

**Zeitschrift:** Acta Tropica  
**Herausgeber:** Schweizerisches Tropeninstitut (Basel)  
**Band:** 39 (1982)  
**Heft:** 1

**Artikel:** Evidence for three respiratory terminals in "Trypanosoma cruzi" epimastigotes  
**Autor:** Carneiro, M. / Caldas, R.A.  
**DOI:** <https://doi.org/10.5169/seals-312960>

### **Nutzungsbedingungen**

Die ETH-Bibliothek ist die Anbieterin der digitalisierten Zeitschriften auf E-Periodica. Sie besitzt keine Urheberrechte an den Zeitschriften und ist nicht verantwortlich für deren Inhalte. Die Rechte liegen in der Regel bei den Herausgebern beziehungsweise den externen Rechteinhabern. Das Veröffentlichen von Bildern in Print- und Online-Publikationen sowie auf Social Media-Kanälen oder Webseiten ist nur mit vorheriger Genehmigung der Rechteinhaber erlaubt. [Mehr erfahren](#)

### **Conditions d'utilisation**

L'ETH Library est le fournisseur des revues numérisées. Elle ne détient aucun droit d'auteur sur les revues et n'est pas responsable de leur contenu. En règle générale, les droits sont détenus par les éditeurs ou les détenteurs de droits externes. La reproduction d'images dans des publications imprimées ou en ligne ainsi que sur des canaux de médias sociaux ou des sites web n'est autorisée qu'avec l'accord préalable des détenteurs des droits. [En savoir plus](#)

### **Terms of use**

The ETH Library is the provider of the digitised journals. It does not own any copyrights to the journals and is not responsible for their content. The rights usually lie with the publishers or the external rights holders. Publishing images in print and online publications, as well as on social media channels or websites, is only permitted with the prior consent of the rights holders. [Find out more](#)

**Download PDF:** 12.01.2026

**ETH-Bibliothek Zürich, E-Periodica, <https://www.e-periodica.ch>**

Departamento de Biologia Celular, Universidade de Brasília, Brasília, Brasil

## Evidence for three respiratory terminals in *Trypanosoma cruzi* epimastigotes

M. CARNEIRO, R. A. CALDAS

### Summary

The respiration of *T. cruzi* epimastigotes was studied using KCN (1 mM) and  $\text{NaN}_3$  (5 mM) as inhibitors and glucose (33 mM) as substrate.  $\text{NaN}_3$  inhibits 18% and KCN 58% of the oxygen uptake when *T. cruzi* cultures enter the stationary phase. The azide-inhibition pattern closely follows endogenous respiration pattern throughout the different growth phases. Titration of the oxygen uptake with cyanide and azide, with the results treated as Dixon plots, indicated the presence of: a) one respiratory terminal sensitive to both cyanide and azide; b) another cyanide-sensitive but azide-insensitive; c) a third insensitive to both inhibitors. Ethidium bromide (5  $\mu\text{g}/\text{ml}$ ) treatment caused the disappearance of the azide-sensitive terminal in the stationary phase.

**Key words:** *Trypanosoma cruzi*; respiration; ethidium bromide; cyanide; azide; respiratory terminals.

### Introduction

The presence of cyanide-insensitive respiration in trypanosomes has been known for some time (von Brand and Tobie, 1947). In bloodstream forms of the *Trypanosoma brucei* group, oxygen consumption insensitive to cyanide is explained by the presence of an  $\alpha$ -glycerophosphate system (Grant and Sargent, 1960; Grant et al., 1961). This terminal oxidase is inhibited by hydroxamates in *T. brucei* (Evans and Brown, 1973). In this species the transition of the bloodstream to culture form is followed by the appearance of a cyanide-insensitive oxidase and then by an oxidase which is cyanide-sensitive (Evans and Brown, 1971).

---

Correspondence: Prof. Ruy A. Caldas, Departamento de Biologia Celular, Universidade de Brasília, 70.910-Brasília, DF-Brasil

In *T. mega*, cyanide-insensitive respiration has been associated with cytochrome *o*, which branches at the ubiquinone-cytochrome *b* region (Ray and Cross, 1972). Steady-state kinetics on the oxygen consumption led to the identification of three terminal oxidases in *T. mega* (Hill and Degn, 1977).

In *T. cruzi* it has been suggested that all three forms have the same degree of sensitivity to cyanide (Rogerson and Gutteridge, 1977). The oxidation of succinate in mitochondrial preparations from epimastigotes is partially sensitive to cyanide (Rogerson and Gutteridge, 1977). This inhibition varies with the age of the culture (Felix et al., 1978). The existence of cytochrome *o* has also been proposed to explain the cyanide-insensitive respiration in *T. cruzi* (Hill and Cross, 1973), although its photochemical action spectra has not been identified. Treatment of *T. cruzi* with the dyskinetoplastic agent ethidium bromide has led to the disappearance of the  $a + a_3$  band, suggesting the presence of cytochrome *o* as an alternative oxidase terminal (Do Campo et al., 1978).

The present paper describes the effect of KCN and  $\text{NaN}_3$  on the respiration of *T. cruzi* and the effect of ethidium bromide treatment on the activity of the two inhibitors.

## Material and Methods

*Growth of organism – T. cruzi.* Y strain (Silva and Nussenzweig, 1953) was maintained in liver infusion-tryptose (LIT) liquid medium (Camargo, 1964) containing 50 U of penicillin G/ml of medium. For large-scale growth 10 ml of inoculum ( $5.0 \times 10^7$  cells/ml) were transferred to 500 ml Erlenmeyer flasks with 100 ml of LIT medium. The flasks were maintained under constant agitation (90 rpm) at 28°C in an incubator-shaker (New Brunswick Scientific Co., Inc., New York, USA). They were sampled for the respiration experiments after the third day of growth.

*Ethidium bromide (EBr) treatment.* For these experiments EBr (Sigma, St. Louis, Mo., USA) solution (0.5 mg/ml) was sterilized by Millipore filtration and added to the LIT medium to a final concentration of 5 µg/ml (Do Campo et al., 1978), immediately before inoculation. The cells were harvested at the stationary-phase of growth.

*Preparation of T. cruzi cells.* The cells were harvested by centrifugation at 2000 g for 15 min at 10–20°C in a refrigerated centrifuge (Sorvall RC-5). They were then washed  $3 \times$  with 0.9% saline solution, and the final pellet was resuspended in a buffered-saline solution (Sylvester and Krassner, 1976) to give a final number of  $10^8$  cells/ml. The cells were counted in a Neubauer chamber.

*Respiration experiments.* Oxygen consumption was monitored polarographically in a Clark-type electrode (YSI oxygen monitor Model 53, Yellow Spring Inc. Co., Ohio, USA). All experiments were carried out at 28°C using 3.0 ml of cell suspension prepared as described previously. Inhibitors were added in a 50 µl sample to give the desired final concentration. The respiratory data were recorded in a 5-min period when there was a linear relationship between time and oxygen consumption. In a standard experiment KCN was added to a final concentration of 1.0 mM, and  $\text{NaN}_3$  5.0 mM; at these concentrations both inhibitors showed their maximal inhibition of  $\text{O}_2$ -uptake (data not shown). Glucose was also added in a 50 µl sample to give a final concentration of 33 mM.

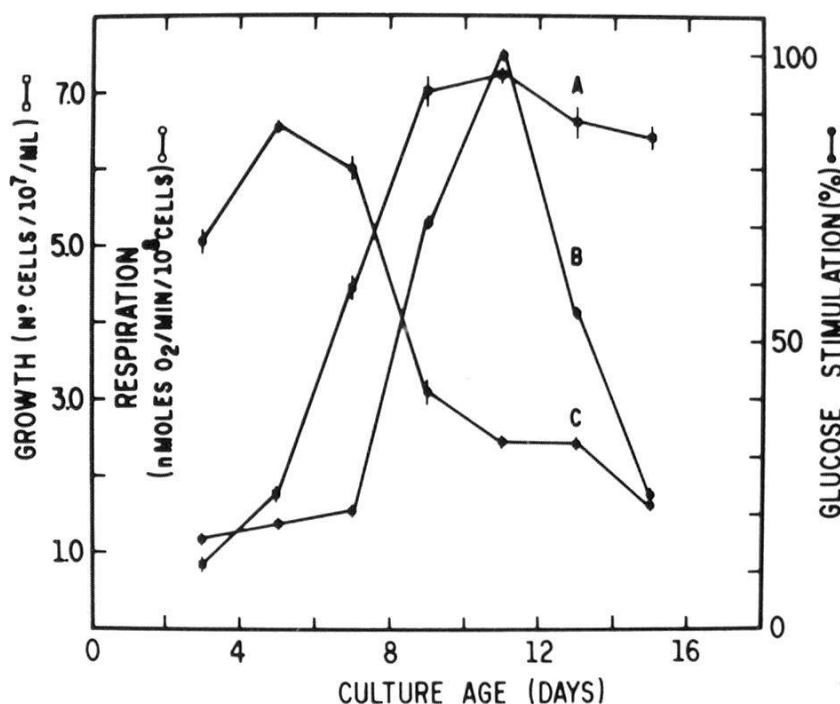


Fig. 1. Endogenous and glucose-stimulated respiration of *T. cruzi* cells as a function of the age of the culture. A typical growth curve for *T. cruzi* in LIT medium is shown (A). The glucose stimulus (B) of the respiration is expressed as the percentage of the endogenous. The endogenous respiration (C) is expressed in nmoles  $O_2$ /min/ $10^8$  cells.

## Results

### *Oxygen consumption during the growth curve and the effects of glucose, KCN and $NaN_3$*

The endogenous respiration greatly decreases after the log phase and the respiratory stimulus caused by addition of glucose (33 mM) increases during the log phase of growth and decreases drastically during the stationary phase (Fig. 1). The inhibition pattern of KCN and  $NaN_3$  as a function of the age of the culture is shown in Fig. 2. The azide inhibition (Fig. 2 C) decreases from the late log to the stationary phase at a much higher rate than KCN inhibition (Fig. 2 B). The azide inhibition pattern (Fig. 2 C) follows closely the endogenous respiration pattern shown in Fig. 1 C.

### *Titration of the oxygen uptake with KCN and $NaN_3$*

Cyanide at saturating concentration inhibits 76% of the respiration at late log-phase (Fig. 3 A) and azide does not have any effect on the cyanide-resistant respiration (Fig. 3 B). Azide inhibits roughly 50% of the oxygen uptake (Fig. 3 C), and after the addition of cyanide a residual respiratory activity (23%), insensitive to both inhibitors, can be seen. These data led us to postulate the existence of three distinct respiratory sites.

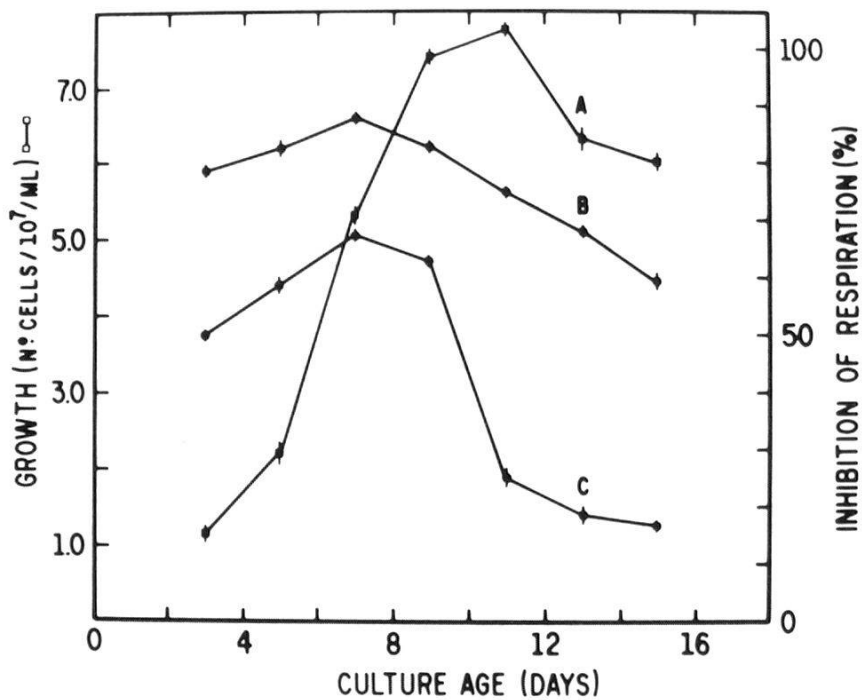


Fig. 2. Effect of respiratory inhibitors on the glucose-stimulated respiration of *T. cruzi*. The inhibition of KCN (B) and NaN<sub>3</sub> (C) is expressed as percentage of the control-respiration in the absence of inhibitors, during the growth curve (A).

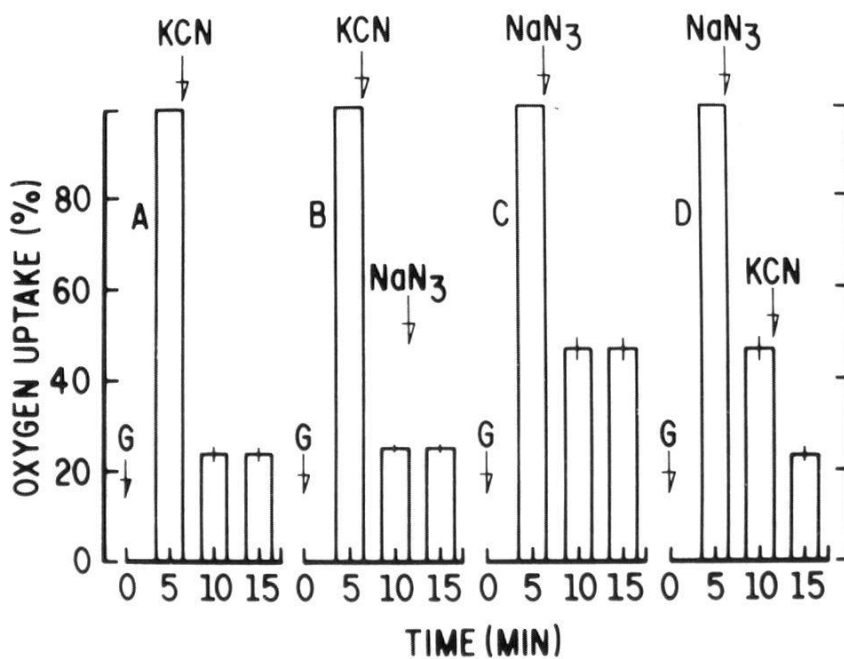


Fig. 3. Titration of oxygen uptake with respiratory inhibitors of late log-phase *T. cruzi* epimastigotes. The arrows indicate the addition of glucose (G), KCN or NaN<sub>3</sub>. A. Control for KCN-inhibition. B. Effect of NaN<sub>3</sub> on the KCN-inhibition. C. Control for NaN<sub>3</sub>-inhibition. D. Effect of KCN on the NaN<sub>3</sub>-inhibition.

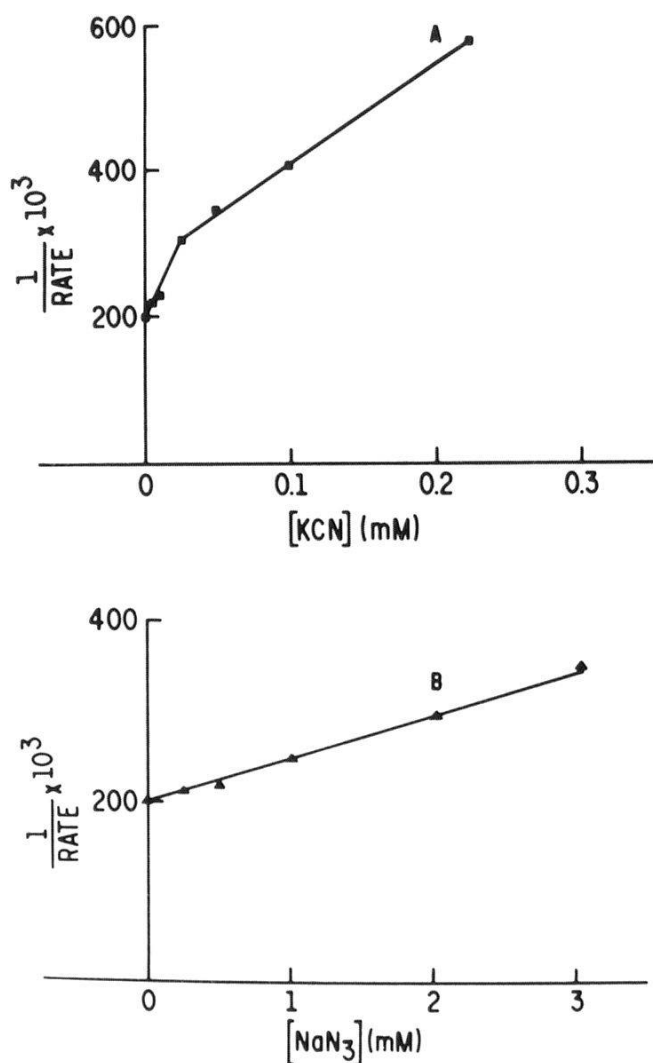


Fig. 4. Dixon plot for the effect of inhibitors on the respiratory rate of late log-phase *T. cruzi* cells. Glucose was used as substrate and KCN (4A) or  $\text{NaN}_3$  (4B) as inhibitors. The rate of oxygen uptake is expressed in nmoles  $\text{O}_2/\text{min}/10^8$  cells.

To verify this postulate, an experiment with low KCN concentration was carried out, and the data were treated in a Dixon plot (Dixon, 1953). The results shown in Fig. 4 A indicated that *T. cruzi* might have two different inhibitory sites for KCN. When the same experiment was done for azide, the Dixon plot obtained indicated the existence of only one inhibitory site (Fig. 4 B).

#### *Respiration experiments with EBr-treated T. cruzi cells*

In the EBr-treated cells the growth was reduced to 60% and the endogenous respiration to 50% of the control (data not shown). The rate of oxygen uptake was the same in both EBr-treated and in the control cells when glucose was used as substrate.

EBr treatment led to the disappearance of the azide sensitive respiratory site (Fig. 5 C). Cyanide inhibited 50% of the respiration of *T. cruzi* (Fig. 5 A, D). Azide had no effect on the residual respiration of KCN (Fig. 5 B).

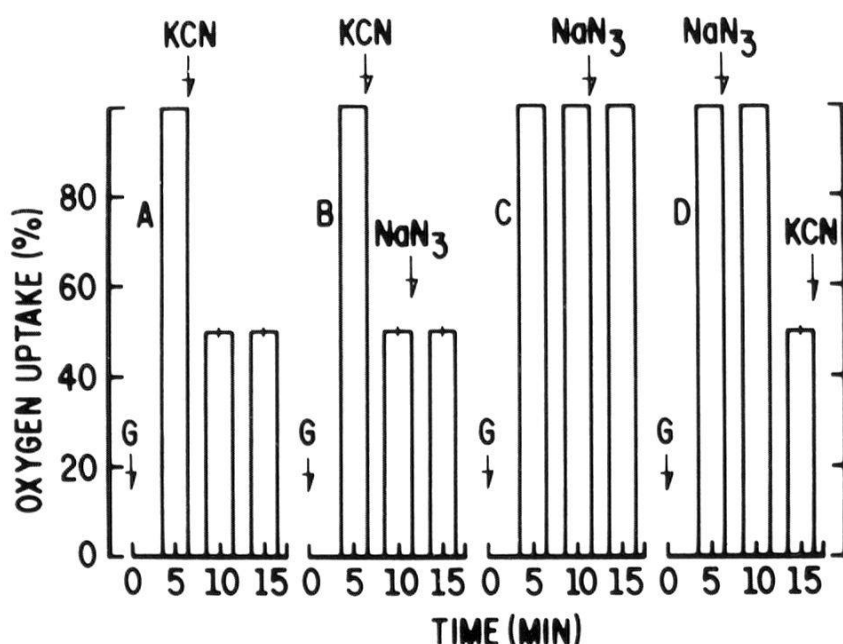


Fig. 5. Titration of oxygen uptake with respiratory inhibitors of stationary-phase *T. cruzi* cells treated with EBr. The arrows indicate the addition of glucose (G), KCN or  $\text{NaN}_3$ . A. Control for KCN-inhibition. B. Effect of  $\text{NaN}_3$  on the KCN-inhibition. C. Control for  $\text{NaN}_3$ -inhibition. D. Effect of KCN on the  $\text{NaN}_3$ -inhibition.

## Discussion

The results shown in Fig. 1 and Fig. 2 indicate that the sensitivity to KCN and  $\text{NaN}_3$  inhibition is somehow correlated with the age of *T. cruzi* cells. At the stage when the cells make less use of glucose for their respiration the main respiratory chain could be either reduced in concentration or activity. This conclusion is based on the extremely low respiratory stimulus caused by glucose after 15 days of growth (Fig. 1) and the low inhibition by  $\text{NaN}_3$  at the same growth stage (Fig. 2). The difference in effectiveness of  $\text{NaN}_3$  and KCN as inhibitors of the respiratory chain has already been reported in *Trypanosomatidae* (Hill, 1976). This difference varies with the age of the culture in *T. cruzi* epimastigotes as reported in the present paper. The changes observed in the inhibitory pattern for KCN and  $\text{NaN}_3$  (Fig. 2) suggest the existence of different respiratory terminals. The titration of the oxygen uptake by *T. cruzi* cells at late log-phase (Fig. 3) and the Dixon plots at low concentrations of KCN and  $\text{NaN}_3$  (Fig. 4) reveal the presence of at least three different respiratory terminals: a) one sensitive to both cyanide and azide; b) another cyanide-sensitive but azide-insensitive; c) a third insensitive to both inhibitors.

The presence of two oxidases in damaged cells of *T. mega* has been proposed based on spectral evidence and biphasic curves obtained in Dixon plots for inhibition of the respiration by KCN,  $\text{NaN}_3$  and antimycin (Ray and Cross, 1972). Steady-state kinetics data have revealed the presence of three terminal oxidases in intact cells of *T. mega*: a) an azide-sensitive, which is sensitive to



salicylhydroxamic acid (SHAM); b) an azide-sensitive, SHAM-insensitive, which is inhibited by CO; c) a third oxidase, insensitive to both azide and SHAM, but inhibited by CO, which was postulated to be cytochrome *o* (Hill and Degn, 1977).

Our data suggested the presence of only one oxidase sensitive to  $\text{NaN}_3$  (Fig. 4) which disappeared in the EBr-treated cells (Fig. 5 B–C). This oxidase in *T. cruzi* has been described as the cytochrome  $a+a_3$  system (Ryley, 1956). Furthermore, the treatment of *T. cruzi* epimastigotes with EBr has led to the disappearance of the spectral bands of the  $a+a_3$  oxidase (Do Campo et al., 1978). Similar results have been obtained in dyskinetoplastic *C. fasciculata* (Hill and Anderson, 1969).

The oxidase more resistant to KCN inhibition (Fig. 4) is shown in our experiments to be insensitive to  $\text{NaN}_3$  (Fig. 5 A–D). These data are in agreement with the presence of cytochrome *o* in *T. cruzi* (Hill and Cross, 1973). The presence of cytochrome *o* has been demonstrated in *T. mega*, *Blastocrithidia culicis* and *Leishmania tarentolae* based on action spectra data for the photochemical relief of CO-inhibition (Kronick and Hill, 1974). To our knowledge there is no similar evidence for *cyt o* in *T. cruzi*.

The third oxidase, which is insensitive to both  $\text{NaN}_3$  and KCN, could be associated with the  $\alpha$ -glycerophosphate ( $\alpha$ -GP) system. In *T. brucei* this system is insensitive to KCN,  $\text{NaN}_3$  and antimycin (Grant and Sargent, 1960; Grant et al., 1961) and it has two components, a dehydrogenase and an oxidase; the latter is of mitochondrial nature (Oppendoes and Borst, 1976). The dehydrogenase is inhibited by SHAM and the oxidase by suramin (Bowman and Fairlamb, 1976).

It has been shown that in *T. cruzi* epimastigotes, trypomastigotes and amastigotes, the  $\alpha$ -GP oxidase activity is associated with the mitochondrial preparation, inhibited by suramin and insensitive to SHAM (Gutteridge and Rogerson, 1979). The dehydrogenase component was not detected in *T. cruzi*, but crude mitochondrial preparations presented a respiration sensitive to SHAM at the exponential phase of growth when succinate was used as substrate (Felix et al., 1978).

The existence of an  $\alpha$ -GP oxidase directly associated with the main respiratory chain has been postulated, with evolutionary implications (Gutteridge and Rogerson, 1979). It is also possible that in *T. cruzi* there is a weak coupling of the two components of the  $\alpha$ -GP system, which are maintained together during extraction depending on the procedure used. Nonetheless the question still remains as to the nature of the respiration of *T. cruzi* insensitive to KCN and  $\text{NaN}_3$ .

The physiological reason for the existence of different respiratory terminals in *T. cruzi* could be explained based on the need of the parasite to adapt to different environmental conditions (insect-gut, blood and animal tissues). In culture we observed a reduction in concentration or activity of the  $\text{NaN}_3$ -sensi-



tive terminal which is followed by the decrease in the utilization of glucose as substrate (Fig. 2). This might be followed by a shift of the oxygen consumption to a terminal more resistant to KCN inhibition (*cyt o?*). If that is the case, this shift could be related to the  $PO_2$  of the medium and/or to the accumulation of organic acids. It has been shown, for instance, that succinic and malic acid are excreted in *T. cruzi* culture (Boiso and Stoppani, 1973). At low  $PO_2$  it is assumed that a respiratory terminal with high affinity for  $O_2$  should be more efficient. In *T. mega*, the *cyt o* has a  $K_{m(O_2)} = 0.143$  M whereas the  $K_{m(O_2)} = 0.350$  M for the  $a + a_3$  oxidase (Hill, 1976). Our data suggest that the change in inhibition pattern of *T. cruzi* during the growth curve might have adaptive implications.

### Acknowledgment

We are thankful to Dr. E. Gander and Dr. L. S. Caldas for critical reading of the manuscript, and to C. R. Felix for helpful discussions at the beginning of this study. This work was partially supported by research grant PDE 05-1-18 from CNPq.

- Boiso J. F., Stoppani A. O. M.: The mechanism of acetate and pyruvate oxidation by *Trypanosoma cruzi*. *J. Protozool.* 20, 673–678 (1973).
- Bowman I. B. R., Fairlamb A. H.: L-Glycerol-3-phosphate oxidase in *Trypanosoma brucei* and the effect of suramin. In: *Biochemistry of parasites and host-parasite relationships*, ed. by H. van den Bossche, p. 501–507. Elsevier North-Holland Biomedical Press, Amsterdam 1976.
- von Brand T., Tobie E. J.: Further observations on the influence of cyanide on some trypanosomes. *J. cell. comp. Physiol.* 31, 49–68 (1947).
- Camargo E. P.: Growth and differentiation in *Trypanosoma cruzi*. I. Origin of metacyclic trypanosomes in liquid medium. *Rev. Inst. Med. trop. S. Paulo* 6, 93–100 (1964).
- Dixon M.: The determination of enzyme inhibitor constants. *Biochem. J.* 55, 170–171 (1953).
- Do Campo R., Boiso J. F., Stoppani A. O. M.: Tricarboxylic acid cycle operation at the kinetoplast-mitochondrion complex of *Trypanosoma cruzi*. *Biochim. biophys. Acta (Amst.)* 502, 466–476 (1978).
- Evans D. A., Brown R. C.: Cyanide insensitive culture form of *Trypanosoma brucei*. *Nature (Lond.)* 230, 251–252 (1971).
- Evans D. A., Brown R. C.: *m*-Chlorobenzhydroxamic acid – an inhibitor of cyanide-insensitive respiration in *Trypanosoma brucei*. *J. Protozool.* 20, 157–160 (1973).
- Felix C. R., Caldas R. A., Ceron C. R., Roitman I.: Cyanide-sensitive and insensitive respiration of *Trypanosoma cruzi*. *Ann. trop. Med. Parasit.* 72, 89–91 (1978).
- Grant P. T., Sargent J. R.: Properties of L- $\alpha$ -glycerophosphate oxidase and its role in the respiration of *Trypanosoma rhodesiense*. *Biochem. J.* 76, 229–237 (1960).
- Grant P. T., Sargent J. R., Ryley J. F.: Respiratory systems in the Trypanosomatidae. *Biochem. J.* 81, 200–206 (1961).
- Gutteridge W. E., Rogerson G. W.: Biochemical aspects of the biology of *Trypanosoma cruzi*. In: *Biology of the kinetoplastida* (2), ed. by W. H. R. Lumsden and A. Evans, p. 619–651. Academic Press, New York 1979.
- Hill G. C.: Electron transport systems in kinetoplastida. *Biochim. biophys. Acta (Amst.)* 456, 149–193 (1976).
- Hill G. C., Anderson W. A.: Effects of acriflavine on the mitochondria and kinetoplast of *Crithidia fasciculata*. *J. Cell Biol.* 41, 547–561 (1969).
- Hill G. C., Cross G. A. M.: Cyanide-resistant respiration and a branched cytochrome system in kinetoplastida. *Biochim. biophys. Acta (Amst.)* 305, 590–596 (1973).

- Hill G. C., Degn H.: Steady-state oxygen kinetics of terminal oxidases in *Trypanosoma mega*. J. Protozool. 24, 563–565 (1977).
- Kronick P., Hill G. C.: Evidence for functioning of cytochrome *o* in kinetoplastida. Biochim. biophys. Acta (Amst.) 368, 173–180 (1974).
- Opperdoes F. R., Borst P.: The effect of salicylhydroxamic acid on the glycerol-3-phosphate oxidase (GPO) of *Trypanosoma brucei*. Its influence on a *T. brucei* model infection and the intracellular location of GPO. In: Biochemistry of parasites and host-parasite relationships, ed. by J. van den Bossche, p. 509–517. Elsevier, North-Holland Biomedical Press, Amsterdam 1976.
- Ray S. K., Cross G. A. M.: Branched electron transport chain in *Trypanosoma mega*. Nature New Biol. 237, 174–175 (1972).
- Rogerson G. W., Gutteridge W. E.: The action of respiratory inhibitors on the culture epimastigote, blood trypomastigote and intracellular amastigotes of *Trypanosoma cruzi*. Parasitology 75, XXVII (1977).
- Ryley J. F.: Studies on the metabolism of protozoa 7-comparative metabolism of eleven species of trypanosomes. Biochem. J. 62, 215–222 (1956).
- Silva H. P., Nussenzweig V.: Sobre uma cepa virulenta de *Trypanosoma cruzi* altamente virulenta para o camundongo branco. Folia clin. biol. (S. Paulo) 20, 191–208 (1953).
- Sylvester D., Krassner S. M.: Proline metabolism in *Trypanosoma cruzi* epimastigotes. Comp. Biochem. Physiol. 55 (B), 443–449 (1976).

