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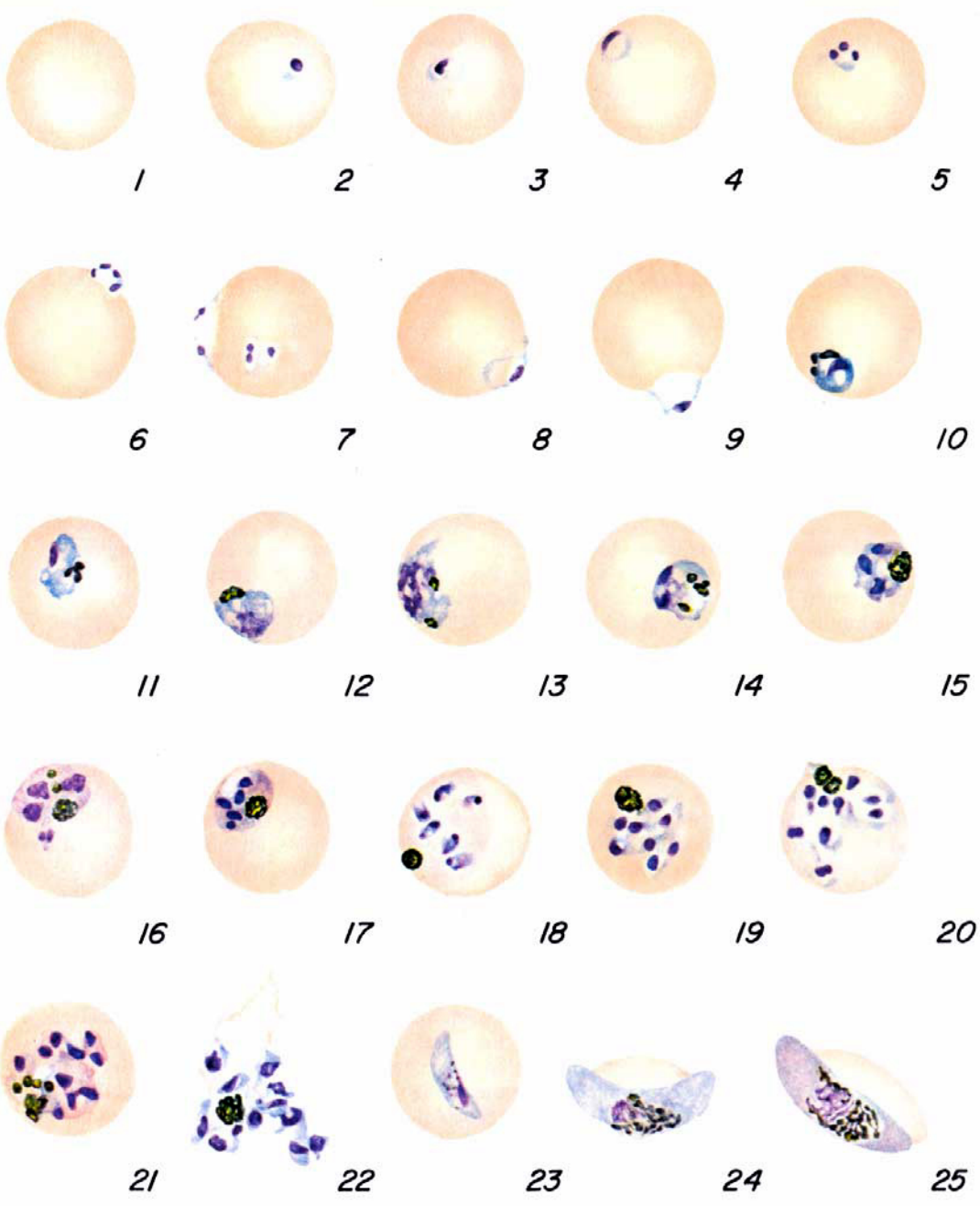
Plasmodium reichenowi Sluiter, Swellengrebel, and Ihle, 1922

REICHENOW (1917, 1917a), working in the Cameroons, saw parasites of malaria in anthropoid apes. In 1920 he published a more detailed study of the blood parasites of the chimpanzee and the gorilla with figures of falciparum-like parasites. His contention was that since these animals live in the vicinity of human habitations and are therefore exposed to bites by the same vectors, their parasites are probably one and the same with those of man. Blacklock and Adler (1922) and Adler (1923) saw parasites resembling *P. falciparum* of man in chimpanzees from Sierra Leone. These investigators were aware that Mesnil and Roubaud (1920) had had partial success in their attempt to infect the chimpanzee with *P. falciparum* via blood inoculation but failed via sporozoites. Inasmuch as Blacklock and Adler doubted Reichenow's conclusion that the infection in the chimpanzee was actually *P. falciparum,* they attempted (1922) to infect man by direct inoculation with the falciparum-like parasite from a heavily infected chimpanzee. The attempt failed. In 1922, according to Adler (1923) they repeated the same experiment with *P. falciparum* which they injected into a three-month-old chimpanzee. The animal did not become infected. They concluded, on the basis of their studies, that the two parasites were different and proposed the name *Plasmodium reichenowi* for the parasite in the chimpanzee. However, Sluiter, Swellengrebel and Ihle had applied the name *Laverania reichenowi* to the chimpanzee parasite in 1922, which Blacklock acknowledged in a short note in 1926, and therefore the credit for the name goes to them. Later investigators have dealt with these parasites as distinct species.

Schwetz (1933, 1933a, 1934) found *P. reichenowi* in the blood of chimpanzees from the Stanleyville area and the upper Congo, and Rodhain (1938) demonstrated the parasite from the same host near Leopoldville. Ducke in 1921, according to Brumpt (1939), found "crescents in the blood of animals taken in Uganda," and Bray (1956) reported the parasite from chimpanzees in Liberia. In 1964, van den Berghe *et al* examined the blood of some fifty chimpanzees and thirty gorillas in the eastern Congo at elevations up to 2,000 meters and failed to find *P. reichenowi* or any other parasite of malaria. More recently (1968), through the kindness of Dr. Betty June Meyers, of the Southwest Foundation for Research and Education, we were able to isolate the parasite from a chimpanzee taken in the eastern part of the Democratic Republic of the Congo near Lake Edward. From these reports it would appear that the parasite occurs in the area bounded by 10°W--30°E and 10°N--5°S.



PLASMODIUM REICHENOWI

Cycle in the Blood

PLATE L

All investigators agree that *Plasmodium reichenowi,* as seen in the peripheral blood, closely resembles *P. falciparum* in the peripheral blood of man. Usually, the parasitemia is marked by the presence of rings and crescents. Other stages appear under stressful conditions or as a result of splenectomy.

The youngest parasites are small rings with a prominent nucleus (Figs. 2-4) or they may contain up to four small chromatin dots (Figs. 5, 6); multiple invasion is not uncommon (Fig. 7).

A prominent feature is the presence of marginal forms which appear as clear blebs with single or double nuclei (Figs. 6, 7, 9). In Bray's experience, accolé forms accounted for 13 percent of the rings. Schwetz (1934) mentioned the abundance of tenue-type forms but these were not a prominent feature of our material. At about 24 hours, the rings generally retreat into the deeper circulation where development continues. Under conditions where growth continues in the peripheral blood, i.e., especially following splenectomy, the pigment appears in discrete clumps, the cytoplasm increases in amount and takes a pronounced blue stain; the nucleus stains bluish-purple to wine color (Figs. 11, 12). With the advent of schizogony, which begins at about 42 hours and moves rapidly, the pigment comes together as a yellowish-black mass, vacuoles appear in the cytoplasm, and the host cell tends to lose color (Figs. 18, 20), but at no time is it fully occupied by the parasite. The mature schizonts contain 10 to 12 merozoites (Fig. 22). The asexual cycle takes approximately 48 hours. Most authors mention the prominence of Mauer's clefts and beading along the periphery of the host cell but they are not shown on our plate because we did not employ special stains. The plate depicts what is seen ordinarily with regular Giemsa stain.

Very young gametocytes rarely appear in the peripheral blood of the intact animal; but, with splenectomy, they make their appearance. According to Bray (1957) and others, these latter forms have difficulty in maturing properly. The development of the gametocytes is well described by Garnham *et al* (1956) and by Bray (1957). The young oval forms, with discrete granules or short rods of pigment, appear first. The oval body is rigid on one side and the other side bends around it in an arc. Cytoplasm collects along the border opposite the nucleus and the pigment (Fig. 23). As the gametocyte grows, it swells and assumes the usual sausage or crescent-shape first described and figured by Reichenow (1920).

The mature macrogametocyte is crescent-shaped and somewhat slender. The cytoplasm stains a pale blue and encloses a compact pale red-staining nucleus with greyish-black pigment granules collected around it (Fig. 24). The microgametocyte is more robust than the distaff parasite. The cytoplasm stains bluish-red and surrounds the centrally located diffuse pale red-staining nucleus and the dispersed brownish pigment (Fig. 25).

Although there is little difference between the parasites of *P. reichenowi* and *P. falciparum,* one difference which appears constant is that the mature gametocytes of reichenowi malaria are more slender and shorter than falciparum parasites. This is easily seen if one compares these forms in Plate XLII with the same forms in Plate L.

The asexual cycle in the blood occupies 48 hours.

Sporogonic Cycle

There are no data on the sporogonic cycle of *Plasmodium reichenowi.*

PLATE L.—*Plasmodium reichenowi*.

Fig. 1. Normal red cell.
Figs. 2-9. Young trophozoites.
Figs. 10-13. Growing and mature trophozoites.
Figs. 14-17. Developing schizonts.
Figs. 18-22. Mature schizonts.
Figs. 23-24. Young adult and mature macrogametocytes.
Fig. 25. Mature microgametocytes.

Cycle in the Tissue

There are no data on this phase of the life-cycle of reichenowi malaria. This is due to the fact that no suitable vector has been found and until that hurdle has been cleared, no progress can be made toward elucidating the tissue phase of the parasite.

Course of Infection

Nothing is known about the course of the early natural infection. All our data are based on observations on naturally infected and blood inoculated captive animals; this information is meager indeed.

Except for the cursory examination of the blood stages by Reichenow (1917, 1917a), Blacklock and Adler (1922), Peel and Rodhain (1946) and others, plus the more detailed studies of these stages by Bray (1956) and by Garnham *et al* (1956) in splenectomized animals, very little is known about the overall infection. The latter authors write of a single animal harboring a natural infection of *P. schwetzi* and *P. reichenowi* which was treated successfully. Two years later the animal was splenectomized only to have *P. reichenowi* parasites appear in the circulating blood. The total length of the observed infection was in the neighborhood of three years; the total length of the infection was undoubtedly a great deal longer.

There is no evidence that the parasite will grow in the rhesus monkey. Rodhain (1938) gave the parasite to *M. mulatta* without success and that has been our experience too. In other simians, the transfer has failed also. For example, Rodhain (1939) transferred parasitized *P. reichenowi* blood to *Cercopithecus schmidti* without success and Bray (1963) failed to gain infection after two attempts using *Cercocebus atys.*

The situation in man generally follows the same line. Blacklock and Adler (1922) gave *P. reichenowi* to two Europeans using both the intravenous and subcutaneous routes without obtaining infection. Later, Rodhain (1939, 1939a) gave *P. reichenowi* blood to two patients and neither one became infected which led Rodhain to say that *P. falciparum* and *P. reichenowi* were not only distinct but also nontransferrable outside the original host species.

Host Specificity

The earliest attempt to find a vector for *P. reichenowi* was that of Blacklock and Adler (1922) who found no evidence of infection after dissecting 40 *Anopheles costalis* (= *gambiae)* mosquitoes which had fed on an infected chimpanzee on two different nights. Rodhain (1941) dissected 76 *A. maculipennis atroparvus,* out of a lot of 165 allowed to feed on a chimpanzee with low gametocyte levels, and found no evidence of infection. The results led Rodhain to suggest that a "special vector" was required. In 1957, Bray tried to infect *A. gambiae* with *P. reichenowi* and found only 4 out of 112 dissected showed oocysts and in 3 of them the oocysts were degenerate. No sporozoites were encountered. He concluded that *A. gambiae* "will not act as a host for *P. reichenowi* ..." There appears to have been no further attempts until we made our trials in 1968. At that time we had an infected chimpanzee whose reichenowi infection showed many apparently mature gametocytes and consequently three species of mosquitoes were allowed to feed: *A. b. balabacensis, A. freeborni,* and *A. stephensi.* When dissected some 6 to 8 days later none showed any evidence of infection. In a way, this was somewhat surprising because *P. schwetzi,* which was being studied at about the same time, had infected two of these species readily. The parasite of malaria is a capricious animal and failure in this instance does not necessarily signify rejection by the mosquitoes but rather it may mean that our feedings were carried out at the wrong time in the course of infections, or, that the physiological conditions of the vertebrate host were other than ideal for the parasite. We believe that further trials, if they present themselves, will lead to success, for it is hard to imagine that under the right conditions this or any other primate malaria would fail to develop in the virtually universal vector, *A. b. balabacensis* or in one of the other experimental vectors available to us.

Immunity and Antigenic Relationships

There is not much to be said on this subject because of the paucity of information. We know that one, two, or all three of the chimpanzee malarias may occur in a single animal at the same time (Schwetz, 1933) or in tandem; but, there is little information on the phenomenon of dominance. In the human malarias, the dominance of *P. falciparum* over *P. vivax* is well recognized and it would be expected that the situation would prevail with *P. reichenowi* and *P. schwetzi* in the chimpanzee. This point was tested recently when we (Coatney, 1968 and Contacos *et al,* 1970) transferred each of these parasites to a splenectomized and to an intact chimpanzee by the inoculation of parasitized blood. Each of the animals developed good infections but what was surprising was that 99 percent of the parasites were *P. schwetzi.* Further study is needed before we can say more about the phenomenon of dominance among the malarias of chimpanzees.

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