Wistar系ラットにおける温熱性唾液分泌と体水分利用効率の系統差

誌名	Japanese journal of veterinary science
ISSN	00215295
著者	古山, 富士弥 吉田, 俊秀 熊崎, 路子
巻/号	50巻2号
掲載ページ	p. 415-423
発行年月	1988年4月

Thermal Salivation and Body Water Economics among Wistar Rat Strains

Fujiya FURUYAMA, Toshihide YOSHIDA[1)], Michiko KUMAZAKI and Kokichi OHARA

Department of Physiology, Nagoya City University Medical School, Kawasumi-cho, Mizuho-ku, Nagoya 467, and [1)]Department of Cellular Genetics, National Institute of Genetics, Mishima 411, Japan

(Received 11 March 1987/Accepted 8 December 1987)

ABSTRACT. Strain difference in thermoregulation under hot environment was studied among Wistar rat strains, especially in relation to thermal salivation and body water economics (BWE). Eight Wistar rat strains were exposed to an ambient temperature (Ta) of 42.5°C, 40% RH. Survival time (ST), saliva spreading (SS), body water loss (BWL), BWE, and wet weight of 3 salivary glands were determined. Strain difference in thermoregulatory ability was as large among Wistar rat strains as it was among *non-Wistar* rat strains. Crj: Wistar survived heat longer than the others. LEW/N Crj, HOS: Wistar, Wistar-Kyoto and Wistar/MS also survived heat longer than Jcl: Wistar, Wistar King A and Wistar/MK. Rats depend on extensive SS in order to survive the heat longer than 2 hr. BWE was highly efficient in strains showing more saliva spreading than others. There was no change in the wet weight of the submaxillary gland in terms of heat tolerance. These findings indicated that thermal salivation is a potential evaporative heat loss system in Ta higher than body temperature (Tb). Thermal salivation is supported by rapid body water mobilization in the early phase and by highly efficient BWE during the following long lasting hyperthermia.—KEY WORDS: body temperature, dehydration, hyperthermia, salivation, thermoregulation.

Jpn. J. Vet. Sci. 50(2): 415–423, 1988

The heat loss system is the basis for thermoregulation. Evaporative heat loss by sweating and respiration is well known as a mechanism for hyperthermia suppression. A visible sweating is not observed in rats, *Rattus norvegicus*. Rats regulate Tb in hot environments by SS on their ventral body surface, losing body water gradually [2, 4, 7, 8, 11, 14, 15]. This is called thermal salivation, which is to be distinguished from salivation induced by taste.

We earlier reported a strain difference in thermoregulatory ability at Ta of 42.5°C, among 12 rat strains [4]. Sprague-Dawley and Fisher 344 survived heat longer than the other 10 rat strains. All rats were killed by heat when their Tb attained 45°C. Heat tolerant individuals spread saliva in order to regulate their Tb just below the maximum survival body temperature of 43.1°C in males and 43.3°C in females. Only two Wistar rats were reported, in spite of the many Wistar rat strains used for experiments in the life sciences. It is a problem whether Wistar rat strains can be regarded yet as a same group in terms of thermoregulation among many rat strains.

It is worth while to study SS in each Wistar strain. SS depends on rapid body water mobilization. Long lasting thermal salivation causes severe dehydration. Then, it is also a problem how BWE reacts during SS in special relation to severe dehydration.

The present study was designed to clarify thermoregulatory ability under a hot environment in each Wistar strain, especially in relation to the role of thermal salivation. BWE during hyperthermia was also studied in relation to dehydration caused by body water mobilization in case of long lasting SS [4].

MATERIALS AND METHODS

Animals. Thirteen-week-old male rats were exposed to heat. Eight Wistar rat strains were Used. Wistar/MK (WM), Jcl: Wistar (JW) and HOS: Wistar (HOS) were obtained from their original colonies. Wistar-Kyoto (WKY), Wistar-Lewis (LEW) and Crj: Wistar (CRJ) were obtained from Charles River Japan, Atsugi. Wistar/MS (MS) and Wistar King A/Hok (WKA) were obtained recently from Shizuoka Laboratory Animal Center. Abbreviations of strain name were not shown in the abstract to avoid possible confusions. Rats were raised for more than 9 weeks prior to heat exposure in a small climatic chamber (1.0m×1.0m×2.0m, W×D×H) according to one room-one strain system and all in-all out system. Ta in the chamber was 24±1°C. The chamber was illuminated from 7:AM to 7:PM with 300 lux. Micro climate in the cage was controlled to standardize their thermal history. Each rat was housed in a cage to prevent huddling, which modifies their thermal history. The chamber and equipment were sometimes disinfected.

Measurements. Colonic temperature (Tc) was measured at the early phase of exposure by bar mercury thermoneter continually and by copper-constantan thermocouple continuously since Tc attained 40.5°C. The thermometer was inserted 5–6 cm from the anal sphincter according to the body size. ST was calculated without thermal death from the heating duration until Tc attained 42.5°C [5]. SS was indicated visually as scores from 0 to 11 in terms of body surface areas upon which saliva was spread: 1, between incisors and on lower lip; 2, jaws; 3, neck; 4–5, chest; 6–9, abdomen; 10, testis; 11, outside of hindlegs; and 12, face beyond eyes. A zero score served to indicate complete dryness. BWL during heat exposure was calculated by body weight (BW) before and after the heat exposure as an index of evaporative water loss. Error by excretion was minimized by 2 hr fasting except for water and forced excretion by depressing the ventral abdomen and inserting a glass bar thermometer into the colon prior to heat exposure. The dropped water during the heat exposure was checked by weighing the mineral oil filled pan under the cage.

Statistical Analysis. values were shown by mean±standard deviation. Data were statistically analysed by Kruskal-Wallis rank test which is a one way classification analysis of variance. Differences in ST, BWL and BWE between each pair of strains were shown by Wilcoxon rank sum test. Difference in SS was shown by Tukey multiple comparison. Spearman rank correlation coefficient was calculated between ST and wet weight of 3 different salivary glands. Analyses were performed by STATPAC-2/4/6, which is a statistical package for ACOS-6 computer (NEC Corporation).

Experiment. Each rat was exposed to Ta of 42.5°C, 40% RH. Heat exposure was begun at 10–11 AM in an illuminated climatic chamber (6.3m×6.3m×2.5m, W×D×H) in which Ta was controlled with an accuracy of 0.1°C, and velocity of straight winds was 0.3–0.7 m/sec. During the heat exposure, rats were caged individually in a steel wire cage. Food intake and drinking were not allowed. Tc was recorded as mentioned above. When Tc attained 42.5°C, rats were transported to a thermally neutral room to avoid heat injury. BW was also measured before and after heat exposure. BWL during the period between Tc of 42.5°C and 45°C was negligible in the pilot experiment. SS was determined when Tc attained 42.5°C. Females were also exposed to heat to study sex difference in thermoregulatory ability. Salivary glands in pentobarbital anesthetized rats were removed and weighed at Ta of 25°C. Submaxillary and

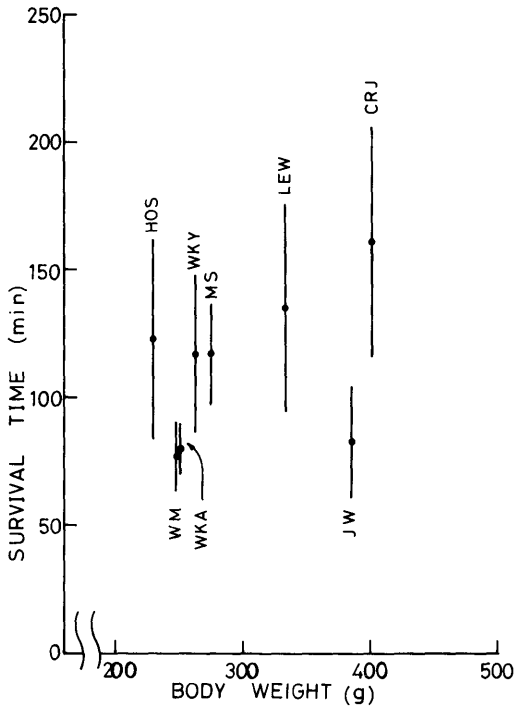

Fig. 1. Survival time plotted against body size. Values were shown by means ±SD. Strain names were abbreviated for convenience of illustration. WM, WKA, JW, MS, HOS, WKY, LEW and CRJ mean Wistar/MK, Wistar King A/Hok, Jcl: Wistar, Wistar/MS, HOS: Wistar, Wistar-Kyoto (WKY/NCrj), Wistar-Lewis (LEW/Crj), and Crj: Wistar, respectively.

sublingual glands were weighed in 6 rat strains. Parotid glands were weighed in 5 rat strains.

RESULTS

ST during heat exposure was plotted against BW in Fig. 1. ST varied according to rat strain ($p<0.01$ by analysis of variance). Table 1 is a statistical table for ST. WKA, WM and JW belonged to heat intolerant group. MS, WKY, HOS, LEW and CRJ resisted heat significantly longer than the 3 strains ($p<0.01$ by Wilcoxon rank sum test). HOS, WKY and MS survived heat longer than JW in spite of small body size.

SS was determined only in 6 rat strains, and varied according to rat strain ($p<0.01$ by analysis of variance) (Fig. 2). SS in WKA and JW was smaller than those in the other 5 strains ($p<0.01$, except $p<0.05$ between LEW and JW, by Tukey multiple comparison) (Table 2). The more a rat strain spread saliva onto the body surface, the longer the strain survived heat (Fig. 2). SS-ST curve was shown by individuals of 4 of those strains (Fig. 3) in order to elucidate the relationship between SS and ST. MS was

Table 1. Strain difference in survival time at ambient temperature of 42.5°C by Wilcoxon rank sum test

Strain[a)]	N	Strain							
		WM	WKA	JW	MS	WKY	HOS	LEW	CRJ
WM	11								
WKA	11	–[b)]							
JW	11	–	–						
MS	11	**	**	**					
WKY	11	**	**	**	–				
HOS	11	**	**	**	–	–			
LEW	11	**	**	**	–	–	–		
CRJ	11	**	**	**	**	**	–	–	

a) For abbreviations of strain name; see Fig. 1.
b) –(not significant), * ($P<0.05$), and ** ($P<0.01$).

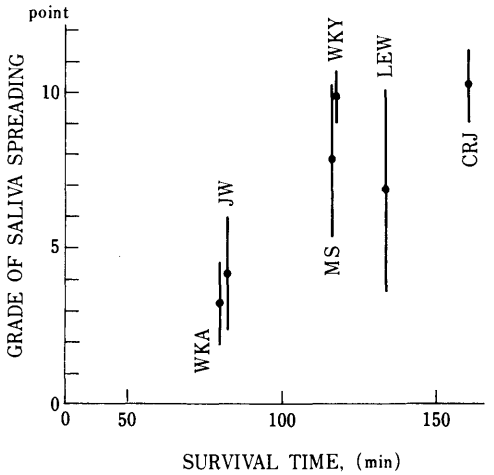

Fig. 2. Scores of saliva spread area plotted against survival time in heat. Values were shown by mean ±SD. For abbreviations of strain names, see Fig. 1.

Table 2. Strain difference in scores of saliva spreading

Strain[a)]	Strain					
	WKA	JW	MS	WKY	LEW	CRJ
WM						
JW	–[b)]					
MS	**	**				
WKY	**	**	–			
LEW	**	*	–	*		
CRJ	**	**	–	–	**	

a) For abbreviations of strain names, see Fig. 1.
b) Differences were tested by Turkey multiple comparison.

more heat tolerant than WKA as mentioned above. CRJ was more heat tolerant than MS ($p<0.01$). It was critical to spread saliva over a large area from mouth to testis in order to survive heat for more than 2 hrs. SS did not increase any more 150 min after the beginning of heat exposure.

Strain difference in BWL during heat exposure was shown in Fig. 4 and Table 3. Strain difference in BWL was observed ($p<0.01$ by analysis of variance). LEW, HOS, WKY and MS lost more body water and survived heat longer than WKA and

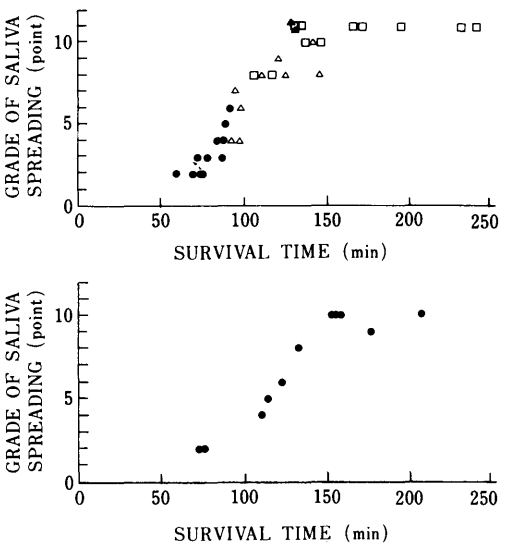

Fig. 3. Scores of saliva spread area of individual rats plotted against survival time in heat.(Upper) Closed circle: Wistar King Aptakeman; open triangle: Wistar/MS; open square: Crj: Wistar-.(Lower) Wistar-Lewis.

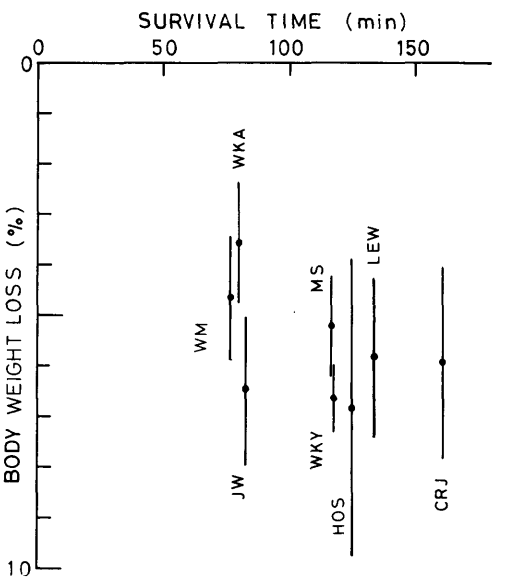

Fig. 4. Body weight loss (%) plotted against survival time. Values were shown by mean ±SD. For abbreviations of strain name, see Fig. 1.

WM. JW lost more body water than WKA, MS and WM, but was not able to depress rapid hyperthermia.

Table 3. Statistical table of strain difference in body weight loss at ambient temperature of 42.5°C by Wilcoxon rank sum test

Strain[a)]	N	Strain							
		WM	WKA	JW	MS	WKY	HOS	LEW	CRJ
WM	11								
WKA	11	−[b)]							
JW	11	*	**						
MS	11	−	−	*					
WKY	11	**	**	−	**				
HOS	11	*	**	−	−	−			
LEW	11	−	*	−	−	−	−		
CRJ	11	−	*	−	−	−	−	−	

a) For abbreviations of strain name; see Fig. 1.
b) −(not significant), * ($P<0.05$), and ** ($P<0.01$).

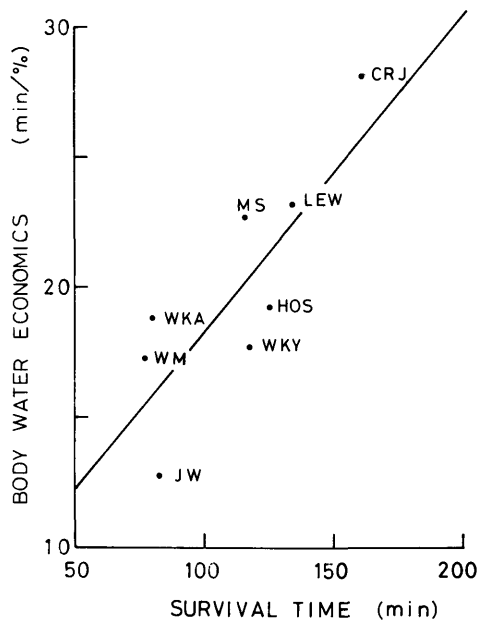

Fig. 5. Mean values of body water economics (ST/BWL) plotted against survival time in heat. The regression line was shown as follows; BEW=0.1223 ST+6.2147. Standard errors of constant and coefficient are 3.9656 and 3.5518, respectively. Analysis of variance was significant ($p<0.05$). Contribution ratio was 0.6777. Multiple correlation coefficients were 0.8232 (R) and 0.7899 (RR). For abbreviations of strain name, see Fig. 1.

BWE was plotted against ST (Fig. 5). The higher the BWE value was, the longer the rats survived heat. Regression line between BWE and ST was shown as follows:

$$BWE = 0.1223\ ST + 6.2147$$

standard error: constant 3.9656, coefficient 3.5518

analysis of variance: $p<0.05$

contribution ratio: 0.6777

multiple correlation coefficient: $R = 0.8232$, $RR = 0.7899$.

WM, WKA and JW were heat intolerant and their ST/BWL values were small. In CRJ and LEW, ST/BWL values were higher than most other strains.

Salivary gland size was studied especially in relation to ST in heat (Fig. 6). Wet weight of submaxillary gland and sublingual gland was obtained only in 7 rat strains, and did not increase according to ST. Parotid gland was weighed only in 5 rat strains, and was near 40 mg/100g BW, except for the hypertrophic gland ($p<0.01$) in WKY. Spearman rank correlation coefficient showed no significant relationship between ST and wet weight of 3 different salivary glands ($p<0.05$).

Sex difference in thermoregulatory ability in a hot environment was shown in Table 4. Females survived heat longer than males in WKY ($p<0.01$), JW ($p<0.05$) and WM ($p<0.05$). In the other 4 strains, no sex difference was observed in ST. Females lost more body water than males in HOS

($p<0.05$), WKA ($p<0.05$), WKY ($p<0.001$) and WM ($p<0.001$). BWE in female HOS ($p<0.02$) and WM ($p<0.05$) was lower than that in males. BWE in male JW was 12.75±1.56 min/% and remarkably lower than that in females ($p<0.001$). In the other 4 strains, there was no sex difference in BWE.

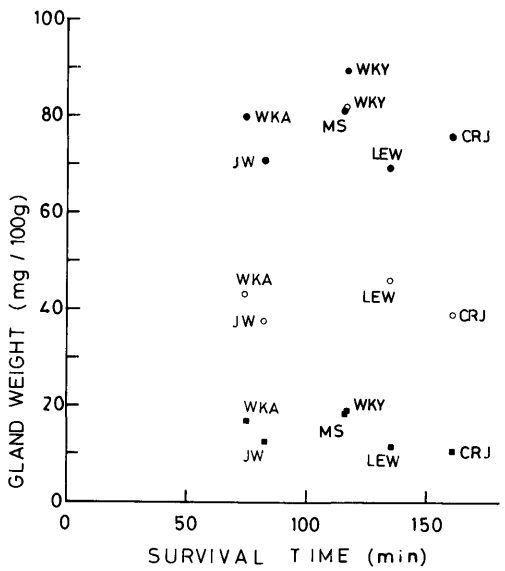

Fig. 6. Mean values of wet weight of salivary glands plotted against survival time in heat. Closed circle: submaxillary gland; open circle: parotid glands; closed square: sublingual gland. For abbreviations of strain name; see Fig. 1.

DISCUSSION

Wistar rat strains originated in an outbred colony of the Wistar Institute in the U.S.A. In 1906, Dr. Donaldson began outbreeding of albino rats at the Wistar Institute. In 1936, the Wistar rat was introduced to the Faculty of Agriculture at The University of Tokyo. WM and JW were sister strains from this colony. MS and WKY were sister strains from WM since 1951 and 1957, respectively. CRJ was separated from the Wistar rat in 1947 and established in 1981 *via* Scientific Products Farm and Charles River in U.S.A. HOS was introduced directly from the Wistar Institute in 1967. In 1909, Dr. King began inbreeding of a part of Wistar rat and named it Wistar King, from which WKA was developed by Dr. Aptakeman. WKA was introduced to Hokkaido University in Japan in 1953. Another part of the Wistar rat was inbred at the Wistar Institute and named LEW. Slc: Wistar was not used in the present study, though it has sometimes been employed for animal experiments in Japan. Slc: Wistar has a Wistar name but is though to be a Fisher 344 [16]. Thus, Wistar rats have been used around the world and consist of many different strains, though they originated in an outbred colony.

It is a problem whether Wistar rats belong

Table 4. Thermoregulatory ability in females

Strain[a)]	Survival time (min)	Body weight loss (%)	Body water economics (min/%)
WM	96.4±25.8*[c)]	8.18±2.05**	12.83±4.53
WKA	98.5±44.5	5.52±2.74*	18.24±3.69
JW	99.4±21.1*	4.73±0.70**	20.92±2.33**
WKY	174.9±26.1**	9.03±1.16**	19.41±2.01
HOS	138.0±38.0	9.83±3.21*	14.59±2.96**[d)]

a) For abbreviations of strain name, see Fig. 1.
b) Mean and SD.
c) Significant sex difference at * ($P<0.05$), and ** ($P<0.01$).
d) Smaller value of females than males.

to the same group despite the numerous rat strains in terms of thermoregulation. In the present study, the strain difference in thermoregulatory ability was as large among Wistar rat strains as it was among 10 other rat strains [4], and the difference among Wistar rat strains was not a minor one. CRJ resisted heat as long as SD rats which proved to be the most heat tolerant strain among the other 10 rat strains [4]. Thus, findings indicate that Wistar rat strains do not belong to the same group in terms of thermoregulation, and the respective Wistar rat strain has to be identified in reports on thermal physiology.

Rats were carefully raised to avoid infections until experiments. Each strain was raised according to the one strain-one room system and all in-all out system. The room and equipment (food container, *etc*) were disinfected by alchohol and disinfectant soap. Antibiotics were mixed into the drinking water twice a month at the younger stage. Possible infection, for example *sialodacryodenitis virus*, was not checked.

No rat died before its Tc attained 42.5°C during hyperthermia. All rats lived for many months after this. Most of them bore infants after transportation to a thermally neutral room. These facts showed that the experiments were performed under well controlled experimental conditions. Heat exposure was begun at 10–11 AM, because rats resist heat longer in daytime than at night [12].

Body size is an important parameter in thermoregulation [1, 6] because the ratio of body surface area to body mass becomes high in small mammals, which keeps their Tb by high oxidative metabolism, high heart rate and rapid respiration even in a thermal neutrality. It is well known that oxygen consumption of rats is about 10 times that of man. When Ta was higher than Tb, much more evaporation was needed for small mammals to minimize hyperthermia, because of the rapid heat intake over their extensive body surface. Evaporative BWL (% of BW) of mouse (21g) was 2.53 times that of rats (350g), and rats also had to evaporate 6.39 times the body water of man (95kg) [6]. If rats have no specific heat loss system, their ST is short and simply depends on body size. Several rat strains survived the heat longer in spite of smaller body size in the earlier study [4] and the present study. These findings suggested the contribution of a special heat loss system, which was thought to be an evaporative heat loss system, the only one in an environment hotter than Tb. In such hot conditions, conductive and convective heat losses are impossible. Thermal salivation is induced by heat stimulation itself and a potential evaporative heat loss system in rats.

Rats show hyperthermia, responding to a step stimulation by ambient heat. In some rats, Tb increases linearly until heat death occurs at Tc of 45±1°C. In others it increases rapidly at first and gradually thereafter. In more heat tolerant individuals, Tb shows a triphasic response pattern consisting of an early rapid increase, equilibrium phase and a final rapid increase [5, 15]. In the equilibrium phase, rats spread saliva on their ventral body surface for evaporative heat loss. The length of the equilibrium phase was reflected in ST [17]. In 1982, Furuyama [4] observed a strain difference in ST and SS by which rats regulate their Tb just below the maximum survivable body temperature of 43.1°C in males and 43.3°C in females. In the present study, we investigated the physiological significance of thermal salivation for resisting heat.

It is difficult to determine the amount of saliva in conscious rats. If saliva is removed for determination, rats cannot spread saliva. So SS was graded by Maling *et al.* [13], and we modified this grading as described in our earlier report [4]. Strain difference in SS could not be calculated by Wilcoxon rank sum test, because too many rats were

graded in the same rank. SS was statistically tested by Tukey multiple comparison. The more widely saliva was spread, the longer rats survived heat in the present study. A typical SS-ST curve was observed in LEW, because of the wide range of ST and high BWE. In the other rat strains, SS was plotted in the left side area of the SS-ST curve of LEW. Thus, it was demonstrated that active thermal salivation and SS are critical for surviving TA of 42.5°C longer than 2 hrs.

BWL is a simple and precise index of evaporative water loss during acute heat exposure. Rapid body water mobilization in the early phase of exposure was critical for surviving heat longer than the others [4]. WM and WKA failed in body water mobilization (Table 2) and their STs were short (Fig. 1, Table 1). JW was traced again in the present study because its BWL exceeded the value expected by ST [4]. In addition to body water mobilization, a high level of BWE must be maintained in the following phase (Fig. 5). These findings suggested that BWE was highly efficient in rat strains which spread saliva extensively. The regression line in the present study showed a high correlation between ST and BWE. Heat resistance depends on a high BWE level.

It is well known that a large salivary gland can secret much saliva *in vitro*. Enlargement of the submaxillary gland was reported in experimentally heat acclimated rats [10]. Among 3 glands, the submaxillary gland is reportedly crucial to thermal salivation [9]. The sublingual gland is too small to contribute to thermal salivation (Fig. 6) and its saliva is not serous. In the present study, the SS activity did not depend on submaxillary gland size. We think that submaxillary gland enlargement is induced only by acute heat acclimation. It was suggested that the strain difference in thermal salivation depends on the difference in the integration system in the central nervous system and the characteristics of gland cell.

Females of a considerable number of rat strains mobilized larger amounts of body water and survived heat longer than males. The only exception was male JW, which was heat intolerant in spite of large BWL. Materials were virgin females, because females became heat intolerant during pregnancy [3]. It is necessary to perform further study on thermoregulation in each menstrual stage.

In conclusion, various strains of Wistar rats are today very different in terms of thermoregulation. Thermal salivation is a potential evaporative heat loss system in Ta higher than Tb. Saliva spreading is sustained by rapid body water mobilization in the early phase and by highly efficient BWE during the following long lasting hyperthermia.

ACKNOWLEDGEMENTS. This study was depended on technical support by Mrs. Hideko Sugiura. The present study was partly supported by a Grant in Aid for Developmental Scientific Research (No. 61870011), SHOWA 61 NENDO KAKENHI NI KAKARU SHIHI by Nagoya City, and A Grant in Aid for Special Project Research (Experimental Animals) (No. 012212, No. 111512 and No. 210710) from the Ministry of Education, Science and Culture of Japan.

REFERENCES

1. Calder III. W. A. 1981. Scaling of physiological process in homeothermic animals. 1981. *Ann. Rev. Physiol.* 43: 301–322.
2. Elme'r, M., and Ohlin, P. 1971. Salivary secretion in the rat in a hot environment. *Acta physiol. scand.* 83: 174–178.
3. Fujita, S., and Yamanouchi, C. 1984. Influence of hot environment on body temperature, heart rate and blood pressure on pregnant rats. *Exp. Anim.* 33: 61–67.
4. Furuyama, F. 1982. Strain difference in thermoregulation of rats surviving extreme heat. *J. Appl. Physiol.: Respirat. Environ. Exercise Physiol.* 52: 410–415.
5. Furuyama, F., Ohara, K., and Ota, A. 1984. Estimation of rat thermoregulatory ability based on body temperature response to heat. *J. Appl. Physiol.: Respirat. Environ. Exercise Physiol.* 57: 1271–1275.

6. Folk, G. E. 1966. Introduction to environmental physiology., Lea & Febiger, Philadelphia. U.S.A.
7. Hainsworth, F. R. 1968. Evaporative heat loss from rats in the heat. *J. Appl. Physiol.* 214: 979–982.
8. Hainsworth F. R., and Stricker, E. M. 1970. Salivary cooling by rats. pp. 611–626. *In*: Physiological and behavioral temperature regulation. (Hardy, J., Gagge, A. P. and Stolwijk, A. J. ed.), Thomas, Springfield, IL, U.S.A.
9. hainsworth, F. R. and Stricker, E. M. 1972. Evaporative colling in the rat: further consideration of functional differences between salivary glands. *Can. J. Physiol. Pharmacol.* 50: 172–175.
10. Horowitz, M. 1976. Acclimatization of rats to moderate heat: Body water distribution and adaptability of the submaxillary salivary gland. *Pflugers Arch.* 366: 173–176.
11. Hubbard, R. W., Mattew, C. B., and Fransisconi, F. 1982. Heat-stressed rats: Effect of atropine, desalivation, or restraint. *J. Appl. Physiol.: Respirat. Environ. Exercise Physiol.* 53: 1171–1174.
12. Isobe, Y., Takaba, K., and Ohara, K. 1980 Diurnal variation of thermal resistance in rats. *Can. J. Physiol. Pharmacol.* 28: 1174–1179.
13. Maling, H. M., Williams, M. A., and Koppanyi, T. 1972. Salivation in mice as an index of adrenergic activity. I. Salivation and temperature response to d-amphetamine and other sialogogues and the effect of adrenergic blocking agent. *Arch. Int. Pharmacodyn. Ther.* 199: 318–322.
14. Nakayama, T., Kanosue, K, Tanaka, H., and Kaminaga, T. 1986. Thermally induced salivary secretion in anesthetized rats. *Pflugers Arch.* 406–351–355.
15. Ohara, K., Furuyama, F., and Isobe, Y. 1975. Prediction of survival time of rats in severe heat. *J. Appl. Physiol.* 38: 724–729, 1975.
16. Tayama, K., Fujii, T., and Higara, K. 1986. Comparison of characteristics between F344 and Slc: Wistar rats—Slc: Wistar rats cannot be distinguished from the F344 strain—.*Exp. Anim.* 35: 65–76.
17. Wright G., Knecht, W., and Wassermann, D. 1977. Colonic heating patterns and the variation of thermal resistance among rats. *J. Appl. Physiol: Respirat. Environ. Exercise Physiol.* 43: 59–64.

要　約

Wistar 系ラットにおける温熱性唾液分泌と体水分利用効率の系統差　古山富士弥，吉田俊秀[1)]，熊崎路子，大原孝吉（名古屋市立大学医学部第二生理学講座）[1)]国立遺伝学研究所細胞遺伝学部門）——Wistar 系ラットの体温調節能力について系統差を，とくに温熱性唾液分泌と体水分利用効率との関連において検討したので報告する．8系統の Wistar 系ラットを，42.5℃-40%RH の人工気候室においたところ，体温調節能は比較的すぐれた系統と，高温非耐性の系統があったが，Crj: Wistar が最もすぐれていた．小型ですぐれた高温耐性の系統もあり，高温耐性に特異的に貢献する機構の存在が示唆され，その一つは温熱性唾液分泌であった．温熱性唾液分泌は，顎下腺の大きさには依存しなかった．体温調節能の高い系統が温熱性唾液分泌および唾液塗布をおこなっているときには，体水分利用効率は高く，体温調節機構と水—浸透圧調節系の協調による高体温抑制が示唆された．