	The number of layers of the epidermis	The thickness of epidermis in µ	The ratio of the thickness of the epidermis to the corium	The number of glands in 1 mm² of the skin
Dorsal side of the fore-limb	6—9	38—72	1:0,7—1:3	40
Ventral side of the fore-limb	5—8	36—72	1:1—1:3,5	30
Dorsal side of the thigh	5—6	23—60	1:1—1:2,2	31
Dorsal side of the shank	5—8	33—65	1:1—1:5	42
Ventral side of the thigh	5—7	30—45	1:0,6—1:2	35
Ventral side of the shank	6—9	33—58	1:0,8—1:2	32
The flank of the body	6—13	29—68	1:0,8—1:5	32
Anterior part of the belly	6—7	45—75	1:1,5—1:4	40
Posterior part of the belly	5—7	34—78	1:1,5—1:4	34
Ventral side of the head	6—9	40—70	1:2—1:4	40
Anterior part of the back	5—7	45—73	1:1,5—1:5,5	32
Posterior part of the back	5—8	45—75	1:1,8 - 1:5,5	27
The average value	5,2—7,3	37,9—69,3	1:1,3—1:4	33,5

son with these organs among other investigated species. On the dorsal side of the body they are larger (the largest having even 1000 µ in diameter), on the ventral side they are smaller, usually 300—600 µ in diameter. Especially great poison glands occur in so called parotid glands.

TABLE 3.

Bufo bufo (L.) ♀

The investigated parts of the body	The number of layers of the epidermis	The thickness of epidermis in µ	The ratio of the thickness of the epidermis to the corium	The number of glands in 1 mm² of the skin
Dorsal side of the fore-limb	5—7	19—54	1:3—1:13	9
Ventral side of the fore-limb	4—7	27—85	1:3—1:13	8
Dorsal side of the thigh	4—7	22—85	1:3—1:14	9
Dorsal side of the shank	5—7	18—50	1:5—1:17	7
Ventral side of the thigh	4—7	24—80	1:3—1:10	6
Ventral side of the shank	4—7	22—80	1:3—1:7	7
The flank of the body	4—8	26—100	1:3—1:10	8
Anterior part of the belly	4—9	30—85	1:3—1:13	9
Posterior part of the belly	4—7	27—82	1:3—1:12	9
Ventral side of the head	5—8	10—70	1:3—1:12	8
Anterior part of the back	5—7	33—80	1:5—1:17	9
Posterior part of the back	5—6	25—68	1:4—1:14	8
The average value	4,4—7,2	26,4—77,4	1:3,5—1:13	8,4

About 30 percent of these poison glands measures 1700 µ in diameter, and the majority of glands reaches 1000 µ in diameter. In the walls of the ducts of the bigger glands we can see very fine glands, probably mucous. The bigger mucous glands open in the vicinity of the outlet of the duct of poison glands to the surface of the epidermis. They have probably the function of facilitating the transport of the contents of poison glands.

The poison glands of *Bufo bufo* (L.) both bigger and smaller have always their own net of capillaries, surrounding them, similarly to a net around a ball (Pl. I. fig. 5). This net is denser in the bigger glands and less dense when they are of smaller size. On an average 12 sections of capillaries on 1 mm were found. It is very interesting to note, that the poison glands of other species under investigation lack their own net of capillaries, though the largest of them i. e. in species of the genus *Rana* in the dorsal skinfolds are bigger than the poison glands of the toad, that always possess their own net of capillaries. The skin glands of the remaining species are very weakly vascularised by means of the blood-vessels of the corium laying in their vicinity.

TABLE 4.

Hyla arborea (L.) ♀

The investigated parts of the body	The numbers of layers of the epidermis	The thickness of epidermis in μ	The ratio of the thickness of the epidermis to the corium	The number of glands in 1 mm² of the skin
Dorsal side of the fore-limb	4—6	20—40	1:3—1:5	129
Ventral side of the fore-limb	4—6	30—50	1:1—1:5	87
Dorsal side of the thigh	4—7	20—40	1:1,5—1:7	123
Dorsal side of the shank	5—6	20—35	1:1,5—1:8	121
Ventral side of the thigh	4—5	13—29	1:1,5—1:8	67
Ventral side of the shank	5—6	13—30	1:1,5—1:4	60
The flank of the body	4—6	13—27	1:1,5—1:5	69
Anterior part of the belly	4—7	20—50	1:1—1:3,5	58
Posterior part of the belly	4—7	20—52	1:1—1:4	53
Ventral side of the head	4—6	20—40	1:1—1:5	81
Anterior part of the back	4—6	22—55	1:2—1:8	142
Posterior part of the back	4—5	20—42	1:2—1:5	135
The average value	4,1—6,1	19,5—45,7	1:1,5—1:5,5	97

TABLE 5.

Rana temporaria L. ♂

The investigated parts of the body	The number of layers of the epidermis	The thickness of epidermis in μ	The ratio of the thickness of the epidermis to the corium	The number of glands in 1 mm² of the skin
Dorsal side of the fore-limb	7—8	40—55	1:3,5—1:7	55
Ventral side of the fore-limb	5—7	33—52	1:3—1:6	52
Dorsal side of the thigh	5—6	22—45	1:4—1:7	48
Dorsal side of the shank	5—7	25—54	1:5—1:10	44
Ventral side of the thigh	5—7	25—45	1:3—1:8	47
Ventral side of the shank	4—6	22—40	1:2,5—1:4	51
The flank of the body	5—8	32—54	1:3—1:8	52
Anterior part of the belly	6—7	40—70	1:1,5—1:4,5	57
Posterior part of the belly	6—7	40—70	1:2—1:5	60
Ventral side of the head	6—8	24—65	1:2,5—1:7	55
Anterior part of the back	5—7	25—65	1:4—1:12	58
Posterior part of the back	5—7	27—54	1:4—1:12	57
The average value	5,2—6,8	29,5—55,5	1:3,2—1:7,7	53

Hyla arborea (L.) (Table 4) belongs as well as *Bufo bufo* (L.) to the suborder *Procoela*. The skin of the dorsal part of the body is smooth and therefore we don't see great fluctuations in the relations of epidermis to the corium. On the ventral part of the body the skin of tree-frog has a granular character. We see in sections an almost regular series of protuberances, consequently the relation of epidermis to the corium shows distinct fluctuations from 1 : 1 to 1 : 7 (on an average 1 : 3,5). The thickness of epidermis is rather variable and its average value is 32,6 μ. The number of glands of the skin is in the tree-frog very considerable and reaches on the dorsal side 142 on 1 mm². The ventral side of the body has almost twice less of them. On an average *Hyla arborea* (L.) has 97 glands on 1 mm² of the skin.

The common frog *Rana temporaria* L. (Table 5) posesses the epidermis consisting of, on an average, 6 layers of cells. Its medium thickness calculated from all the investigated parts of the body is 42,5 μ. The thinnest epithel have the posterior limbs and especially their ventral side. The relation of epidermis to the corium doesn't show any considerable fluctuations and is about 1 : 5,4. On an average among common frog we find 53 glands on 1 mm² of the skin.

The epithel of *Rana terrestris* A n d r z. (Table 6) is thinner than that of *Rana temporaria* L. The average numerical value is 38,6 μ. The cha-

TABLE 6.

Rana terrestris A n d r z. ♀

The investigated parts of the body	The number of layers of the epidermis	The thickness of epidermis in μ	The ratio of the thickness of the epidermis to the corium	The number of glands in 1 mm² of the skin
Dorsal side of the fore-limb	4—6	30—55	1:1,5—1:2	53
Ventral side of the fore-limb	4—5	30—40	1:1—1:1,5	47
Dorsal side of the thigh	4—5	20—35	1:1,5—1:3,5	50
Dorsal side of the shank	4—6	22—50	1:1—1:6	43
Ventral side of the thigh	4—6	22—40	1:1,5—1:3	44
Ventral side of the shank	4—5	22—40	1:1—1:2,5	48
The flank of the body	4—6	20—30	1:1—1:3	51
Anterior part of the belly	5—7	35—70	1:0,8—1:3,5	52
Posterior part of the belly	4—5	22—40	1:0,8—1:3,5	50
Ventral side of the head	4—6	22—60	1:1,5—1:3	45
Anterior part of the back	5—6	27—65	1:1,5—1:4	54
Posterior part of the back	5—6	28—65	1:1,5—1:4,5	50
The average value	4,4—5,7	25,7—51,6	1:1,2—1:3,5	49,6

TABLE 7.

Rana esculenta L. ♀

The investigated parts of the body	The number of layers of the epidermis	The thickness of epidermis in μ	The ratio of the thickness of the epidermis to the corium	The number of glands in 1 mm² of the skin
Dorsal side of the fore-limb	4—5	27—45	1:3—1:5	48
Ventral side of the fore-limb	4—5	25—40	1:3—1:4	45
Dorsal side of the thigh	4—5	27—45	1:5—1:12	43
Dorsal side of the shank	4—5	27—40	1:5—1:10	41
Ventral side of the thigh	4—5	22—54	1:5—1:8	45
Ventral side of the shank	4—5	25—40	1:5—1:8	52
The flank of the body	4—5	25—40	1:7—1:14	44
Anterior part of the belly	4—5	30—50	1:5—1:10	48
Posterior part of the belly	4—5	35—51	1:5—1:8	44
Ventral side of the head	5—6	33—48	1:5—1:9	42
Anterior part of the back	5—6	36—52	1:6—1:10	34
Posterior part of the back	4—6	36—55	1:8—1:15	32
The average value	4,1—5,2	29,4—48,8	1:5.2—1:9.6	42,3

TABLE 8.

Species	The number of layers of the epidermis	The thickness of epidermis in μ	The ratio of the thickness of the epidermis to the corium	The thickness of epidermis+corium in μ	The number of glands in 1 mm² of the skin
Bombina bombina (L.)	3,3—5,5	15,1—30,5	1:3,8—1:7,1	134,5	47
The average value	4,4	22,8	1:4,9	134	47
Pelobates fuscus (L a u r.)	5,2—7,3	37,9—69,3	1:1,3—1:4	192,9	33,5
The average value	6,2	53,6	1:2,6	193	33
Bufo bufo (L.)	4,4—7,2	26,4—77,4	1:3,5—1:13	477,4	8,4
The average value	5,8	51,9	1:8,2	477	8
Hyla arborea (L.)	4,1—6,1	19,5—45,7	1:1,5—1:5,5	146,7	97,1
The average value	5,1	32,6	1:3,5	147	97
Rana temporaria L.	5,2—6,8	29,5—55,5	1:3,2—1:7,7	272	53
The average value	6,0	42,5	1:5,4	272	53
Rana terrestris A n d r z.	4,4—5,7	25,7—51,6	1:1,2—1:3,5	127,3	49,6
The average value	5,0	38,6	1:2,3	127	50
Rana esculenta L.	4,1—5,2	29,4—48,8	1:5,2—1:9,6	328,4	42,3
The average value	4,6	39,1	1:7,4	328	42

racteristic feature of this species is that the corium is very thin as compared with epithel. We find very often places where the corium has almost the same thickness as the epidermis or is even thinner e. g. in some points on the ventral side of the trunk. The medium ratio of epidermis to the corium is 1 : 2,3. Since the thickness of the skin depends chiefly on the thickness of the corium that is weakly developed in *Rana terrestris* A n d r z., this species has the thinnest skin of all the investigated forms. Its average thickness is 127 μ. The number of glands is slightly smaller than in *Rana temporaria* L. We found on an average 49 glands on 1 mm² of the skin.

The last species under investigation is *Rana esculenta* L. (Table 7). The epidermis of this species consists in the average of 4—5 layers of cells. Its medium thickness for whole the body is 39,1 μ. Similarly to the both foregoing species the thinnest epidermis is on the posterior limbs. The corium is very strongly developed. So, the skin is a big one and its thickness is on an average 328 μ i. e. three times the thickness of the skin of *Rana terrestris* A n d r z. The ratio of epidermis to the corium is rather changeable. The medium ratio is 1 : 7,4. We note only 42 glands on 1 mm² and its distribution in the skin is very unequal.

B. The Vascularisation of the Skin

To the most part of the skin of trunk of the *Salientia* the blood is conveyed by means of *a. cutanea magna* which transports a weakly oxygenated blood as branch of *ductus pulmo-cutaneus*. It makes possible the utilising of the skin as a respiratory surface. In animals belonging to the genus *Rana, Bombina* and *Bufo* the territory to which *a. cutanea magna* conveys the blood is very similar. In *Pelobates* this territory is a little smaller. In the spadefoot toad and the firebellied toad *a. cutanea magna* is not connected by an anastomose with other vessels but in some individuals of *Bufo bufo* (L.) and in all the species of genus *Rana* this vessel is connected by means of *ramus auricularis a. c. m.* with the arteries parting from the aorta. The posterior part of the trunk-skin is also supplied with blood by means of *aorta caudalis*-branches (*Pelobates*) or *a. ischiadica*-branches (*Rana esculenta* L.) where the *aorta caudalis* is absent. Moreover in the firebellied toad the skin of the back is supplied by means of arteries parting from the *a. ischiadica*, no matter of the presence of *aorta caudalis*. The principal vessel receiving the blood from the skin of the trunk is *vena cutanea magna*. This vessel in *Bombina bombina* (L.) opens to the *v. subscapularis*, while among the other species to the *v. subclavia*. The skin of the extremities receives the blood from arteries running in the neighbourhood. (S z a r s k i 1948). The investigated species show very considerable differences regarding the density of the skin-capillaries. There exist not only distinct differences between the species

114

but even among the specimens of a given species we note considerable fluctuations of the vascularisation of particular regions of the skin. It is best illustrated by means of the tables 9—15.

TABLE 9.
Bombina bombina (L.)

The investigated parts of the body	The number of the meshes of the capillary-net per 1 mm² of the skin			
	Specimen			
	First ♂		Second ♂	Third ♂
	I method of calculation	II method of calculation	II method of calculation	II method of calculation
Dorsal side of the fore-limb	68	46	49	40
Ventral side of the fore-limb	57	41	43	34
Dorsal side of the thigh	60	42	44	35
Dorsal side of the shank	103	86	94	79
Ventral side of the thigh	97	82	79	71
Ventral side of the shank	62	51	56	46
The flank of the body	76	64	59	48
Anterior part of the belly	60	50	51	40
Posterior part of the belly	96	73	71	61
Ventral side of the head	62	49	46	40
Anterior part of the back	150	106	109	91
Posterior part of the back	101	81	85	76
The average value	88	70	72	61

Bombina bombina (L.) has the weakest net of capillaries among all the investigated species. We found on an average 70, 72 and 61 meshes of the capillary-net on 1 mm² of the skin. The dorsal part of the body is more vascularised than the ventral one with the exception of the skin of the thigh which on the ventral side is more vascularised. The diameter of skin-capillaries is less than those of the lungs. The latter capillaries have the diameters 11—20 μ, the former 8—13 μ.

Pelobates fuscus (L a u r.) (Table 10) possesses the net of capillary vessels considerably more developed than former species. It has on an average 116 and 109 meshes of the capillary-net on 1 mm² of the skin. The posterior part of the skin on the ventral side of the trunk is a little more vascularised than the posterior part of the dorsal one and the skin of the ventral side of the body is less vascularised than that of the dorsal parts. Like in the former species the diameter of the skin-capillaries is a little less than this of the lungs-vessels. They are 7—11 μ, and 9—15 μ wide.

The common toad has a more developed net of skin-capillaries. As we see from the table 11 there is an average for the whole body 179 and 171

TABLE 10.

Polobates fuscus (Laur.)

The investigated parts of the body	The number of the meshes of the capillary-net per 1 mm² of the skin		
	Specimen		
	First ♀		Second ♂
	I method of calculation	II method of calculation	II method of calculation
Dorsal side of the fore-limb	105	87	82
Ventral side of the fore-limb	92	73	75
Dorsal side of the thigh	141	95	89
Dorsal side of the shank	149	112	106
Ventral side of the thigh	134	90	83
Ventral side of the shank	84	58	54
The flank of the body	220	138	133
Anterior part of the belly	138	96	92
Posterior part of the belly	232	152	143
Ventral side of the head	96	92	97
Anterior part of the back	216	150	137
Posterior part of the back	162	136	128
The average value	156	116	109

TABLE 11.

Bufo bufo (L.)

The investigated parts of the body	The number of the meshes of the capillary-net per 1 mm² of the skin		
	Specimen		
	First ♀		Second ♂
	I method of calculation	II method of calculation	II method of calculation
Dorsal side of the fore-limb	121	127	132
Ventral side of the fore-limb	169	120	123
Dorsal side of the thigh	210	162	163
Dorsal side of the shank	190	131	128
Ventral side of the thigh	196	138	130
Ventral side of the shank	205	116	112
The flank of the body	360	228	220
Anterior part of the belly	322	205	179
Posterior part of the belly	428	281	270
Ventral side of the head	190	123	118
Anterior part of the back	276	178	169
Posterior part of the back	218	161	156
The average value	255	179	171

of meshes of the vessels-net on 1 mm² of the skin. The skin on the ventral side is in toads considerably more vascularised than that of the dorsal side. Especially strong is vascularised the posterior part of the skin on the ventral side. We find here 281 and 270 meshes of the vessels net on 1 mm² of the skin. The diameter of skin-capillaries is equal or a little greater than this of the lungs capillaries (their respective sizes are 7— 14 μ and 8—14 μ). The skin-capillaries of the ventral side of the body are thicker than those of the dorsal one.

TABLE 12.

Hyla arborea (L.)

The investigated parts of the body	The number of the meshes of the capillary-net per 1 mm² of the skin			
	Specimen			
	First ♀		Second ♀	Third ♀
	I method of calculation	II method of calculation	II method of calculation	II method of calculation
Dorsal side of the fore-limb	176	100	95	90
Ventral side of the fore-limb	173	93	90	83
Dorsal side of the thigh	114	77	66	66
Dorsal side of the shank	138	92	91	80
Ventral side of the thigh	282	154	141	139
Ventral side of the shank	100	40	36	34
The flank of the body	196	117	110	103
Anterior part of the belly	228	138	128	130
Posterior part of the belly	321	190	175	185
Ventral side of the head	110	111	99	107
Anterior part of the back	177	122	120	116
Posterior part of the back	176	106	103	95
The average value	191	121	114	112

Hyla arborea L. (Table 12) has a weaker net of the skin-capillaries than the common toad (121, 114 and 112 meshes of the net on 1 mm² of the skin). Similary to the common toad the skin of the ventral side and especially of its posterior part is much more vascularised than the skin of the dorsal side. The skin of the ventral side of the thigh is also more vascularised than the dorsal one. The diameter of capillaries of the ventral side of the body is distinctly greater than of those situated on the dorsal side. The diameter of the former is 7—15 μ, of the latter 7—11 μ. The ratio of the diameter of skin-capillaries to those of lungs is similar to this, which was found in common toad. On account of the regularly granular structure of the skin of the ventral side of the body the net of capillaries forms something like baskets laying on the elevation of the skin. The net which lays between those elevations is much less dense.

TABLE 13.
Rana temporaria L.

The investigated parts of the body	The number of the meshes of the capillary-net per 1 mm² of the skin			
	Specimen			
	First ♂		Second ♀	Third ♀
	I method of calculation	II method of calculation	II methof of calculation	II method of calculation
Dorsal side of the fore-limb	225	178	176	212
Ventral side of the fore-limb	216	153	146	171
Dorsal side of the thigh	228	170	160	200
Dorsal side of the shank	229	158	145	182
Ventral side of the thigh	341	213	197	250
Ventral side of the shank	214	128	123	169
The flank of the body	269	195	190	231
Anterior part of the belly	217	157	158	190
Posterior part of the belly	218	180	170	213
Ventral side of the head	175	141	134	162
Anterior part of the back	332	218	214	261
Posterior part of the back	307	200	190	236
The average value	253	180	173	212

TABLE 14.
Rana terrestris A n d r z.

The investigated parts of the body	The number of the meshes of the capillary-net per 1 mm² of the skin		
	Specimen		
	First ♀		Second ♀
	I method of calculation	II methof of calculation	II method of calculation
Dorsal side of the fore-limb	90	76	73
Ventral side of the fore-limb	67	50	51
Dorsal side of the thigh	80	77	74
Dorsal side of the shank	100	99	101
Ventral side of the thigh	205	172	160
Ventral side of the shank	65	40	37
The flank of the body	100	91	93
Anterior part of the belly	67	59	58
Posterior part of the belly	82	76	73
Ventral side of the head	58	54	52
Anterior part of the back	176	134	127
Posterior part of the back	162	113	105
The average value	110	94	90

This fact underlines the characteristic arrangement of capillaries on the ventral side of the body.

Rana temporaria L. has a very strongly developed net of skin-capillaries (on an average 180, 173, 212 meshes of the capillary-net per 1 mm² of the skin). Some parts of the skin on the dorsal side of the body are more vascularised than the corresponding parts on the ventral side. The only exception is the skin of the thighs which is considerably more vascularised on the ventral than on the dorsal side (Table 13). The skin-capillaries possess here a smaller diameter than the capillaries of the lungs. They are 6—11 μ and 9—18 μ respectively.

TABLE 15.

Rana esculenta L.

The investigated parts of the body	The number of the meshes of the capillary-net per 1 mm² of the skin		
	Specimen		
	First ♀		Second ♂
	I method of calculation	II method of calculation	II method of calculation
Dorsal side of the fore-limb	287	248	256
Ventral side of the fore-limb	262	193	173
Dorsal side of the thigh	260	181	158
Dorsal side of the shank	314	240	228
Ventral side of the thigh	283	238	217
Ventral side of the shank	187	100	104
The flank of the body	291	249	248
Anterior part of the belly	278	205	175
Posterior part of the belly	278	228	207
Ventral side of the head	254	173	164
Anterior part of the back	439	307	289
Posterior part of the back	367	272	260
The average value	298	227	214

Rana terrestris A n d r z. (Table 14) has a very weakly developed net of skin-capillaries. The density of capillary-net was found to be 94 and 90 meshes per 1 mm² of the skin i.e. twice less than in the common frog which lives almost in the same conditions. The distribution of the density of capillary-net in particular parts of the body is similar to that described in the common frog. The vascularisation of the ventral side of the thigh is very dense, and considerably exceeds the best vascularised parts of the dorsal side of the body. Taking into accounnt considerable surface of the ventral side of the thigh in genus *Rana* in comparison with the total surface of the body and its very good vasculari-

sation we have to atribute considerable participation of this part of the skin to the general cutaneous respiration. The skin-capillaries like those in the common frog have smaller diameter than the capillaries of the lungs. The thickness of capillaries of the skin varies between 7—12 μ and those of the lungs from 7—17 μ.

TABLE 16.

Species	The number of the meshes of the capillary-net per 1 mm² of the skin			
	Specimen			
	First		Second	Third
	I method of calculation	II method of calculation	II method of calculation	II method of calculation
Bombina bombina (L.)	88	70	72	61
Pelobates fuscus (L a u r.)	156	116	109	—
Bufo bufo (L.)	255	179	171	—
Hyla arborea (L.)	191	121	114	112
Rana temporaria L.	253	180	173	212
Rana terrestris A n d r z.	110	94	90	—
Rana esculenta L.	298	227	214	—

Rana esculenta L. has the best vascularised skin of all the investigated species. The average density of the capillary-net calculated for all parts of the body is 227 ánd 214 per 1 mm². The vascularisation of the dorsal side of the body is much better than in the two former species. The skin of ventral side of the thigh is relatively less vascularised than in Rana temporaria L. and Rana terrestris A n d r z. The capillaries, especially on the dorsal side of the body, have the diameter 2—3 times smaller than the capillaries in the lungs. We don't find such a relation in the other investigated species. The diameter of the skin-capillaries is 6—10 μ and those of lungs varies considerably from 9—24 μ. Great differences occur also in the vascularisation of the dorsal and ventral sides of the shank (Table 15).

We have to remember that the differences shown by the investigated species regarding the vascularisation of their skin doesn't give us a pro-

per evaluation of the skin-respiration in particular species if we'll not take under consideration the total surface and the weight of the body of these animals. Therefore the total length of skin-capillaries was calculated and divided by the weight of the body expressed in grams. The length of skin-capillaries was counted by assuming for simplicity, that the meshes of the capillary-net have a shape of regular squares. If for example among three investigated specimens of *Hyla arborea* (L.) the average density of the meshes of the capillary-net was found to be 121, 114 and 112 per 1 mm² (the mean value 115,7), the average number of the sections of vessel in this species was counted to be 10,76 per 1 mm of the skin ($\sqrt{115,7}$). If we consider the meshes of capillaries as having the shape of squares the total length of capillaries in 1 mm² of the skin will be $2\sqrt{115,7}$ i.e. 21,52 mm of capillaries per 1 mm² of the skin. Since the surface of the skin is 3 520 mm² and the weight 6,8 gm. we have 11,114 m of capillaries per 1 gram of the weight of the body. The mistake due

TABLE 17.

Species	The weight of the body in grams	The surface of the skin in mm²	The total length of skin capillaries in meters	The length of skin-capillaries in meters per 1 gm. of the weight of the body
Bombina bombina (L.)	6,6	3 150	51,849	7,85
Pelobates fuscus (L a u r.)	16 0	5 430	115,224	7,20
Bufo bufo (L.)	48,0	9 870	261,160	5,44
Hyla arborea (L.)	6,8	3 520	75,750	11,14
Rana temporaria L.	28,0	6 860	188,357	6,72
Rana terrestris A n d r z.	17,3	5 236	104,264	6,03
Rana esculenta L.	53,0	10 950	325,215	6,14

to the above mentioned simplification is negligible and the values obtained by means of this method differ by 1—2% from those performed with a curvometer on the drawings made by means of the Abbè-camera lucida. We can note from the calculations given in tables that no matter of the great differences in density of vascularisation of the skin, the length

of capillaries per 1 gram of the weight of the body in all the investigated species is not very far one from the other. The only exception is *Hyla arborea* (L.) The number of skin-capillaries in this species is almost twice more than in other species.

THE VASCULARISATION OF THE PALATE

The mucous membrane of the mouth-cavity is vascularised by the branches of first aortic arch (*a. carotis communis*) and therefore redeves the blood oxygenated in the same grade as this to the brain, though it has certainly a respiratory function. (Szarski 1948). The capillaries of the palate form a more or less dense net and in the walls of vessels there are very strongly developed diverticles. The object of this arrangement is probably the enlargement of the respiratory surface and the diminution of

TABLE 18.

Species	The number of the meshes of the capillary-net in the mucous membrane of the palate on 1 mm²	The percentage of the augmentation of the respiratory surface due to the diverticles	The surface of the meshes with the diverticles	The length of capillaries including diverticles in meters	The length of capillaries per 1 g of the weight of the body
Bombina bombina (L.)	46	3—5%	48	1,082	0,163
Pelobates fuscus (L a u r.)	182	75%/80%	327	5,611	0,350
Bufo bufo (L.)	180	to 120%	396	8,557	0,178
Hyla arborea (L.)	161	to 120%	354	3,317	0,486
Rana temporaria L.	123	80—85%	227	4,500	0,160
Rana terrestris A n d r z.	64	30—40%	89	2 230	0,128
Rana esculenta L.	158	85—90%	307	8,890	0,167

the rapidity of the blood circulation. The diverticles among *Bombina bombina* (L.) are very scarce and enlarge the surface of the vessels not more than by 3—5 percent. In *Rana terrestris* A n d r z. these diverticles enlarge the surface of the vessels up to 40 percent and in other species even far more. (Pl. II. figs. 9—13). It is necessary to add that the common toad has

the diverticles weakly developed with the exception of the environs of choanae. (Pl. II. fig. 12). Nevertheless the vessels have highly sinusoidal course and this enlarges considerably their length and consequently their respiratory surface (Pl. II. fig. 13). The density of the net of capillaries of the palate of the investigated species coincides only partially with the vascularisation of the skin. The most weakly developed net of capillaries of the palate possess firebellied toad and *Rana terrestris* A n d r z. The best vascularised palate was found in typically terrestrial species as *Bufo bufo* (L.). *Hyla arborea* (L.) and *Pelobates fuscus* (L a u r). The species which have the best developed net of skin-capillaries i.e. *Rana esculenta* L. and *Rana temporaria* L. occupy the middle place. All these facts are presented in Table 18.

The length of capillaries of the palate per 1 gm. of the weight of the body is very similar in investigated species and varies in sufficiently narrow limits from 0,128 m (*Rana terrestris* Andrz.) to 0,178 m (*Bufo bufo* L.). The only considerable vascularisation was found in *Pelobates fuscus* L a u r. (0,350 m) and *Hyla arborea* L. (0,486 m). The net of vessels in the neighbourhood of choanae is in all investigated species more dense than in the remaining parts of the palate. It is necessary to point that in the calculations of the vascularisation of the mounth-cavity the capillaries of the tongue and the bottom of the mouth-cavity were not taken into consideration.

THE VASCULANSATION OF LUNGS

During the providing of preparations and embedding in paraffin it was noticed that the size of lungs in comparison with size of the body is very differentiated among investigated species. Also great variety of the shape of lungs was noticed. In most cases the lungs possess a shape of an oval sack, tapering a little in the caudal direction.

In *Pelobates fuscus* (L a u r.) the lungs in their posterior parts are very considerably narrower and show an elongation resembling a finger which is curved rostrally. The lungs of the spadefoot toad are of greater size in comparison with the body than those of the other species. In the fire-bellied toad the lungs are of still greater relative size. They have the form of an egg directed with its dull end backward. The complexity of the lung walls shows among investigated species considerable differences too.

The lungs of the firebellied toad are the simplest. They possess a shape of a sack and have very weakly developed septa which only slightly enlarge the respiratory surface of the lungs. A little more complex is the inner surface of the lungs of the spadefoot toad. The further succession is as follows: *Rana terrestris* A n d r z., *Hyla arborea* (L.), *Rana temporaria* L., *Rana esculenta* L. and *Bufo bufo* (L.) (Fig. 2, and Table 19). It is necessary to point out that the septa possess always the net of capillaries on

their both surfaces. Therefore they enlarge doubly the respiratory surface.

From the geometrical point of view the lungs are irregular lumps. For that reason in order to calculate their surface it is necessary to do some simplifications regarding their external shape and also their internal structure. However the observation of their longitudinal and transversal sections shows, that we can consider them as ellipsoid (with the exception of the lungs of *Pelobates fuscus* (L a u r.) which have the shape rather of a cone with a semicircular bottom) with the septa protruding toward the interior. The septa are ribbon-shaped. They run meridian and parallel on the internal surface of the lungs. We may consider the transversal sections of the lungs as a series of circular rings of different diameters, and the longitudinal sections as a series of elliptical rings. The longer and shorter axis of ellipsoid is easy to calculate from the longitudinal and transversal sections of the lungs. After having found these data we can calculate the surface of the ellipsoid using the formula: $P = 2\pi b (b + \frac{a}{\varepsilon}$ arc $\sin\varepsilon)$ where: a — shorter semi-axis of ellipsoid, b — longer semi-axis of ellipsoid, ε — (excentric) $= \frac{c}{a}$. The value of c we find as follows: $a^2 - b^2 = c^2$. The surface of septa was calculated separately for these which run along the lungs (elliptical rings) and for those running transversally (circular rings); the results were added together
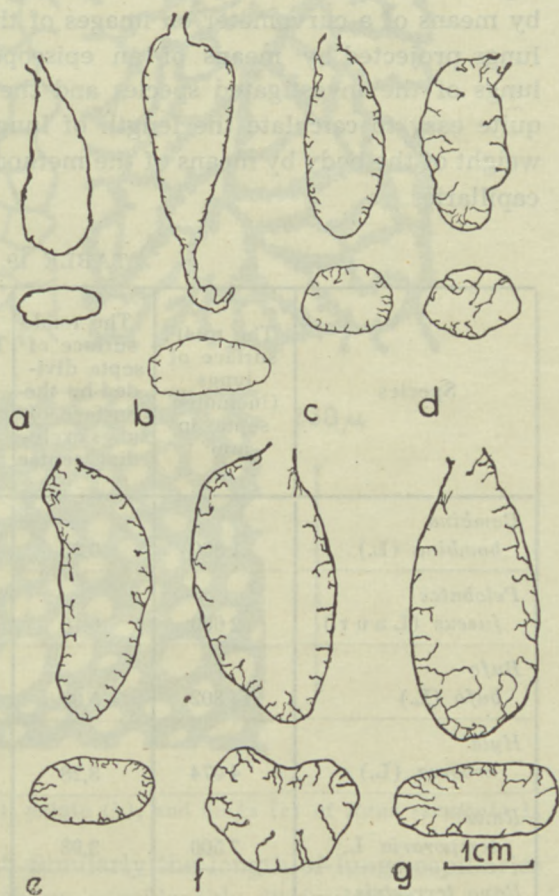
Fig. 2. Longitudinal and cross sections of the lungs of salientians:
a) *Bombina bombina* (L.),
b) *Pelobates fuscus* (L a u r.),
c) *Rana terrestris* A n d r z.,
d) *Hyla arborea* (L.),
e) *Rana temporaria* L.,
f) *Rana esculenta* L.,
g) *Bufo bufo* (L.)

with the former and so the total internal surface of lungs was found. In order to facilitate the calculations the uniform height of the septa in a given lung was assumed. Therefore the average height of them was calculated by suming (in each investigated species) the length of the septa in both transversal and longitudinal section and dividing by the number of septa that occured in a given section. The length of septa was measured by means of a curvometer on images of the photographs of the section of lungs projected by means of an episcope. From the known surface of lungs of the investigated species and the density of capillaries-net it is quite easy to calculate the length of lungs-capillaries per 1 gram of the weight of the body by means of the method used in calculation of the skin-capillaries.

TABLE 19.

Species	The total surface of lungs (including septa) in mm²	The total surface of septa divided by the surface of lungs excluding septae	The number of the meshes of capillary net per 1 mm²	The total length of lungs-capillaries in meters	The length of lungs-capillaries per 1 gm. of the weight of the body
Bombina bombina (L.)	1 300	0,25	280	43,628	6,60
Pelobates fuscus (L a u r.)	2 660	0,76	490	117,838	7,36
Bufo bufo (L.)	14 802	5,09	520	674,971	14,06
Hyla arborea (L.)	4 674	3,28	625	233,700	34,36
Rana temporaria L.	7 500	3,93	458	321,000	11,46
Rana terrestris A n d r z.	4 368	2,67	612	216,216	12,49
Rana esculenta L.	15 182	4,50	408	613,352	11,57

The density of the capillary-net of lungs like this of skin shows considerable differences (Pl. I. figs. 6—8). It is necessary to point out that this density is very variable in different parts of lungs. General'y the posterior parts are more vascularised than the anterior ones. The diameter of the lungs-capillaries is greater than this of the skin-capillaries. This is especially distinct, as it was mentioned before, in *Rana esculenta* L. (Fig 3). Only in *Bufo bufo* (L.) and in *Hyla arborea* (L.) the lungs-capillaries are

of the same diameter and even a little narrower than the skin-capillaries. We may notice from the measurements given in Table 19 that the grade of the enlarging of the respiratory surface of lungs by septa is among in-
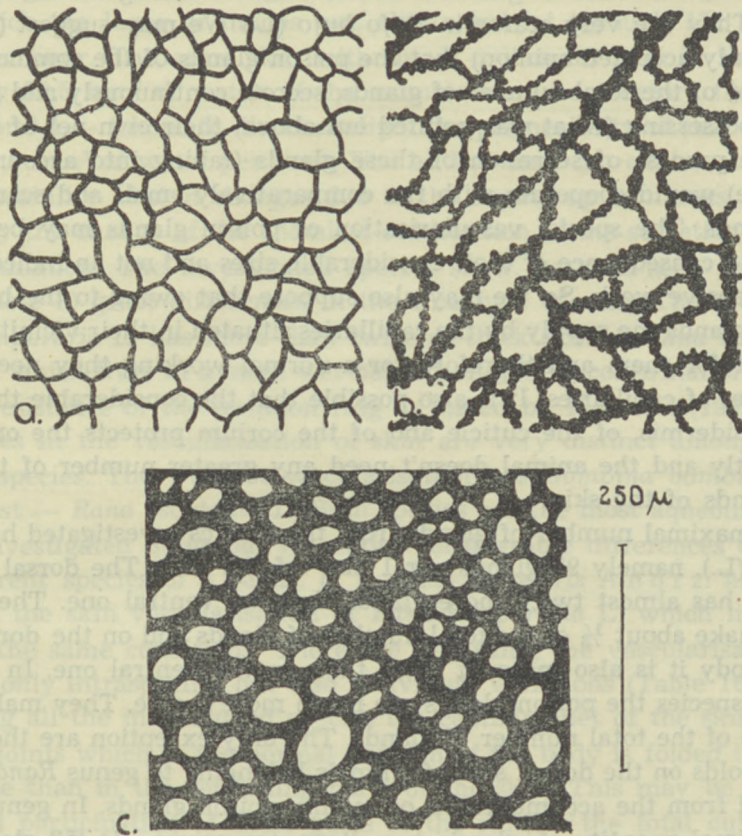

Fig. 3. The capillaries in the skin (a), palate (b), and lungs (c) of *Rana esculenta* L.

vestigated species very different. Similarly the length of lungs-capillaries per 1 gram of the body weight shows considerable dissimilarity.

DISCUSSION

We may notice from the comparison of the average values as to the particulars of the skin structure of the investigated species (given in Tables 1—7) that the more terrestrial species have the epidermis thicker than the species having a more aquatic mode of life. The thick epidermis decreases the danger of an excessive loss of water by the organism. The considerable thickness of epidermis in *Pelobates fuscus* (L a u r.) and *Bufo bufo* (L.) can also be explained as a strengthening of the bodys cover necessary for the active burrowing of these animals in the earth. The typically terrestrial *Hyla arborea* (L.) has a thin epidermis indeed but a great

quantity of skin glands protects the organism from the loss of water. The thin epidermis of this species is rather an accomodation to the mobile mode of life of this animal as this fact facilitates the cutaneous respiration (Table 8). The number of glands is rather variable among the investigated species. They are very scarce in *Bufo bufo* (L.) We may suggest (against a commonly accepted opinion) that the poison glands of the common toad, making ⅓ of the total number of glands, secrete continuously and intensively as possessing (what was pointed out above) their own net of capillaries. The process of secretion of these glands (taking into account their large size) would cooperate with the comparatively small and scarce mucous glands. The special vascularisation of poison glands may be however only a consequence of their considerable sizes and not an indication of their intensive work. So we may also suppose that owing to the big sizes of these glands the supply by the capillaries situated in their vicinity is not sufficient for them and therefore for a normal working they need a separate net of capillaries. It is also possible that the considerable thickness of the epidermis, of the cuticle and of the corium protects the organism sufficiently and the animal doesn't need any greater number of the mucous glands of the skin.

The maximal number of glands from the species investigated has *Hyla arborea* (L.), namely 97 glands per 1 mm² of the skin. The dorsal side of its body has almost twice more glands that the ventral one. The poison glands make about ⅓ of the total number of glands and on the dorsal side of the body it is also more of them than on the ventral one. In the remaining species the poison glands are much more scarce. They make from $1/12$ to $1/6$ of the total number of glands. The only exception are the longitudinal folds on the dorsal side of animals belonging to genus *Rana*. These are build from the accumulations of mainly poison glands. In genus *Rana* the maximal quantity of glands has *Rana temporaria* L. (52 glands per 1 mm² of the skin), and the minimal *Rana esculenta* L. (42 glands per 1 mm² of the skin). *Rana terrestris* A n d r z. occupies a medium place. The differences are not large but quite clear and were confirmed by the investigation of 2 additional specimens of each species. T a n n e n b a u m (1930) stated however that *Rana esculenta* L. has a greater number of glands than *Rana temporaria* L. He supposes, on the basis of his investigation, that the difference between terrestrial and aqueous animals is expressed also in the structure of the glands themselves. In the terrestrial animals they have a long duct (*Bufo bufo* (L.)) what decreases the danger of drying up. In the aqueous animals the ducts are considerably shorter (*Bombina bombina* (L.)). In my opinion, however, the length of ducts of the glands is caused mainly by the thickness of epidermis and not by the adaptation of the glands themselves.

The considerable quantity of glands in more aqueous animals (*Bombina bombina* (L.), *Rana esculenta* (L.)) serves probably by means of plen-

tiful production of mucus for the protection against excessive diffusion of water into the interior of the body. According to the investigations of D i n e s m a n (1948) the mucus considerably restrains the passage of water trough the skin. So e. g. 1 cm² of the skin of *Rana temporaria* L. from which the layer of mucus was eliminated let through 151 mm³ of water per hour. The same skin with intact mucus let pass in the some time only 30,5 mm³ of water. If the animals were kept before the experiment for 0,5 — 1 hour in direct sunlight the permeability of skin decreased to 19,6 mm³ of water per hour. The author does not explain whether the permeability of skin changes due to the drying up of mucus, or it is caused by the change of the chemical composition of the secretion during the illumination. The investigated species show, as it is seen from the table (Table 8) great differences in the thickness of skin. The fact, that *Rana temporaria* L. has more than twice as thick skin as *Rana terrestris* A n d r z., which lives in a more wet habitat, may be a confirmation of the greater resistance of the common frog as stated by H e r t e r (1941). The differences in the vascularisation of skin are very distinct among investigated species. The weakest vascularisation has *Bombina bombina* (L.) the richest — *Rana esculenta* L. Both species are the most aqueous forms among investigated *Salientia*. We notice considerable differences even in the different species of a genus. E. g. *Rana terrestris* A n d r z. has only a half of the skin vascularisation of *Rana temporaria* L. which lives almost in the same conditions. There are regarding the vascularisation of skin not only intraspecific but also individual variations (Table 16).

Among all the investigated species the capillary-net of the skin covering the joints which in the normal position of the body is folded is much less dense than in the remaining parts of the skin. This may be due to the small participation of these parts of the skin in the total cutaneous respiration as a result of their poor contact with the air. The weak vascularisation of these parts may be however only a consequence of considerable mutual pressure which subsists in these parts of the body. This fact can render difficult the development of capillaries and the circulation of blood.

The diameter of the vessels supplying the skin (with the exception of *Hyla arborea* (L.) and *Bufo bufo* (L.), is less than the diameter of the capillaries of lungs. The reason of this may be the necessity of a considerable decrease of the velocity of circulation of blood, because only in this case the saturation of erytrocytes by oxygen may approach the physiological limit. A considerable thickness of epidermis renders difficult the osmotic penetration of oxygen. The cutaneous respiration of the common toad is probably a little larger as it follows from the density of the capillary-net. The poison glands of common toad have their own net of capillaries surrounding them and the top parts of those nets which lay

just below the capillaries of epidermis may participate in the respiration process.

For a better illustration of the differences in the density of the vascularisation of the individual parts of the skin, special diagrams were made
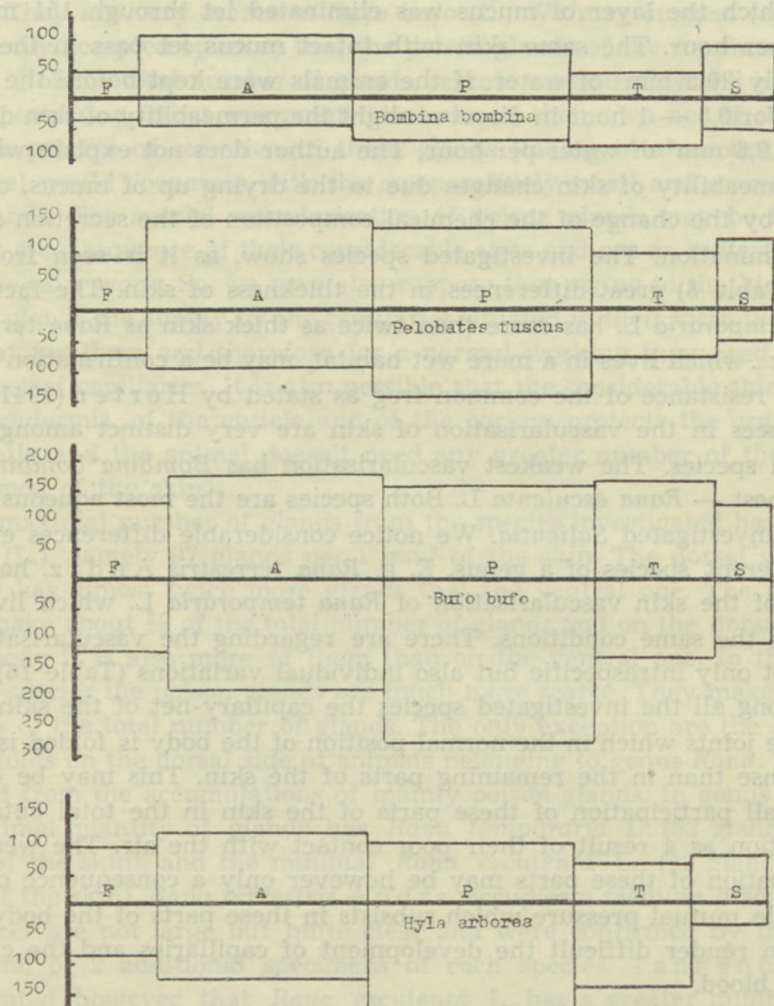
Fig. 4a. Diagrams showing the proportional share in the skin respiration of various parts of the body. F — fore-limb, A — anterior part of the trunk, P — posterior part of the trunk, T — thigh, S — shank.

(Fig. 4 a, b). In the diagrams abscissa represent the total body surface of the species investigated. It was drawn to equal length in all species to obtain better relative estimate. It is divided into segments, whose relative lengths correspond to the relative surfaces of skin covering various parts of the body (F = fore-leg, A = anterior part of the trunk,

P = posterior part of the trunk, T = thigh, S = shank). The dorsal side are imagined above the horizontal line, the ventral sides under the horizontal line. The ordinates represent the number of the meshes of capillary net per 1 mm² of the skin. Owing to this, the areas of the diagrams exhibit the relative role played by the different parts of the skin in the gas-exchange.
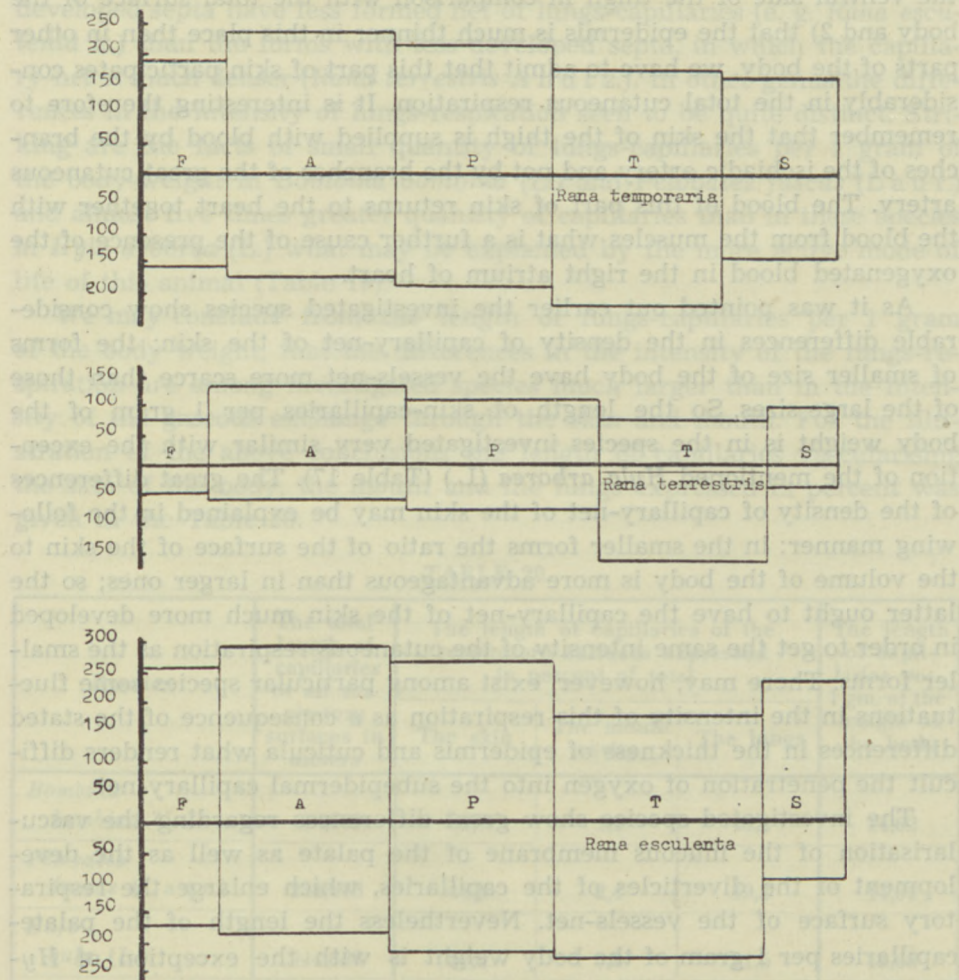
Fig. 4b. Diagrams showing the proportional share in the skin respiration of various parts of the body.

We may notice from these diagrams that in the majority of animals the vascularisation of the dorsal parts of the body is richer than of the ventral ones. The only exception are *Bufo bufo* (L.) and *Hyla arborea* (L.) Their dorsal side of the body is much less vascularised than the ventral one. In all the investigated species the anterior part of the back possess

a more vascularised skin than the posterior part. The vascularisation of the anterior part of the belly is poorer than that of the posterior one. With the exception of *Bufo bufo* (L.) and *Pelobates fuscus* (L a u r.) the skin of the ventral side of the thigh is in all the investigated species very richly vascularised and especially in genus *Rana*. Taking into account 1) considerable surface which, especially in genus *Rana,* has the skin of the ventral side of the thigh in comparison with the total surface of the body and 2) that the epidermis is much thinner in this place than in other parts of the body, we have to admit that this part of skin participates considerably in the total cutaneous respiration. It is interesting therefore to remember that the skin of the thigh is supplied with blood by the branches of the ischiadic artery and not by the branches of the great cutaneous artery. The blood of this part of skin returns to the heart together with the blood from the muscles what is a further cause of the presence of the oxygenated blood in the right atrium of heart.

As it was pointed out earlier the investigated species show considerable differences in the density of capillary-net of the skin: the forms of smaller size of the body have the vessels-net more scarce than those of the large sizes. So the length of skin-capillaries per 1 gram of the body weight is in the species investigated very similar with the exception of the mentioned *Hyla arborea* (L.) (Table 17). The great differences of the density of capillary-net of the skin may be explained in the following manner: in the smaller forms the ratio of the surface of the skin to the volume of the body is more advantageous than in larger ones; so the latter ought to have the capillary-net of the skin much more developed in order to get the same intensity of the cutaneous respiration as the smaller forms. There may, however, exist among particular species some fluctuations in the intensity of this respiration as a consequence of the stated differences in the thickness of epidermis and cuticula what renders difficult the penetration of oxygen into the subepidermal capillary-net.

The investigated species show great differences regarding the vascularisation of the mucous membrane of the palate as well as the development of the diverticles of the capillaries, which enlarge the respiratory surface of the vessels-net. Nevertheless the length of the palate-capillaries per 1 gram of the body weight is with the exception of *Hyla arborea* (L.) and *Pelobates fuscus* (L a u r.) very similar (Table 18). The more intensive respiration through the mouth-cavity which in comparison with the other species shows the tree frog is probably caused by the more active mode of life and in the spadefoot toad by considerable size of mouth-cavity in comparison to the size of the whole the body. The variations in the intensity of respiration through the mouth-cavity may be caused in particular species by the differences in the intensity of ventilatory movements of mouth-cavity and lungs and also by diffe-

rences in thickness of the epidermis of mouth-cavity. The species posses-
sing the epidermis thicker than the other species has also a thicker
epidermis in mouth-cavity.

Considering the length of the lungs-capillaries per 1 gram of the body,
the intensity of the lungs-respiration in the species of genus *Rana* appears
to be very similar no matter of the differences in the organisation of
lungs. This follows from the fact, that the lungs of the forms with well
developed septa have less formed net of lungs-capillaries (e. g. *Rana escu-
lenta* L.) than the forms with less developed septa, in which the capilla-
ry-net is much denser (*Rana terrestris* A n d r z.). In other genus the diffe-
rences in the intensity of lungs-respiration seen to be quite distinct. Stri-
king are the facts of small quantity of lungs-capillaries per 1 gram of
the body-weight in *Bombina bombina* (L.) and *Pelobates fuscus* (L a u r.)
and almost five times greater quantity of capillaries than in these species
in *Hyla arborea* (L.) what may be explained by the more active mode of
life of this animal (Table 19).

We may conclude from the length of lungs-capillaries per 1 gram
of the body weight, that the differences in the intensity of the lungs-re-
spiration are among investigated species much larger than in the inten-
sity of the gaseous exchange through the skin and mouth. For the illu-
stration of the above conclusions the length of capillaries vascularising
the skin of the body, the mouth and the lungs expressed in percent was
given in the Table 20.

TABLE 20.

Species	The total length of capillaries of all respiratory surfaces in meters	The length of capillaries of the respiratory surfaces expressed in percent of total			The length of capillaries per 1 gm. of the weight of the body
		The skin	The mouth cavity	The lungs	
Bombina bombina (L.)	96,559	53,7	1,1	45,2	14,62
Pelobates fuscus (L a u r.)	238,673	48,3	2,4	49,3	14,91
Bufo bufo (L.)	944,688	27,6	0,9	71,5	19,68
Hyla arborea (L.)	312,767	24,2	1,1	74,7	45,99
Rana temporaria L.	513,857	36,6	0,9	62,5	18,35
Rana terrestris A n d r z.	322,710	32,4	0,7	66,9	18,65
Rana esculenta L.	947,457	34,3	0,9	64,8	17,87

132

As we see from this table the most poorly vascularised respiratory surfaces possesses *Bombina bombina* (L.) (14,62 m. of capillaries per 1 gram of the body) and the next is *Pelobates fuscus* (L a u r.) (14,91 m/gm). The length of capillaries in genus *Rana* is very similar and varies from 17,87 m/gm to 18,65 m/gm. The common toad has a little more of capillaries (almost 20 m/gm) and the best vascularised respiratory surfaces possesses *Hyla arborea* (L.), (almost 46 m/gm).

By expressing on the basis of the length of capillaries of skin, mouth-cavity and lungs per 1 gm. of the body-weight the relative participation of these surfaces in respiration we may state large differences among the investigated species. So in the firebelied toad the skin capillaries make 53,7 percent, the lungs-capillaries only 45,2 percent of the total. In the spadefoot toad the skin-capillaries make 48,3 percent and these of the lungs 49,3 percent of the total. In the genus *Rana* the skin-capillaries amount to 32,4 percent in *Rana terrestris* A n d r z., to 34,3 percent in *Rana esculenta* L. and 36,6 percent in *Rana temporaria* L. The lungs-capillaries amount to 66,9, 64,8 and 62,5 percent respectively. Even smaller percent than in genus *Rana* make the skin-capillaries in the common toad (27,6) and in the tree frog (24,2). So in these species the lungs-respiration plays probably a more important role that in remaining ones. The lungs-capillaries make in common toad 71,5 percent of the total quantity of the capillaries of the respiratory surfaces and in the tree frog even 74,7 percent. The quantity of capillaries of the mouth-cavity doesn't show in all the investigated species any considerable variations and amount from 0,7 to 1,1 percent of the total length of capillaries. The only exception is *Pelobates fuscus* (L a u r.) in which the capillaries of the mouth- cavity make 2,4 percent. From the above results it could be concluded that the considerable differences exist in the gaseous exchange among *Salientia,* and also in the general metabolism. We have to remember however, that such conclusions based on the morphological study of the respiratory surfaces only, ought to be accepted with great reservation if they are not confirmed by the more exact physiological investigations on the different species of *Salientia*. Such investigations, as far as I know, with the exception of genus *Rana* were not yet performed.

SUMMARY

The surface of the skin, lungs and of the mucous membrane of the mouth-cavity was investigated, with special attention to the distribution of capillaries, in following species: *Bombina bombina* (L.), *Pelobates fuscus* (L a u r.), *Bufo bufo* (L.), *Hyla arborea* (L.), *Rana temporaria* L., *Rana terrestris* A n d r z., *Rana esculenta* L.,

The distribution of capillaries was studied by means of 1) counting of cross-sections of capillaries on section of the skin, 2) counting of the meshes in the vessels net observed from the surface.

The investigated species show remarkable differences in the thickness of the epithel, of the corium, in the number of skin glands, in the development of the net of capillaries. The values are collected in tables (1—20).

Bufo bufo (L.) has only 8 glands in 1 mm² of the skin. *Hyla arborea* (L.) has 97 of them on the same surface.

The smallest number of meshes in the net of capillaries of the skin characterises *Bombina bombina* (L.) (67 on 1 mm²), the largest was found in *Rana esculenta* L. (220 on 1 mm²). The species of greater dimension have a greater density of the net, the smaller species have a vascularisation of the skin less dense. Owing to this fact, the length of skin capillaries falling on 1 gram of the body-weight is in all investigated species rather similar (11,14 m in *Hyla arborea* (L.), 7,85 m in *Bombina bombina* (L.), 5,44 m in *Bufo bufo* (L.)).

The capillaries of the palate have more or less developed blind outgrowths. The length of the capillaries of the palate falling on 1 gram of the body-weight does not differ markedly in investigated species.

The investigated species show great differences in the shape of lungs, their internal structure and vascularisation. The ratio of the surface of the lungs excluding septa to the surface of the septa, expresses the complexity in the structure of the lungs. It amounts to 0,25 in *Bombina bombina* (L.) and 5,09 in *Bufo bufo* (L).

The total length of capillaries of respiratory surfaces falling on 1 gram of the body-weight is largest in *Hyla arborea* (L.) (45,99 m) and smallest in *Bombina bombina* (L.) (14,62 m).

The proportional share of the capillaries of the skin, lungs and mouth-cavity in the gaseous exchange can be estimated from the relation of their total lengthes. In *Bombina bombina* (L.) the capillaries of the skin amount to 53,7 percent, the capillaries of the lungs to 45,2 percent. In *Hyla arborea* (L.) the capillaries of the skin amount 24,2 percent, the capillaries of the lungs to 74,7 percent. The capillaries of the palate amount in investigated species only 0,7 to 2,4 percent of the total length of the capillaries of respiratory surfaces.

REFERENCES

1. B a s t e r t, Ch. E. 1929: Über die Regulierung des Sauerstoffverbrauches aus den Lungen der Frösche, im Hinblick auf ihr Tauchvermögen. Z. vgl. Physiol. 9. 212—258.
2. B e t h g e, E. 1898: Das Blutgefässsystem von *Salamandra maculata, Triton taeniatus und Spelerpes fuscus*, mit Betrachtungen über den Ort der Athmung beim lungenlosen *Spelerpes fuscus*. Zeit. wiss. Zool. 63. 680—707.
3. B o h r, Ch. 1900: Über die Haut- und Lungenathmung der Frösche, Skandin. Arch. Physiol. 10. 74.
4. D i n e s m a n, L. G. 1948: Adaptacja amfibii k rozlicznym usłowiam własżnosti wozducha. Zool. żurn. 27. 231—239. 1948.

134

5. D o l k, H. E. und P o s t m a, N. 1927: Über die Haut- und die Lungenatmung von *Rana temporaria*. Z. vgl. Physiol. 5. 417—444.

6. F i c a l b i, E. 1899: Su alcuni vasi sanguiferi tegumentali di un anfibio (*Hyla viridis*) e sui loro rapporti con derma e epiderme. Lo Sperim. 53. 5—20.

7. H e r t e r, K. 1941: Die Physiologie der Amphibien. Kükenthal u. Krumbach. Handb. d. Zoolog. 6. Berlin.

8. J o r d a n, H. J. 1927: Übungen aus der vergleichenden Physiologie. Berlin.

9. J o r d a n, H. J. 1929: Allgemeine vergleichende Physiologie der Tiere. Berlin.

10. K r o g h, A. 1904: On the cutaneous and pulmonary respiration of the frog. Skandin. Arch. Physiol. 15. 328.

11. L a s k o w s k i, M. 1929: O pobieraniu tlenu przez skórę u żaby. Acta Biol. Exper. 4. 1—32.

12. L e y d i g, F. 1898: Vascularisiertes Epithel. Arch. mikr. Anat. 52. 152—155.

13. M a u r e r, F. 1897: Blutgefässe im Epithel. Morph. Jahrb. 25. 190—201.

14. M e d v e d e v, L. 1937: The vessels of the caudal fin in amphibian larvae and their respiratory function. Zool. Žurn. 16. 393—403.

15. N o b l e, G. K. 1925: The integumentary, pulmonary, and cardiac modifications correlated with increased cutaneous respiration in the amphibia: A solution of the „hairy frog" problem. J. Morphol. 40. 341—416.

16. S z a r s k i, H. 1948: On the blood-vascular system of the *Salientia*. Bull. Acad. Pol. Sc. B II 1947. 145—211.

17. T a n n e n b a u m, E. 1930: Beiträge zur vergleichenden Anatomie der Hautdrüsen der einheimischen anuren Batrachier auf ökologischer Grundlage. Zoologica, Band 30. Heft 78.

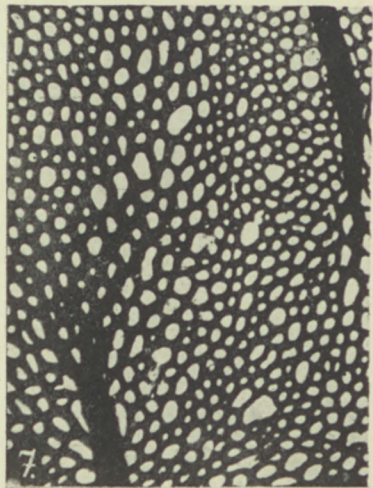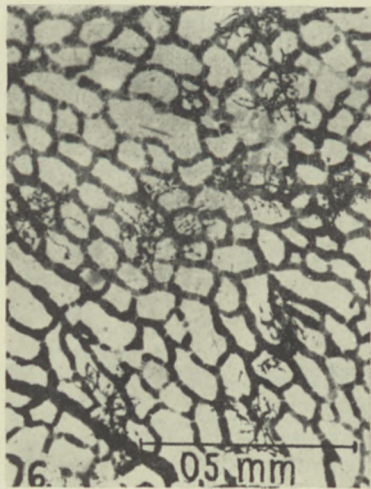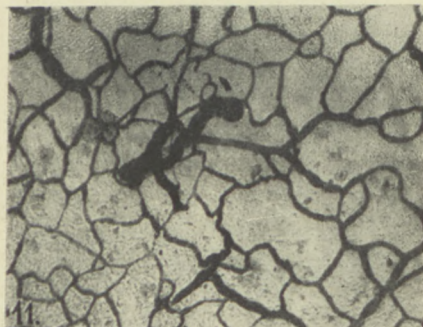18. T e r e n t i e w, P. W. 1950: Laguszka. Sowietskaja Nauka. Moskwa. 1950.
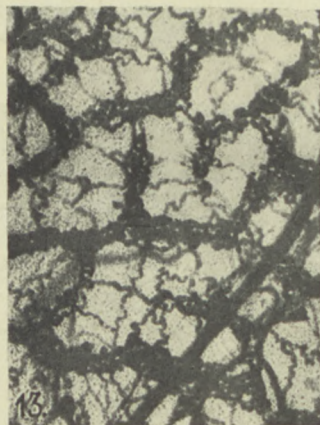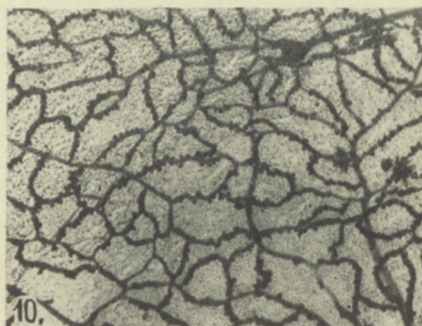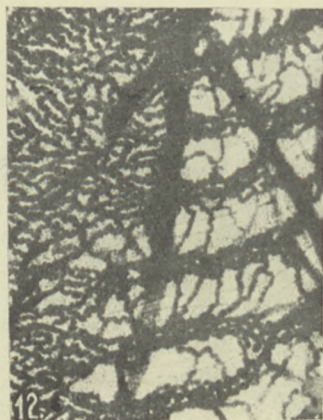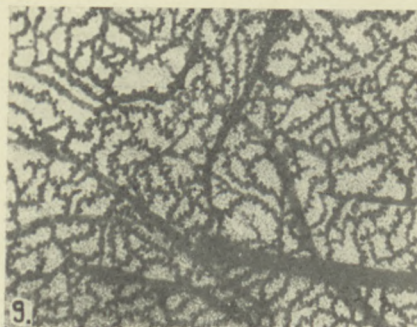
PLATE I.

Fig. 5. The vascularisation of the skin glands in *Bufo bufo* (L.)
Fig. 6. Capillaries of the lungs in *Bombina bombina* (L.)
Fig. 7. Capillaries of the lungs in *Rana esculenta* L.
Fig. 8. Capillaries of the lungs in *Hyla arborea* (L.)

PLATE II.

0,5 mm

Fig. 9. Capillaries of the palate in *Hyla arborea* (L.)
Fig. 10. Capillaries of the palate in *Rana terrestris* A n d r z.
Fig. 11. Capillaries of the palate in *Bombina bombina* (L.)
Fig. 12. Capillaries of the palate in *Bufo bufo* (L.) in the vicinity
        of choanae.
Fig. 13. Capillaries of the palate in *Bufo bufo* (L.) in the posterior
        part of the mouth
        cavity.