Short Communications

Caecilians exhibit cutaneous respiration and high evaporative water loss

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Scolecomorphus kirki exhibited a mean resting $\dot{V}O_2$ at 20% rh and 20°C of 0,052 ± 0,009 ml O_2 g^{-1} h^{-1}. The mean RQ was 1,06 and 54,5% of total CO_2 production was eliminated cutaneously. Evaporative water loss from the skin was high (28,32 ± 6,10 mg H_2O g^{-1} h^{-1}) and the animals are apparently strongly dependent on a moist microhabitat.

Scolecomorphus kirki het 'n gemiddelde rustende $\dot{V}O_2$ van 0,052 ± 0,009 ml O_2 g^{-1} h^{-1} by 20% rh en 20°C. Die gemiddelde RK was 1,06 en 54,5% van die totale CO_2-produksie het deur die vel verlore gegaan. Waterverlies deur verdamping was hoog (28,32 ± 6,10 mg H_2O g^{-1} h^{-1}) en die diere is blykbaar baie afhanklik van 'n vogtige mikro-habitat.

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Caecilians are legless, burrowing amphibians belonging to the order Gymnophiona. They are unusual in not having a typical amphibian skin. Instead, they possess osteoderms that have presumably evolved from crossopterygian fish scales and these may indicate a close evolutionary link between caecilians and the first animals to live on dry land (Bennett & Wake 1974). They also usually possess only a single, complex, and highly vascularized lung and both these features have led to the supposition that caecilians do not employ cutaneous respiration and that they may exhibit a low rate of evaporative water loss. In point of fact, however, caecilians are very rare animals and very little is known of their physiology. Very few studies on their respiration have been performed (see Bennett & Wake 1974) and all of these suffer from very small sample sizes. For these reasons we examined oxygen consumption ($\dot{V}O_2$), carbon dioxide production ($\dot{V}CO_2$), respiratory patterns, and evaporative water loss (EWL) in the caecilian *Scolecomorphus kirki*.

The specimens were collected in Malawi, where they occur mainly between altitudes of 1200 and 1500 m. The animals weighed from 4,5 to 10,5 g and ranged in length from 195 to 300 mm. They were maintained in a large terrarium half-filled with moist leaf litter and fed earthworms *ad libitum* throughout the experimental period.

Oxygen consumption at rest and at 20°C was measured by placing a pre-weighed animal in a sealed 100 ml gas syringe that was then kept in a temperature-controlled cabinet for 60 min. Thereafter, a 20 ml gas sample from the syringe was injected as a bolus into a gas flow-through system which allowed measurement of the oxygen percentage by means of an Applied Electrochemistry Inc. S-3A oxygen analyser and the water vapour pressure of the gas sample by means of a Vaisala HMI 14 meter. Details of the technique and the calculations involved are given in Lighton, Bartholomew & Feener (1987).

The rate of carbon dioxide production ($\dot{V}CO_2$) by *S. kirki* at rest, at 20°C, was measured using a flow-through system. Air was scrubbed of carbon dioxide, using soda lime, and drawn through a respirometer at a flow rate of 500 ml min^{-1}. The respirometer consisted of a perspex cylinder which housed the experimental animal. The Vaisala HMI 14 humidity meter, immediately distal to the respirometer, recorded the relative humidity and temperature of the excurrent air, while an Analytical Development Co. (ADC) 225 Mk 3 infrared gas analyser, connected to a chart recorder, monitored the carbon dioxide level in the air stream. All instruments were calibrated using certified span gases. The animals were blotted dry and weighed before being placed in the respirometer. Generally, the animals were left for at least two hours before a stable, low $\dot{V}CO_2$ value was recorded.

The $\dot{V}CO_2$ lost via the buccopharyngeal and pulmonary surfaces was measured with the same system used to determine the $\dot{V}CO_2$ for the whole body. Exactly the same procedure was followed but in this instance the animals were encased in thin, sticky, polyethelene sheeting that formed an air-tight cocoon, leaving only the head exposed. Thread was secured around the 'neck' and body to ensure a tight seal. Once a value for this avenue of $\dot{V}CO_2$ had been recorded, the animals were unwrapped and the $\dot{V}CO_2$ of the whole body was measured. On alternate occasions the total $\dot{V}CO_2$ was measured first and then the pulmonary $\dot{V}CO_2$ to ensure that the results obtained were not affected by the previous treatment. The treatment differences were tested for statistical significance using Student's paired *t* test (Zar 1974).

To measure EWL, individual specimens were blotted dry, weighed, and placed in a small constant temperature chamber for at least 2 h before reweighing. The chamber was kept at 20°C and air was drawn through it at 400 ml min^{-1}. The relative humidity of the air entering the chamber was maintained at either 42 ± 0,95% or 4 ± 1,62% by an ADC WG 600 water vapour generator. A Vaisala humidity meter and thermistor measured the relative humidity and temperature of the excurrent air continuously. Evaporative water loss was measured both by the change in mass of the animals (gravimetrically) and by comparing the water vapour content of the incoming air with that of the excurrent air (electronically).

Results from the gas exchange experiments showed that the mean resting $\dot{V}O_2$ of *S. kirki* at 20% rh and 20°C was 0,052 ± 0,009 ml g^{-1} h^{-1} (Table 1). Total resting $\dot{V}CO_2$ at ambient humidity (40%) and 20°C was 0,055 ± 0,013 ml g^{-1} h^{-1}. The values obtained for resting metabolic rate ($\dot{V}O_2$) are similar to those reported by

Table 1 Respiratory data for the caecilian *S. kirki* at 20°C (all units are ml g^{-1} h^{-1})

	N	Mean	*S.D.*	Range
Oxygen consumption	13	0,052	±0,009	0,038–0,069
Total carbon dioxide production	18	0,055	±0,013	0,032–0,080
Buccopharyngeal and pulmonary carbon dioxide production	15	0,025	±0,015	0,012–0,060

Bennett & Wake (1974) for *Caecilia occidentalis*, *Geotryptes seraphini*, and *Typhlonectes compressicauda*. The latter studies provided values ranging from 0,037 to 0,149 ml O_2 g^{-1} h^{-1} but sample sizes for the various species were only 1, 4, and 2 respectively. The $\dot{V}O_2$ and $\dot{V}CO_2$ results obtained in the present study are markedly lower than $\dot{V}O_2$ values observed in terrestrial anurans and approximate more closely the range established for plethodontid salamanders (Whitford & Hutchison 1967; Whitford 1973). Chart recordings over several hours showed that $\dot{V}CO_2$ was continuous in *S. kirki* and breathing was not interrupted by periods of apnoea.

The overall mean respiratory quotient (RQ) calculated from the mean $\dot{V}O_2$ and $\dot{V}CO_2$ values was 1,06 but several individual values were as low as 0,86. Hutchison, Whitford & Kohl (1968) report a range of RQ values from 0,53 to 1,26 for anurans and the results obtained in our study suggest the animals were mainly engaged in carbohydrate metabolism (Brown 1964).

The difference between the $\dot{V}CO_2$ of the caecilians encased in the plastic wrap and those left uncovered amounted to 0,030 ml g^{-1} h^{-1} (Table 1) and this difference was statistically significant ($t = 6{,}048$; $d.f. = 31$; $p < 0{,}01$). It would seem therefore that the skin surface of *S. kirki* is employed extensively for the efflux of CO_2 from this organism. In fact, only 45,5% of the total CO_2 production was lost via the buccopharyngeal and pulmonary surfaces.

There are no published values of water loss for caecilians although other amphibians have been well studied. The data in Table 2 show good agreement between the two methods employed to measure EWL in *S. kirki*, although the gravimetric method probably overestimated EWL slightly while the opposite was true for the electronic method. The mean values obtained show that EWL in *S. kirki* was high (2,44 mg cm^{-2} h^{-1}) and similar to rates reported for plethodontid salamanders (3,0–5,0 mg cm^{-2} h^{-1}) at 40% rh (MacMahon 1965; Spotila 1972; Brown, Hastings & Frye 1977).

Table 2 Evaporative water loss ($\bar{x} \pm S.D.$) from the caecilian *S. kirki* at 20°C; all units mg g^{-1} h^{-1}

	Relative humidity	
Method	4%	42%
Gravimetric	28,32±6,10	18,25±6,53
Electronic	24,83±5,53	15,55±6,05

These results are not unexpected in view of the moist microhabitat in which *S. kirki* is usually found.

To conclude, it would appear as if caecilians employ the skin surface as a major site for the elimination of carbon dioxide (54,5% of total CO_2 production). Moreover, in spite of the fact that caecilian skin is thicker than that of frogs and salamanders and contains osteoderms (Bennett & Wake 1974), EWL from the skin surface is high and suggests that *S. kirki*, at least, is strongly dependent on a moist microhabitat. The very low resting metabolic rate recorded for this species may also have important adaptive significance.

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